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Article

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1. Introduction

With the fourth industrial revolution and manufacturing innovations that started in Germany, the fashion industry is changing. The concepts of smart factories and automation are mixed complexly and used in the fashion industry. On the other hand, there are considerable differences between factory automation and smart factories. Factory automation refers to a system that automates the entire unmanned factory and manufacturing process using automatic equipment, such as computers and robots. In contrast, smart factories give each function to various objects related to manufacturing. Each of these objects is a factory that communicates to each other through internet of things (IoT) devices and can autonomously connect, collect, and analyze data [1]. Smart factory and automation systems can enable the development of a fashion system based on the product quantities that are better balanced with market demand, more consistent with the customers' needs, highly customized, and transparent for their entire lifecycle [2].

Garments are essential items for humans. As the population increases and lifestyles change, customers' needs for various new clothing styles are also increasing. The process of manufacturing garments is a labor-intensive and mass-produced industry. Serious environmental problems and social costs have occurred due to excessive mass production to supply new products to the market quickly. In addition, producers continue to move their production bases to developing countries with lower wages to lower production costs. Focusing on the 4.0 smart factory, the garment manufacturing industry needs to be transformed into an automated manufacturing process through several technologies such as computer systems and digital facilities because of the limitations of the relocation of the production base and the needs of customers.

The automation of garment manufacturing has been suggested as one of the measures for rapid military production because soldiers can be mobilized to the army quickly to improve military power. On the other hand, automation of the garment industry has not been implemented to any large extent because clothing products do not undergo the same form or production process, such as devices or automobiles. The styles are diverse and change very often, and there is a size issue. Even with the same design, the pattern varies depending on the size, and the process may be different. The initial investment cost to build an automated facility in the production site is high. In addition, automation is not so urgently needed because it still has an inexpensive workforce available.

The complete automation of garment manufacturing is impossible because a human force is still needed to control the direction and position of the sewn fabric during the sewing process. Regardless of how much technology develops, more than 95% automation appears impossible because garment styles change very quickly, and its forms are so numerous. Nevertheless, partial automation is being realized gradually. Research on automation is aimed at automatically and easily manufacturing garments and textiles for sale rather than prototypes [3]. Therefore, a future garment manufacturing system is expected to be a smart factory. This is because the production costs are increasing gradually, and reactive and local production according to customization needs is required. As shown in Figure 1, in the near future, the fashion industry is expected to transform into the means of instant production and delivery of clothing designed and ordered by customers [4].

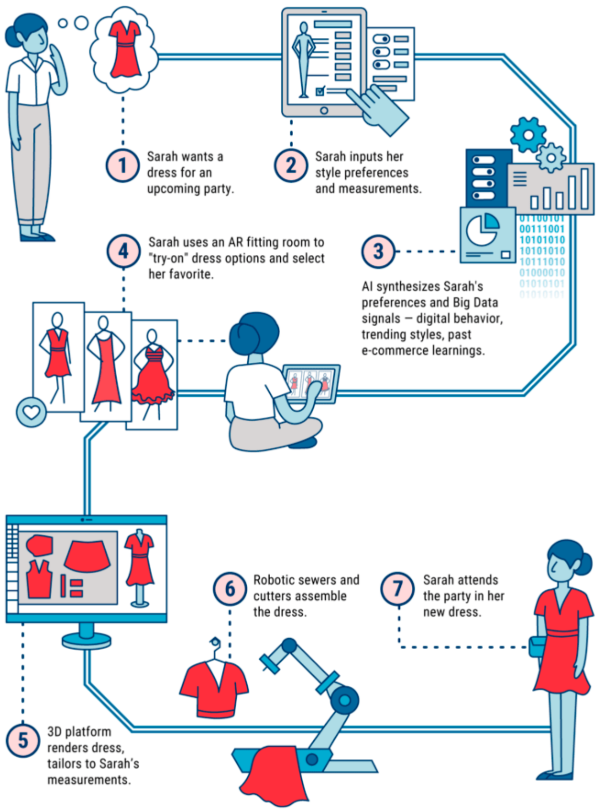


Figure 1. Scheme of the impact of technology on fashion industry [4].

Research has been actively conducted in the field of automation of garment manufacturing for many years, particularly in robot gripping and automatic sewing systems [3,5–8].

A robot-based sewing system named SEWBO (Sewbo, Inc., Seattle, WA, USA) sewed all the necessary seams of a T-shirt automatically using an industrial robot arm. Within the project speed factory of Adidas, a new sewing system to sew two layers of textiles automatically has been developed by the Institute für Textiletechnik of the RWTH Aachen University. The system consists of two transport rollers to guide textiles with different contours through the sewing process individually [3]. Philipp Moll proposed an innovative concept for garment manufacturing. The concept comprised a holistic, general production line from cutting, and transport to the sewing process with the following three parts: fast automated single-ply cutting, automatic robotic pick-up of fabric parts and transfer to an automatic hanging transport system, and sewing process with a traditional sewing technique and robotic 3D assembling [9].

This paper proposes a system to establish an automated process for garment manufacturing with various machines and technologies. To this end, the currently developed automated sewing system was examined, and a new automatic manufacturing process for smart clothing was proposed. Smart clothing is a new clothing concept with the convergence of information and communication technology (ICT) [10]. Therefore, the material constituting it is relatively limited compared to that generally required to produce fashion clothing, and the design is also simple. For these reasons, smart clothing was selected as the target item for establishing an automated process for manufacturing garments. For this purpose, the 2D–3D computer aided design (CAD) system, technical embroidery technology, robot-based gripping system, and automatic sewing system were used to connect the process and analyze the correlation between textile and process conditions at each stage. Through this, the production system for a sports bra with a light-emitting diode (LED) system was optimized.

