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Automation Application in Product Labeling: Benefits, Challenges, Key Components and Technologies: A Review

Iliyasu Kayode Okediran[1], David Oluwaseyi Adewale[1*], Musibaudeen Olatunde Idris[1], Abideen Temitayo Oyewo[1] and Abdulhafiz Ademola Adefajo[1]
[1]Mechanical Engineering Department, Osun State University, Nigeria
*email corresponding author: daveadewale14@gmail.com

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Abstract

The automation of product labeling has emerged as a critical advancement in manufacturing, enhancing efficiency and precision in packaging processes. This paper provides a comprehensive review of the application of automation in product labeling, focusing on the significant benefits and technological advancements that have transformed the labeling process in modern production environments. The study begins with an overview of the production line and explores how automated labeling systems integrate with other automation technologies to enhance efficiency, accuracy, and flexibility. Key components and technologies, such as vision inspection systems, robotics, and smart labels, are examined in detail, highlighting their role in ensuring precise and consistent labeling. The paper also addresses the challenges and considerations involved in implementing and maintaining automated labeling systems, including integration with existing machinery, maintaining accuracy, and regulatory compliance. In conclusion, the review underscores the significant advancements driving the future of labeling automation, emphasizing how innovations in artificial intelligence (AI), the Industrial Internet of Things (IIoT), and sustainable practices are poised to further revolutionize the industry and drive new levels of efficiency and precision.

Keywords: *Automation; product labeling; production; industrial automation; manufacturing; manufacturing efficiency; labeling systems*

Abstrak

Otomatisasi pelabelan produk telah muncul sebagai kemajuan penting dalam manufaktur, yang meningkatkan efisiensi dan presisi dalam proses pengemasan. Makalah ini memberikan tinjauan komprehensif tentang penerapan otomatisasi dalam pelabelan produk, dengan fokus pada manfaat signifikan dan kemajuan teknologi yang telah mengubah proses pelabelan dalam lingkungan produksi modern. Studi ini dimulai dengan tinjauan umum lini produksi dan mengeksplorasi bagaimana sistem pelabelan otomatis terintegrasi dengan teknologi otomatisasi lainnya untuk meningkatkan efisiensi, akurasi, dan fleksibilitas. Komponen dan teknologi utama, seperti sistem inspeksi visual, robotika, dan label pintar, diperiksa secara terperinci, yang menyoroti perannya dalam memastikan pelabelan yang tepat dan konsisten. Makalah ini juga membahas tantangan dan pertimbangan yang terlibat dalam penerapan dan pemeliharaan sistem pelabelan otomatis, termasuk integrasi dengan mesin yang ada, menjaga

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akurasi, dan kepatuhan terhadap peraturan. Sebagai kesimpulan, tinjauan ini menggarisbawahi kemajuan signifikan yang mendorong masa depan otomatisasi pelabelan, yang menekankan bagaimana inovasi dalam kecerdasan buatan (AI), Industrial Internet of Things (IIoT), dan praktik berkelanjutan siap untuk lebih merevolusi industri dan mendorong tingkat efisiensi dan presisi baru.

Kata Kunci: Otomasi; pelabelan produk; produksi; otomasi industri; manufaktur; efisiensi manufaktur; sistem pelabelan

1. Introduction

Product labeling is a crucial component of the manufacturing and retail process, involving the application of informative tags or stickers on a product's packaging (Olorunda and Adetunde, 2018). This process ensures that consumers have access to essential information and that products comply with various regulatory requirements. The label prominently displays the product's name, making it easily identifiable to consumers. This aspect of labeling is critical for marketing and brand recognition, as it allows consumers to quickly find and choose the product they are looking for. For products such as food, cosmetics, and pharmaceuticals, labels provide a detailed list of ingredients or components. This information is essential for consumers who need to be aware of allergens, potential irritants, or substances they wish to avoid for health or dietary reasons. Labels offer clear guidelines on how to use or apply the product effectively and safely. Labels also contain contact details of the manufacturer or distributor, including their name, address, and phone number, are included on the label. This information enables consumers to seek further assistance or report issues related to the product. Many products, particularly consumables and pharmaceuticals, feature an expiration date on the label to ensure that they are used within a safe timeframe. Labels also include critical safety warnings and cautions to protect consumers from potential risks. For example, a cleaning product might have warnings about harmful fumes, while a toy label could highlight age-appropriateness and small parts that pose choking hazards.

In the early days of manufacturing, all processes were manual, heavily reliant on skilled labor (Acemoglu and Restrepo, 2020). Workers controlled every aspect of production, from assembling parts to applying labels (Alam et al., 2024). Manual product labeling, in particular, was a labor-intensive process. Workers would carefully place labels on products by hand, using glue or other adhesives. This method was not only time-consuming but also prone to inconsistencies and errors. Labels might be misaligned, wrinkled, or applied unevenly, leading to a lack of uniformity across products. The industrial revolution brought about mechanization, where machines began to assist or replace human labor in some tasks (Baur and Iles, 2023). In the context of labeling, simple mechanical devices were developed to help with the process. Manual labeling machines, for example, allowed workers to apply labels more quickly and with greater consistency than by hand. However, these machines still required significant human intervention.

Automation transformed manufacturing, evolving from simple mechanization to fully integrated systems that manage entire production lines (Packianathan, 2024). This transformation brought about the next phase of product labeling automation. Semi-automated labeling machines could automatically apply labels to products, significantly increasing speed and reducing the likelihood of human error. However, these machines still required human operators for tasks such as feeding products into the machine and removing products from the machine. The advent of computers and robotics in the early 50s led to a dramatic shift towards full automation (Filip, 2021). In fully automated manufacturing systems, including labeling, machines could operate with minimal human involvement. Products could move through a conveyor system where sensors would detect their presence and position, and labeling machines would apply labels with high precision (Caldwell, 2023). These fully automated systems were capable of running continuously, offering unmatched speed, accuracy, and consistency. With fully automated labeling, the entire process could be managed by a centralized control system, reducing the need for human labor and virtually eliminating the risk of errors.

The objective of this study is to provide a comprehensive review of the application of automation in product labeling, with a focus on elucidating the benefits of automated labeling systems, examining their integration within modern production lines, and identifying the key components and technologies that drive these systems. Additionally, the study aims to analyze the challenges and considerations involved in the implementation and maintenance of automated product labeling systems, offering insights that can guide manufacturers in optimizing labeling processes and achieving greater operational efficiency. As industries increasingly adopt automated solutions to enhance efficiency, precision, and compliance, understanding the various technologies, applications, and challenges associated with automated labeling systems is crucial. Ultimately, this review aims to serve as a resource for engineers, manufacturers, and decision-makers looking to optimize their labeling processes through automation.

Figure 1 presents a detailed flowchart illustrating the structure and key elements of the automation application in product labeling. This diagram provides a comprehensive overview of the main sections covered in the review, including the benefits, challenges, and essential components of automated labeling systems. The flowchart begins with an overview of the review topic, branching out into three primary areas: Benefits of Automation, highlighting aspects such as increased efficiency and cost savings; Challenges in Automation, addressing potential technical and integration issues; and Key Components and Technologies, which includes crucial elements like labeling machines, PLC systems, sensors, and vision systems. By visually representing these interconnected elements, the flowchart facilitates a clearer understanding of the complex interactions and considerations involved in automated labeling, offering readers a structured and accessible summary of the review's content.

2. Method

This review was conducted through a comprehensive search of academic literature, industrial reports, and case studies related to automation in product labeling. The key focus areas included technological advancements, benefits of automation, challenges, and future trends. The literature search involved databases such as IEEE Xplore, ScienceDirect, Google Scholar, Google Searches as well as leading industry journals and white papers. Search terms included "automation in labeling," "PLC in labeling. Only sources from peer-reviewed journals, books, authoritative industry reports and verifiable websites published between 2010 and 2024 were included.

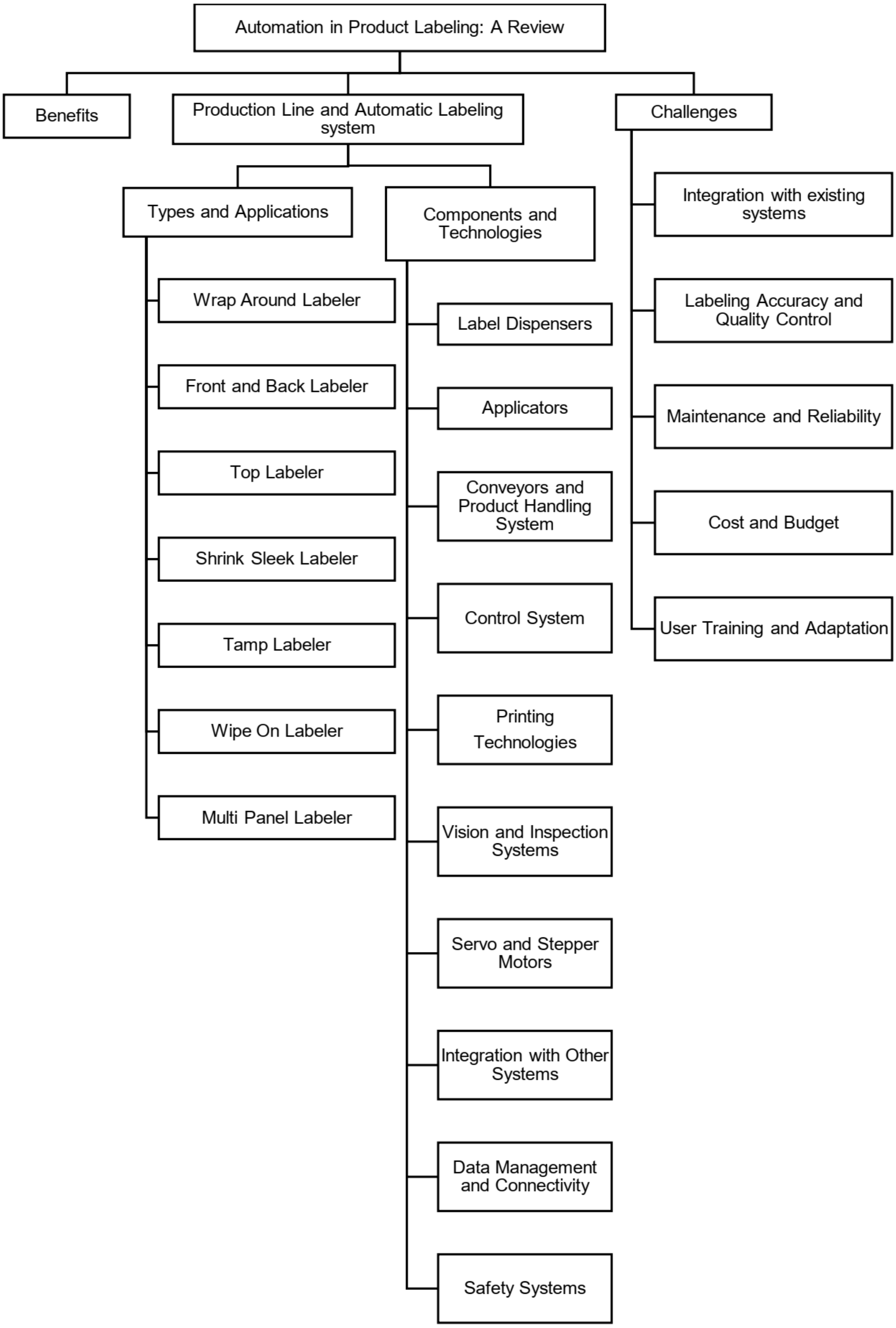


Figure 1. Flowchart of Study.

Information from the selected literature was extracted, categorized, and analyzed under key themes, including automation benefits, system components, and challenges in implementation. Detailed attention was given to the technological descriptions of components such as label applicators, conveyor systems, and control mechanisms like HMIs and PLCs, which play critical roles in enhancing precision and efficiency in product labeling systems. The extracted data was reviewed and synthesized to provide a structured overview of the field. Key findings were organized into sections that discuss the benefits of automation (efficiency, cost savings, precision), critical components (vision systems, labeling heads, and control systems), and challenges (integration, accuracy, and maintenance). The analysis also explored emerging trends such as AI and IIoT integration in labeling systems.

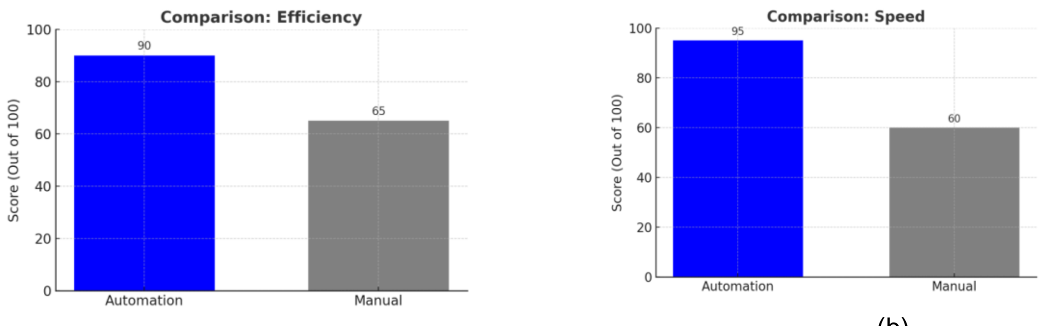
3. Benefits of Automation of Product Labeling

The automation of product labeling presents a range of technical advantages that are critical for optimizing production processes. This discussion will systematically outline the benefits, including enhanced consistency and precision in labeling, reduced incidence of human error, and accelerated throughput. Additionally, automated systems facilitate real-time adjustments and comprehensive monitoring, thereby ensuring adherence to regulatory standards and accommodating dynamic labeling requirements. The reduction in labor costs and the significant improvement in overall operational productivity underscore the strategic value of integrating automation into labeling operations.

3.1. Increased Efficiency and Speed

Automatic product labeling systems are designed to operate at high speeds, often reaching labeling rates of hundreds of products per minute, depending on the system configuration and product type (Caldwell et al., 2009). This high throughput is achieved through advanced servo motor control, which allows precise and rapid movement of labels from the feed system to the application point (Abdul Ali et al., 2020). By synchronizing the labeling process with conveyor speeds, the system minimizes delays and maximizes efficiency. In contrast to manual labeling, which is limited by human speed and endurance, automated systems maintain consistent output 24/7, significantly increasing overall production capacity.

Figure 2 (a and b) presents a comparison between the efficiency and speed of automated and manual product labeling, with ratings out of 100. The data indicates that automation outperforms manual labeling in both efficiency and speed.

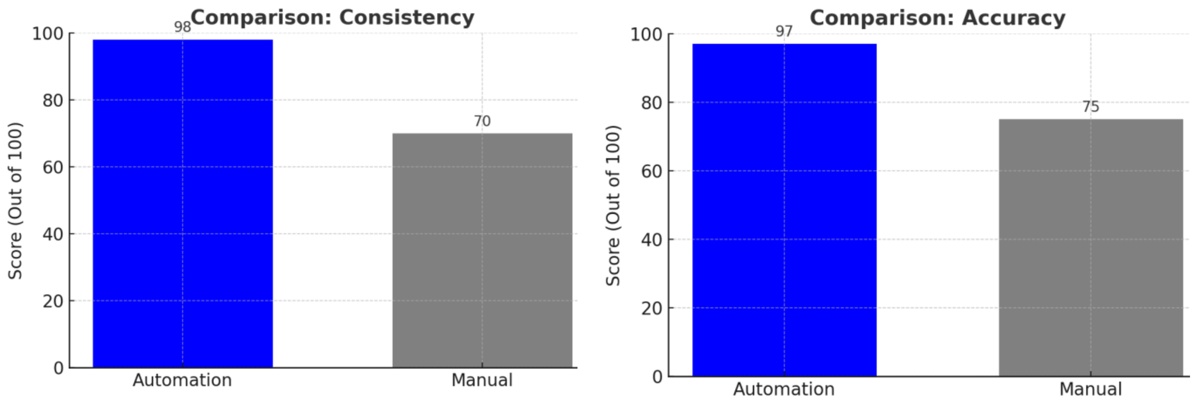


(a) (b)

Figure 2. Comparison between automation and manual labeling: (a) efficiency and (b) speed.

3.2. Consistency and Accuracy

Automated labeling systems utilize precision-engineered components such as advanced stepper motors, optical sensors, and machine vision systems to ensure labels are applied with high accuracy. The systems can detect product orientation and position, adjusting the label application process in real time to ensure perfect placement (Labudzki and Leopold, 2019). This level of precision is critical in industries where label positioning is vital for brand integrity and compliance with regulatory standards. Automated systems also feature feedback loops that adjust the application force and timing, ensuring that labels are consistently applied without wrinkles or misalignment, which can occur with manual labeling. Figure 3 (a and b) presents a comparison between the consistency and accuracy of automated and manual product labeling, with ratings out of 100. The data indicates that automation outperforms manual labeling in both consistency and accuracy.



(a) (b)

Figure 3. Comparison between automation and manual labeling: (a) Consistencyy and (b) Accuracy.

3.3. Cost Saving

The cost savings associated with automatic labeling are realized in several ways. First, the reduction in labor costs is significant, as fewer operators are needed to manage the labeling process. Secondly, automated product labelling systems reduce material waste through precise label application, minimizing the number of rejected products due to labeling errors (Labudzki and Leopold, 2019). Additionally, automated systems often incorporate energy-efficient components such as variable frequency drives (VFDs) and energy recovery systems, which lower operating costs over time (Ibekwe et al., 2024). While the capital investment for automated labeling equipment can be substantial, the return on investment (ROI) is often realized within a few years due to the cumulative savings. Figure 4 presents a comparison between the cost savings of automated and manual product labeling, with ratings out of 100. The data indicates that automation outperforms manual labeling in saving costs.

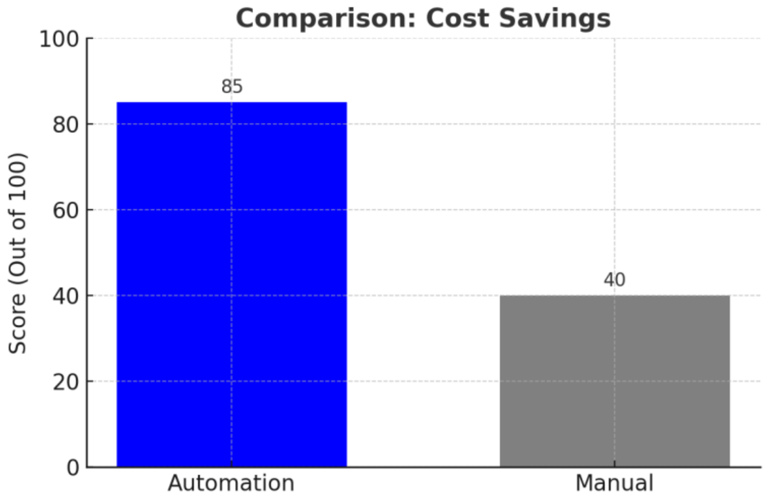


Figure 4. Cost saving comparison between automation and manual labeling

3.4. Enhanced Flexibility

Modern automatic labeling machines are designed with modularity and adaptability in mind (Denisa et al., 2023). These systems can be quickly reconfigured to accommodate different label sizes, shapes, and materials, as well as various product dimensions. This flexibility is achieved through programmable logic controllers (PLCs) and human-machine interfaces (HMIs), which allow operators to quickly change settings and calibrate the machine for different production runs (Azizpour et al., 2024). Additionally, many systems offer tool-free changeovers, reducing downtime when switching between products. This adaptability is crucial for manufacturers who need to respond quickly to market demands or customize products for different regions or customers.

3.5. Improved Product Presentation

The precision of automatic labeling ensures that labels are applied consistently, enhancing the visual appeal of the product. This is particularly important in sectors such as food and beverage, pharmaceuticals, and cosmetics, where the presentation can influence consumer perception and brand loyalty (Srivastava et al., 2022). Automated systems can apply labels with tight tolerances, ensuring that logos, text, and graphics are perfectly aligned. Moreover, some advanced systems can apply multiple labels, such as front, back, and tamper-evident seals, in a single pass, ensuring a cohesive and professional product presentation.

3.6. Reduced Labor Requirements

Automated labeling systems significantly reduce the need for manual intervention, allowing companies to reallocate their workforce to more complex tasks. This reduction in manual labor not only lowers direct labor costs but also decreases the risk of repetitive strain injuries, which are common in manual labeling operations (Mariappan et al., 2015). Additionally, automated systems are equipped with self-diagnosing capabilities, reducing the need for frequent maintenance and supervision (Paul et al., 2024). This leads to a safer work environment and lower associated healthcare and compensation costs.

Figure 5 presents a comparison between the reduced labor effect of automated and manual product labeling, with ratings out of 100. The data indicates that automation outperforms manual labeling in reducing labor.

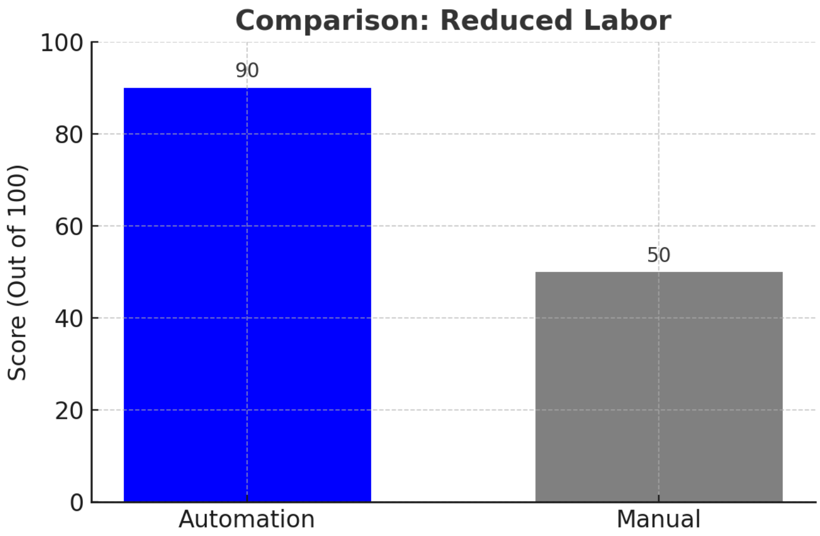


Figure 5. Reduced labor comparison between automation and manual labeling

3.7. Traceability and Compliance

Automatic labeling systems can be integrated with enterprise resource planning (ERP) systems and databases, ensuring that each product is labeled with accurate and compliant information (Olaoye and Potter, 2024). This is particularly important in industries such as pharmaceuticals, where traceability is critical for regulatory compliance. Automated systems can print and apply variable data such as batch numbers, expiration dates, and serial numbers, which are then verified by inline vision systems. This integration ensures that each label is linked to a specific product batch, enhancing traceability and simplifying recall processes if necessary.

3.8. Scalability

Automatic labeling systems are inherently scalable, making them suitable for both small-scale operations and large industrial facilities. Modular design allows manufacturers to expand their labeling capabilities as production demands increase, without needing to replace the entire system (Denisa et al., 2023). This scalability is supported by features such as adjustable conveyors, customizable label applicators, and the ability to integrate additional labeling heads or modules. Automated systems can also adapt to changes in production speed, ensuring consistent label application even as the throughput increases.

3.9. Integration with Other Systems

Automated labeling systems are designed to seamlessly integrate with other production line equipment, such as filling, capping, and packaging machines. This integration is achieved through standard communication protocols like Ethernet/IP, Modbus, or OPC UA, which allow for real-time data exchange between machines (Tapia et al., 2023). As a result, the entire production process can be synchronized, reducing bottlenecks and improving overall efficiency. Furthermore, integrated systems can share data such as production rates, label usage, and error logs, enabling better process control and optimization.

3.10. Real-Time Monitoring and Reporting

Many automated labeling systems are equipped with advanced sensors and software that provide real-time monitoring and diagnostics. This data is often displayed on HMIs, allowing operators to monitor key performance indicators (KPIs) such as labeling speed, error rates, and machine uptime. Additionally, the collected data can be logged and analyzed to identify trends, optimize maintenance schedules, and predict potential issues before they lead to downtime. This proactive approach to maintenance and process optimization helps maintain high levels of efficiency and reduces the likelihood of unexpected failures.

4. Production Line and Automatic Product Labeling System

In the highly controlled environment of modern industrial production, the labeling of packaged and finished products is a process that is meticulously designed to ensure precision, efficiency, and reliability. This phase, where critical information such as product details, manufacturing dates, batch numbers, and barcodes are applied, is seamlessly integrated into the broader packaging system (Olorunda and Adetunde, 2018). As each product completes its initial stages whether filling, assembly, or sealing, it enters the final packaging phase. Here, sophisticated machinery, such as form-fill-seal (FFS) units or automated wrapping systems, encases the product in its final packaging, preparing it for labeling (Das et al., 2018). These machines are designed to work at high speeds, shaping and sealing the packages in a uniform manner that facilitates the next step. The packaged products are then transferred to the labeling station via a precisely synchronized conveyor system. The movement of these conveyors is carefully controlled, maintaining consistent spacing between each package. This ensures that when the products arrive at the labeling station, they are correctly aligned and positioned for the application of labels.

At the heart of the labeling process is the labeling station, a highly specialized system that integrates seamlessly with the production line. This station is equipped with advanced labeling heads capable of applying labels with pinpoint accuracy. These labels contain essential information, dynamically generated and printed in real-time, reflecting details such as product identity, manufacturing information, and batch-specific data. As the packaged products approach the labeling station, a network of sensors, often photoelectric or ultrasonic, detects their presence and exact position. These sensors feed data back to the system's central controller, usually a PLC, which adjusts the labeling mechanism on-the-fly (Azizpour et al., 2024). The labeling head, utilizing a method tailored to the product's packaging, whether it's wipe-on, tamp-blow, or air-blow, applies the label in the correct location.

The integration of data management is critical at this stage. The system interfaces with enterprise software, such as an MES or ERP system, to pull relevant production data that is then printed onto each label (Olaoye and Potter, 2024). This could include barcodes, QR codes, or RFID tags, enabling traceability throughout the supply chain. The printing technology, whether thermal transfer, direct thermal, or inkjet, ensures that the labels are both durable and legible, and meet industry standards (Zheng et al., 2021; Ruiz et al., 2022). Once the labels are applied, the products pass through an inspection area where vision systems perform a detailed quality check. These systems verify that each label is correctly applied, accurately positioned, and contains the correct information. Any discrepancies, such as misaligned labels, incorrect data, or printing errors, are immediately identified. The system, responding in real-time, can correct these issues by reprinting or repositioning the labels, or by diverting defective products to a reject bin.

After successfully passing through the labeling and inspection stages, the products continue down the production line to final packaging processes. Here, they may be grouped into secondary packaging, such as boxes or pallets, ready for shipment. The labels applied during the earlier stage now play a crucial role in ensuring that the products are correctly identified and tracked as they move through logistics and distribution channels. Throughout this entire process, the labeling system is closely monitored via a centralized HMI (Azizpour et al., 2024). Operators have real-time access to production data, allowing them to adjust parameters, monitor the flow of products, and respond quickly to any alerts. The system also includes diagnostic tools that predict maintenance needs, ensuring that the labeling equipment operates continuously with minimal downtime. In this way, the automatic labeling of packaged and finished products is not just a mechanical task but a critical component of the overall production process. It involves a complex interplay of precision engineering, real-time data integration, and rigorous quality control, all working together to ensure that every product leaving the factory is properly identified and ready for the market.

Table 1 provides a comprehensive overview of various types of automated labeling machines, each designed to address specific labeling requirements across different packaging applications. The table categorizes these machines based on their operational mechanisms and typical use cases. For instance, the Wrap-Around Labeler is utilized for labeling cylindrical or oval containers, making it ideal for bottles and cans. In contrast, the Front and Back Labeler applies labels to the front and back sides of flat or rectangular containers, such as boxes and pouches. The table also highlights specialized machines like the Shrink Sleeve Labeler, which applies a full-body sleeve label that conforms to the container when heated, and the In-Mold Labeler, which integrates labeling into the molding process for plastic containers. Additionally, the Tamp Labeler and Wipe-On Labeler are employed for irregularly shaped products and smooth-surfaced containers, respectively. The Dot Labeler focuses on spot labeling, while the Multi-Panel Labeler is used for applying labels to multiple sides of a container. Finally, the Automatic Label Dispenser is designed to automate the dispensing of labels, often complementing manual or semi-automatic labeling processes. This table serves as a reference for selecting the appropriate labeling machine based on the packaging requirements and product characteristics. Figure 6 (a,b,c,d,e and f) are diagrams of various types of automated labeling machines listed in Table 1.

Table 1. Types of automated label machine and their applications (Vipak, n.d., Saintytec, 2023, Icapsulepack, 2024).

No	Type	Application
1	Wrap Around Labeler: Applies labels around cylindrical or oval containers using a rotating mechanism	Bottles, jars, and cans
2	Front and Back Labeler: Applies labels to the front and back sides of flat or rectangular containers	Boxes, pouches, and flat products
3	Top labeler: Applies labels to the top surface of containers or packages	Cartons, trays and flat items
4	Shrink sleek labeler: Applies a full-body sleeve label that shrinks and conforms to the container when heated	Bottles, cans and jars
5	Tamp labeler: Uses a tamping mechanism to press the label onto the container as it moves	Irregularly shaped products and surfaces
6	Multi panel labeler: Applies labels to multiple panels or sides of a container	Boxes and multi faced surfaces

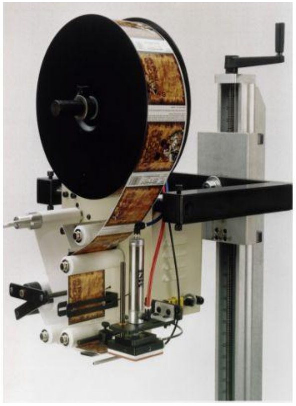
(a)

(b)

Figure 6. Automated label machine: (a) Wrap around labeler (Herma GmbH, n.d.), (b) Front and back labeler (ZH Packaging Machine, n.d.), (c) Top labeler (Herma GmbH, n.d.), (d) Shrink sleeve labeler (TradeIndia, n.d.), (e) Tamp labeler (Cleveland Equipment, n.d.) and (f) Multi panel labeler (Pharmaceutical Tech, n.d.)

(c)

(d)



(e)

(f)

Continued Figure 6.

4.1. Key Components and Technologies in the Automation of Product Labeling

In the automation of product labeling, several critical components and technologies facilitate the efficiency and effectiveness of the system. This section will provide a detailed analysis of these key elements, including sensor technologies, and integrated control systems. Additionally, the discussion will cover the application of robotics, vision inspection systems, and conveyor automation, highlighting their roles in optimizing labeling precision and throughput. Understanding these components and their synergistic interactions is essential for evaluating the capabilities and performance of automated labeling systems.

Figure 7 illustrates the key components of an automatic labeling machine, providing a detailed overview of its operational structure. The diagram highlights the primary elements involved in the labeling process, including the labeling station, where labels are applied to containers, and the conveyor system, which transports products through the machine. It also features the label applicator, responsible for precisely placing labels onto containers, and the control panel, which allows for the adjustment of machine settings and operational parameters. Additionally, the feed system and discharge unit are depicted, showing how products are fed into and discharged from the machine. By presenting these components in a clear, visual format, the diagram facilitates a better understanding of how each part contributes to the efficient and accurate labeling of products. This comprehensive view helps in grasping the integrated functionality of the machine and its role in the automated labeling process.

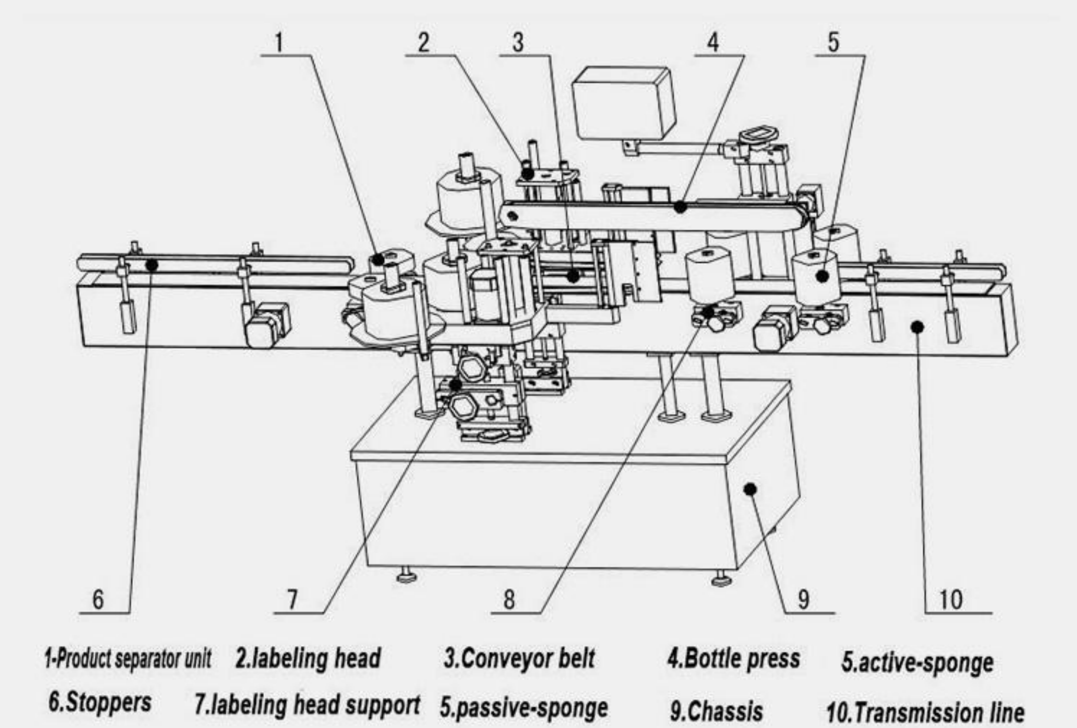


Figure 7. Some Components of Automatic Labeling Machine (Icapsulepack, 2024).

4.2. Label Dispensers

Label dispensers are integral components within automated labeling systems, designed to dispense labels with high precision and consistency. They consist of three main parts: label web, peeler plate, drive rollers.

4.2.1 Label Web

The label web consists of a continuous roll of labels adhered to a backing liner, typically made of silicone-coated paper (Kelar Tucekova et al., 2020). The web feeds through the labeling machine under controlled tension. Advanced tension control systems, including load cells and feedback loops, maintain consistent tension to prevent web breakage and ensure accurate label placement (Chen and Zhang, 2018).

4.2.2 Peeler Plate

The peeler plate is a sharp component over which the label web is fed. It functions as a separator between the label and its liner. The labels are pulled over the strip plate until detected by a photo sensor or limit switch. Strip plates can vary in design and material, with common options being plastic, metal coil, or aluminum (Romanoff et al., 2020).

4.2.3 Drive Rollers

The drive rollers are responsible for advancing the label web through the system. These rollers are driven by high-precision servo motors, which provide exact control over the web's speed and position (Kim et al., 2023). The use of closed-loop control systems with encoder feedback ensures that each label is dispensed accurately, even at high speeds. The material and surface finish of the rollers are chosen to provide optimal grip without damaging the label web (Nascimento et al., 2019).

4.3. Applicators

Applicators are crucial elements in automated labeling systems, responsible for the precise and efficient application of labels to products. Types of applicators include wipe-on applicators, blow-on applicators, tamp-on applicators and corner wrap applicators.

4.3.1 Wipe-On Applicators

Wipe-on applicators use a mechanical or pneumatic arm equipped with a brush, roller, or pad to apply labels to products. The applicator arm's movement is controlled by a combination of servo motors and pneumatic actuators, ensuring precise timing and force (Nawaz et al., 2020). The applicator's speed and pressure are adjustable to accommodate different product surfaces and label adhesives, ensuring a secure and wrinkle-free application (Zhou et al., 2021).

4.3.2 Blow-On Applicators

Blow-on applicators use a burst of compressed air to apply labels to the product surface without physical contact. The labels are held in position by a vacuum or static charge on a perforated applicator pad. When the product is in position, a precisely timed pulse of air propels the label onto the product. The air pressure, timing, and distance between the applicator and product are critical parameters, often controlled via PLCs, to ensure accurate application on high-speed lines (Zhang et al., 2019).

4.3.3 Tamp-On Applicators

Tamp-on applicators employ a tamp pad that moves linearly to press the label onto the product. The pad's movement is typically powered by a pneumatic cylinder or servo motor, allowing for adjustable stroke length and speed (Fujita et al., 2019). The tamp pad is often designed with a soft, flexible surface to conform to the product's contours, ensuring even pressure distribution and firm adhesion. These systems may also feature a vacuum system to hold the label on the pad during positioning (Fujita et al., 2019).

4.3.4 Corner-Wrap Applicators

Corner-wrap applicators are designed to apply labels that cover two adjacent sides of a product, such as the front and top or side and front. The system uses a combination of a peel edge, vacuum tamp, and wipe mechanism to secure the label to one side before wrapping it around the corner. The timing and coordination of the applicator's movements are critical, often managed by high-speed PLCs, to ensure precise alignment and adhesion on both surfaces (Xi and Qin, 2021).

4.4. Conveyors and Product Handling Systems

Conveyors and product handling systems are essential for the seamless integration and automation of labeling processes. They help in facilitating product movement and alignment. Various components make up the conveyors and product handling system. These components work together to ensure efficient product transport, precise positioning, and minimal disruption in automated labeling workflows, ultimately enhancing overall system performance and throughput.

4.4.1 Conveyor Belts

Conveyor belts in labeling systems are engineered for precision movement and synchronization with the labeling process. They are typically powered by servo or AC motors with variable frequency drives (VFDs) for speed control (Zeng et al., 2020). The conveyor speed is synchronized with the labeling system via a master control system, ensuring that products are presented to the labeling station at the correct speed and position (Zeng et al., 2020). The belts themselves are made from materials selected for durability and low friction, such as urethane or modular plastic (Dobrotă et al., 2020; Gilg and Steven, 2023).

4.4.2 Guides and Positioning Systems

Product guides, such as side rails and pushers, are adjustable and are often equipped with quick-release mechanisms for rapid changeovers. These systems ensure that products remain correctly aligned as they pass through the labeling machine (Wu, 2023). For more complex product handling, star wheels or timing screws are employed to accurately space and orient products before they reach the labeling station. These components are driven by servo motors and synchronized with the conveyor belt to maintain precise control over product positioning.

4.4.3 Star Wheels and Timing Screws

Star wheels and timing screws (also known as feed screws) are crucial for managing the flow of products into the labeling area, especially in high-speed environments. Star wheels rotate to align and space products as they enter the labeling station, while timing screws advance products with precise spacing (Wu, 2023). These components are often custom-designed for the specific product shape and size, ensuring consistent orientation and minimizing the risk of mislabeling. They are typically driven by servos for fine-tuned control.

4.5. Control Systems

Control systems are the backbone of automated labeling operations, ensuring precise coordination and functionality across various system components. Technical architecture of control systems include programmable logic controllers (PLCs), distributed control systems (DCS), and human-machine interfaces (HMIs). They help in managing input and output signals, executing control algorithms, and facilitating real-time monitoring and adjustments.

4.5.1 Programmable Logic Controllers (PLCs)

PLCs form the core of the automation control in labeling systems. These devices are responsible for coordinating all machine functions, including label dispensing, applicator movement, and product handling (Krupa et al., 2021). Modern PLCs are equipped with high-speed processors, allowing them to execute complex control algorithms in real time. They also support multiple communication protocols (e.g., Ethernet/IP, Modbus TCP) for integration with other production line equipment and enterprise systems. Advanced PLCs may include motion control capabilities, managing servo and stepper motors with millisecond precision (Krupa et al., 2021).

4.5.2 Human-Machine Interface (HMI)

HMIs provide the user interface for operators to control and monitor the labeling system (Krupa et al., 2021). These touch-screen interfaces display real-time data on system performance, such as labeling speed, error rates, and machine status. HMIs are typically designed with user-friendly graphical interfaces, enabling operators to adjust parameters, perform diagnostics, and initiate maintenance procedures with ease. Advanced HMIs may also include data logging and trend analysis features, helping operators identify and address potential issues before they affect production (Krupa et al., 2021).

4.5.3 Sensors

Sensors are critical for ensuring precise operation of the labeling system (Krupa et al., 2021). Optical sensors, such as through-beam or reflective sensors, detect the presence and position of products as they move through the system. Inductive sensors are used to detect metal objects, while ultrasonic sensors are employed for detecting transparent or irregularly shaped products. The data from these sensors is processed in real time by the PLC, which adjusts the timing of the label application to ensure accuracy. In some cases, laser or photoelectric sensors are used for more advanced detection and positioning (Krupa et al., 2021).

4.6. Printing Technologies

Printing technologies are fundamental to the automated labeling process, providing the means to apply high-quality, legible information on product labels. Printing methods used in labeling systems include thermal transfer, direct thermal, inkjet, and laser printing.

4.6.1 Thermal Transfer Printers

Thermal transfer printers use a heat-sensitive ribbon to transfer ink onto the label substrate. This technology is widely used for printing high-resolution barcodes, batch numbers, and other variable data directly onto labels (Glasser et al., 2019). The thermal transfer process is highly reliable, producing durable prints that are resistant to smudging and fading. These printers are often integrated into the labeling system, allowing for real-time printing of data just before label application (Glasser et al., 2019).

4.6.2 Inkjet Printers

Inkjet printers in labeling systems use piezoelectric or thermal technology to deposit tiny droplets of ink onto the label surface (Lai et al., 2019). These printers can operate at high speeds, making them suitable for dynamic environments where labels need to be printed and applied on-the-fly. The key advantage of inkjet printing is its flexibility in printing variable data, such as serial numbers or expiration dates, on a wide range of substrates. Inkjet printers are also capable of printing in multiple colors, making them ideal for branding and decorative applications (Lai et al., 2019).

4.6.3 Laser Marking

Laser marking systems use focused laser beams to engrave or etch information onto labels or directly onto products. This technology is ideal for applications requiring permanent and tamper-proof markings, such as serial numbers, QR codes, or compliance symbols (Beiner, 2020). Laser marking is non-contact, reducing wear on the equipment and minimizing the risk of product damage. The system's speed and precision are controlled by galvanometer-driven mirrors, allowing for high-speed marking with micron-level accuracy. Laser marking systems can be integrated into labeling lines for continuous, high-throughput operations (Beiner, 2020).

4.7. Vision and Inspection Systems

Vision and inspection systems are critical for ensuring the accuracy and quality of labels in automated labeling processes. Vision systems are integrated into labeling operations to perform tasks such as label alignment, barcode scanning, and quality control.

4.7.1 Machine Vision

Machine vision systems are critical for quality control in automatic labeling. These systems use high-resolution cameras and image processing algorithms to inspect labels after they have been applied. The vision system can verify label presence, alignment, orientation, and content, ensuring that each product meets quality standards. Advanced machine vision systems can detect even minute defects, such as smudged text or misaligned graphics, and trigger rejection mechanisms to remove defective products from the line. Integration with the PLC allows real-time feedback and adjustments to the labeling process (Seitaj, 2024).

4.7.2 Barcode Scanners

Integrated barcode scanners are used to read and verify barcodes on applied labels, ensuring that they are correctly printed and scannable. These scanners use laser or camera-based technology to decode barcodes at high speeds. The data is cross-referenced with production databases to ensure that each product is correctly identified and traceable. Some systems also include 2D barcode scanners capable of reading QR codes and DataMatrix codes, which are increasingly used in industries such as pharmaceuticals and electronics (Seitaj, 2024).

4.7.3 Optical Character Recognition (OCR)

OCR technology is used to read and verify text printed on labels, such as lot numbers, dates, and product names. The OCR system captures images of the text and converts it into digital data, which is then compared against expected values stored in the system's database. This technology is particularly useful in ensuring compliance with regulatory requirements, where accurate labeling of product information is critical. OCR systems are integrated with machine vision and PLCs for real-time verification and feedback (Jain, 2023; Seitaj, 2024).

4.8. Servo and Stepper Motors

Servo and stepper motors are integral to the precision and control of automated labeling systems. Servo motors have the ability to provide precise speed and position control through feedback mechanisms and plays a role in enhancing accuracy and efficiency. Stepper motors on the other hand operates through discrete steps, offering reliable control in applications requiring precise incremental movements.

4.8.1 Servo Motors

Servo motors are used extensively in labeling systems for precise control of applicator movements, label feed mechanisms, and product handling equipment. These motors are equipped with feedback sensors, typically encoders that provide real-time position and speed data to the control system. This closed-loop feedback allows for highly accurate positioning and smooth operation, even at high speeds. Servo motors are particularly valuable in applications requiring variable speed and torque, such as labeling products of different sizes or shapes (Adams, 2024).

4.8.2 Stepper Motors

Stepper motors are used in applications where precise control is needed, but with lower speed and torque requirements compared to servo motors (Huang et al., 2021). These motors operate in discrete steps, allowing for exact positioning without the need for feedback sensors. Stepper motors are commonly used in label dispensers, where they control the advance of the label web with high accuracy. The simplicity and reliability of stepper motors make them ideal for applications where cost-effectiveness and ease of integration are important (Huang et al., 2021).

4.9. Integration with Other Systems

Integration with other systems is crucial for optimizing the performance and functionality of automated labeling operations. Communication protocols like Ethernet/IP, Profibus, and OPC help in seamless data exchange and coordination between systems.

4.9.1 ERP and MES Integration

Automatic labeling systems can be integrated with Enterprise Resource Planning (ERP) and Manufacturing Execution Systems (MES) to streamline data flow and production management (Sika, 2022). This integration allows for real-time updates of label content, such as product names, batch numbers, and expiry dates, based on production orders from the ERP system (Tsai et al., 2020). MES integration provides detailed tracking of labeled products, enabling traceability throughout the production process (Hirvonen et al., 2021). Data exchange between the labeling system and these enterprise systems is typically handled via standardized communication protocols, such as OPC UA or MQTT (Wei et al., 2020).

4.9.2 Robotic Integration

In advanced labeling systems, robots may be used for tasks such as product feeding, orientation, and secondary operations like packing or palletizing (Yan, 2020). Robotic arms equipped with vision systems can accurately position products for labeling, ensuring consistency even with irregularly shaped items (Qiu et al., 2022). Robots can also be used to apply labels in difficult-to-reach areas or to perform complex labeling tasks, such as applying multiple labels to different parts of a product. Integration between the labeling system and robotic cells is managed through PLCs and networked control systems, allowing for coordinated operation (Qiu et al., 2022).

4.10. Data Management and Connectivity

Data management and connectivity are pivotal in enhancing the functionality and efficiency of automated labeling systems. Connectivity solutions, such as industrial Ethernet, wireless networks, and cloud-based platforms, facilitate seamless data exchange and integration across various system components.

4.10.1 IoT and Industry 4.0

IoT and Industry 4.0: IoT (Internet of Things) technology enables labeling systems to collect and transmit data in real-time, supporting Industry 4.0 initiatives (Barriga et al., 2022). Sensors embedded in the labeling machinery monitor critical parameters, such as temperature, humidity, and machine vibration, which can impact label application. This data is transmitted to cloud-based platforms for analysis, enabling predictive maintenance and process optimization. IoT connectivity also allows for remote monitoring and control of labeling systems, providing manufacturers with the flexibility to manage operations from any location (Barriga et al., 2022).

4.10.2 Wireless Communication

Wireless communication protocols, such as Wi-Fi, Bluetooth, or Zigbee, enable seamless integration of labeling systems with other production line equipment and enterprise systems (Yang et al., 2019). Wireless sensors can be used to monitor machine performance and environmental conditions without the need for complex wiring. This flexibility simplifies system installation and maintenance, especially in large-scale or dynamic production environments. Wireless communication also supports mobile HMI devices, allowing operators to control and monitor labeling systems from anywhere in the facility.

4.11. Safety System

Safety systems are crucial for ensuring the secure operation of automated labeling systems and protecting personnel and equipment. Technical components and protocols involved in implementing robust safety measures include emergency stop systems, safety interlocks, and guard systems.

4.11.1 Safety Sensors and Interlocks

Safety Sensors and Interlocks: Safety sensors and interlocks are critical for preventing accidents and ensuring safe operation of labeling systems. These systems detect when safety guards or doors are open and prevent the machine from operating until they are securely closed. Safety light curtains, pressure-sensitive mats, and emergency stop buttons are commonly used in high-risk areas to protect operators from moving parts. These safety systems are integrated into the machine's control system, often with redundancy and fail-safe mechanisms to ensure reliable operation (Sharif et al., 2022).

4.11.2 Emergency Stop Systems

Emergency stop systems provide operators with a quick and effective way to halt the labeling machine in case of an emergency. These systems typically include multiple emergency stop buttons located at key points around the machine. When activated, the emergency stop system immediately cuts power to the machine and engages mechanical brakes to bring all moving parts to a rapid stop. The system is designed to minimize the risk of injury or damage to the machine and products. In advanced systems, the emergency stop may also trigger automated diagnostics to identify the cause of the emergency and assist in recovery (Ağseren, 2024).

5. Challenges and Consideration in Implementing The Automation of Product Labeling

Implementing automation in product labeling presents several challenges and considerations that must be addressed to achieve successful integration and operation. Key obstacles include the complexity of system integration, the need for customization to accommodate diverse labeling requirements, management of initial investment costs, system reliability, maintenance requirements, and the need for operator training.

5.1. Integration with Existing Systems

5.1.1 Challenges

Integrating a new automated labeling system with an existing production line is often fraught with challenges. One primary issue is ensuring compatibility between the new system and older equipment. Many production lines utilize legacy machinery that may not be designed to interface seamlessly with contemporary labeling technologies (Hanum et al., 2020). This can result in technical incompatibilities that disrupt the production flow or necessitate significant modifications to existing equipment (Hanum et al., 2020).

Additionally, integrating the labeling system with other critical management systems, such as Manufacturing Execution Systems (MES) and Enterprise Resource Planning (ERP) platforms, introduces further complexity (Liu et al., 2023). These systems must work together to ensure that labeling information is accurate and synchronized with real-time production data. This integration often requires custom software solutions or middleware to bridge gaps between disparate systems, ensuring smooth communication and data exchange (Liu et al., 2023). ERP systems are designed to automate and integrate fundamental business activities, assisting companies in streamlining their operations (Laulita et al., 2022). However, the integration of ERP systems can be time-consuming and may require years of implementation (Kwang et al., 2019).

5.1.2 Considerations

To overcome these integration challenges, a thorough compatibility assessment is essential. This involves evaluating existing equipment and systems to identify potential conflicts or areas requiring modification (Lv, 2024). Upgrading legacy machinery or implementing intermediate technology solutions may be necessary to facilitate seamless integration (Etxeberria et al., 2022).

Data integration should be carefully planned, involving close collaboration with system integrators, software developers, and IT specialists (Leng et al., 2021). Developing a robust interface between the labeling system and other management platforms ensures real-time data synchronization and minimizes disruptions to the production process (Leng et al., 2021). Clear communication and detailed planning are crucial to achieving a harmonious integration that enhances overall efficiency.

5.2. Labeling Accuracy and Quality Control

5.2.1 Challenges

Maintaining high standards of labeling accuracy is crucial in ensuring product quality and regulatory compliance. Errors such as misaligned labels, incorrect information, or defects in the labels can have serious consequences, including product recalls, customer dissatisfaction, and regulatory fines (Farhangi, 2024). These issues can lead to significant operational problems, including product recalls, customer dissatisfaction, and regulatory fines. Vision inspection systems, while advanced, are not infallible. They may struggle to detect certain types of errors, especially if labels are damaged, poorly printed, or if the production environment introduces variables such as dust or temperature fluctuations.

Inaccurate labeling not only affects compliance but can also impact brand reputation and consumer trust.

5.2.2 Considerations

To address these accuracy and quality control challenges, investing in high-resolution vision inspection systems is paramount. These systems should be equipped with advanced features capable of detecting a wide range of labeling issues, including misalignment, smudging, and missing information (Cruz et al., 2020). Regular calibration and maintenance of these systems are essential to ensure they operate at peak performance (Cruz et al., 2020).

Implementing robust quality control procedures is also critical. This includes conducting routine inspections, utilizing error-detection algorithms, and establishing corrective action protocols for any issues identified. By maintaining rigorous quality control standards, manufacturers can ensure that labels meet both regulatory requirements and customer expectations (Cruz et al., 2020). Additionally, the use of deep learning algorithms in automated optical inspection processes contributes to real-time quality assurance, benefiting from advancements in image processing and camera technology (Yang et al., 2020).

5.3. Maintenance and Reliability

5.3.1 Challenges

Automated labeling systems are complex machines subject to wear and tear over time. Mechanical failures, software glitches, or other technical issues can lead to system downtime, disrupting production and impacting overall efficiency. Regular maintenance is required to prevent these issues, but it can be costly and resource-intensive.

Maintaining the reliability of the system is a continuous process that involves not only repairing faults but also anticipating and preventing potential problems (Zwolińska & Wiercioch, 2022). This requires a dedicated approach to maintenance and a clear strategy for addressing issues as they arise (García & Salgado, 2022).

5.3.2 Considerations

Preventive maintenance plays a significant role in enhancing machine reliability, as evidenced by studies on the impact of preventive maintenance on machine reliability in various industrial settings (Ben et al., 2021; Cahyati, 2024). To optimize maintenance strategies, factors such as downtime, severity of failures, spare parts availability, and maintenance costs need to be considered (Sanja et al., 2023). Reliability-centered maintenance policies, real-time reliability evaluation, and condition-based maintenance data analysis are essential for ensuring the effectiveness of maintenance activities and avoiding unnecessary downtime (Bai & Zeng, 2019; Meyer et al., 2021). In automated systems such as automated labeling systems, the use of predictive maintenance based on machine learning and industry 4.0 technologies can enable zero-failure maintenance by providing early warnings of potential faults (Singh, 2023; García, 2023). Furthermore, the application of deep survival models and neural networks can aid in accurately estimating the remaining useful life of machine components, contributing to proactive maintenance planning (Chu et al., 2020).

A proactive maintenance strategy is essential for ensuring the reliability of automated labeling systems. Implementing a preventive maintenance program involves scheduling regular inspections, servicing, and component replacements to address potential issues before they lead to system failures. Technical support and training for operators and maintenance personnel are also critical. Ensuring that staff is well-trained in both the operation and troubleshooting of the labeling system helps to address problems promptly and efficiently. Establishing a support contract with the equipment manufacturer or supplier provides additional assurance of expert assistance and access to replacement parts (Noureddine et al., 2020). Proactive maintenance, which includes preventive, predictive, and reliability-based strategies, is widely recognized in various industries for its effectiveness in maintaining equipment and preventing failures.

5.4. Cost and Budget Constrains

5.4.1 Challenges

The initial investment required for purchasing and installing an automated labeling system can be substantial. For example, Shvets (2024) mentions that for an average farm with 200 cows, initial investments in automation can range from €450,000 to €500,000. This significant upfront cost can pose a challenge for organizations considering the adoption of automated systems. Moreover, Kim et al. (2022) point out that the high up-front costs of Total Laboratory Automation (TLA) systems are a major restriction to their adoption, indicating a common trend across different industries. In addition to the initial investment, ongoing operational costs such as maintenance, repairs, and software updates can further strain budgets and impact financial planning. Balancing the upfront cost with the potential long-term benefits of the labeling system is crucial. It's important to evaluate the return on investment (ROI) and ensure that the system provides value that justifies its cost.

5.4.2 Considerations

A comprehensive cost-benefit analysis should be conducted to assess the potential ROI of the labeling system. This analysis should consider factors such as increased production efficiency, reduced labor costs, and improved product quality. Developing a detailed budget that accounts for both initial investment and ongoing costs is essential for managing financial constraints. This budget should include provisions for maintenance, repairs, and potential system upgrades. Allocating funds for these expenses ensures that the labeling system remains effective and adaptable to future needs.

Zhao (2024) and Suo & Cao (2021) emphasize the significance of conducting a cost-benefit analysis to evaluate both direct and indirect benefits. Zhao (2024) propose a quantitative analysis model that considers the monetization of indirect benefits, providing a framework for assessing the overall impact of a system. Suo & Cao (2021) highlight the importance of considering the cost components in a cost-benefit analysis, indicating that ecosystem services assessments often overlook these crucial aspects. Dambaulova (2023) discusses the benefits of automated systems and the importance of deriving valuable insights from related research to conduct a simplified cost-benefit analysis. This underlines the need to explore existing literature to understand the quantifiable benefits associated with such systems. While not directly related to labeling systems, Ahmad et al. (2023) provides insights into cost-benefit analyses for solar systems, highlighting the importance of considering the financial implications and savings over time.

5.5. User Training and Adaptation

5.5.1 Challenges

Training personnel to operate and maintain the automated labeling system can be a significant challenge, particularly if the system introduces new technologies or processes. Resistance or apprehension from staff accustomed to older methods may hinder the transition process, emphasizing the importance of managing this change efficiently (Nkosi et al., 2022; Perikli, 2024). Managing this transition effectively is crucial for successful implementation.

5.5.2 Considerations

Implementing a comprehensive training program is vital for ensuring that operators and maintenance personnel are well-prepared to use the automated labeling system. This program should include hands-on training, instructional materials, and ongoing support to help staff adapt to the new technology (Fei et al., 2021). Managing the transition to automated labeling involves addressing staff concerns and fostering a positive attitude towards change. Clear communication about the benefits of the new system and providing ongoing support helps to facilitate adaptation and integrate the system smoothly into existing workflows (Gino et al., 2023).

To ensure successful adoption of new technologies, appropriate strategies that resonate with the target audience are essential (Nyamekye, 2024). Also, the training program should cover cognitive, affective, and psychomotor learning domains to address various skills and knowledge aspects (Gino et al., 2023). The development of training datasets using automated labeling techniques can significantly accelerate the evaluation of system performances (Fei et al., 2021). Additionally, utilizing Information and Communication Technologies in conjunction with the Flipped Learning model can enhance educational practices (Cueva & Inga, 2022).

In conclusion, a well-designed training program, coupled with effective communication and ongoing support, is vital for the successful implementation of automated labeling systems. By addressing staff concerns, fostering a positive attitude towards change, and ensuring comprehensive training, organizations can facilitate a smooth transition and maximize the benefits of automated labeling technology.

6. Conclusion

This review has highlighted the transformative impact of automation on product labeling, illustrating how advanced technologies have enhanced efficiency, accuracy, and flexibility in labeling processes across various industries. Automated labeling systems have become integral to modern production lines, seamlessly integrating with other automation technologies to streamline operations and reduce human error. The key components and technologies that underpin these systems, such as vision inspection systems, robotics, and smart labels, play a crucial role in ensuring that labels are applied with precision and consistency.

However, the implementation and maintenance of automated labeling systems are not without challenges. Issues such as integration with existing systems, maintaining labeling accuracy, adapting to diverse product formats, and ensuring regulatory compliance require careful planning and strategic management. Despite these challenges, the benefits of automation in product labeling, ranging from improved operational efficiency to enhanced product quality, are undeniable. As industries continue to evolve, the future of product labeling will be shaped by emerging trends such as AI integration, IIoT connectivity, and the increasing demand for sustainability. Manufacturers who successfully navigate the complexities of automation will be well-positioned to capitalize on these trends, achieving greater productivity and meeting the growing expectations of consumers and regulators alike.

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