2. Case Study of Manufacturing Process Automation in Clothing and Textile Fields

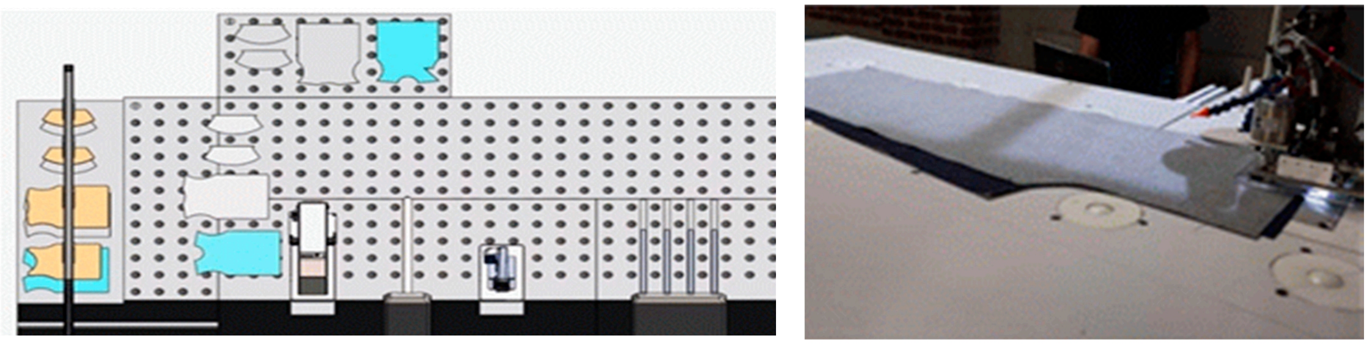
2.1. SEWBOT

Steve Dickerson, a founder of Softwear Automation in Atlanta and a professor at the Georgia Institute of Technology, studied robotics technology for sewing and launched SEWBOT, which is an automatic sewing system. This system consists of an automatic sewing machine (ASM), The robotic arm to carry and move the fabrics, and budgers which move the fabric in all directions so that the fabric can be sewn, as shown in Figure 2. The ASM can perform various sewing tasks such as creasing, organizing clothes, attaching fabrics, and basic sewing. The robotic arm uses air-absorbing technology to transfer fabrics of various sizes quickly to the ASM without wrinkling [3].

(**a**) (**b**) (**c**)

Figure 2. System of SEWBOT: (**a**) automatic sewing machine (ASM); (**b**) robotic arm; (**c**) budgers.

In 2017, Softwear Automation presented a fully automated T-shirt work-line, as shown in Figure 3. Unlike research that imitates the human hands or develops separate grippers to handle textiles, they suggested a new approach, which is a type of conveyor system based on a vacuum ball to carry a single textile at each stage of garment manufacturing. This system is equipped with a vacuum ball on the table. Each installed ball can be moved in both directions. Therefore, the adsorbed cutting material can move freely according to the movement of the ball. By combining the vision system, the contour of the textile is detected and moved accurately, and the automatic sewing facility is arranged according to the process. These have enabled unmanned manufacturing system that can be sewn without human intervention. Using this system, it takes approximately four minutes from the cutting of the fabric to the sewing of the finished product, allowing the production of 800,000 shirts annually. In addition, floor rugs, bathroom mats, pillows, and car mats can be manufactured using the fully automated systems. Unfortunately, because all the processes are connected by a single ball system, the problem of space limitation needs to be solved. In addition, current robotic handling technology has limitations on the items that can be handled because only rigid materials, such as cotton, can be used. On the other hand, full automation of the garment manufacturing process is expected to become a reality in the near future through research to expand the technology to various fabrics, such as cotton–PET blend fabric, silk, and mesh fabrics.

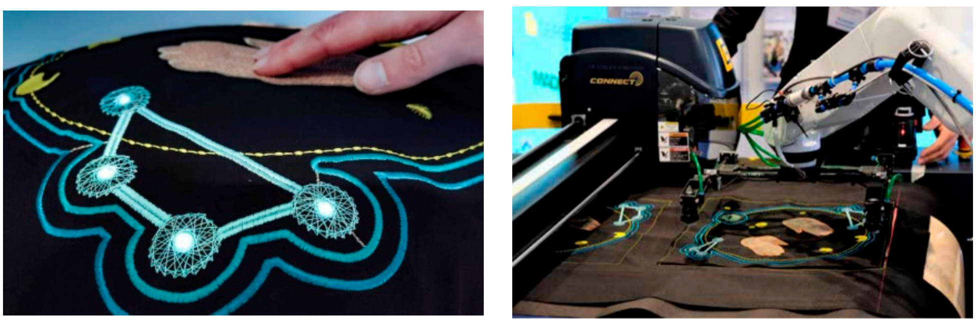


(**a**) (**b**)

Figure 3. New conveyor systems of Softwear Automation: (**a**) scheme for the system; (**b**) operation state for jeans.

2.2. Micro-Factory

ITA(Institut für Textiltechnik of RWTH Aachen University) and an industrial partner (Gerber Technology GmbH, Korea Institute of Industrial Technology, VETRON Typical Europe GmbH, Wear it Berlin GmbH, ZSK Stickmaschinen GmbH) have developed the smart textile micro-factory. This system manufactures smart cushions, as shown in Figure 4a, which enable interactions with the user through intense and light pulses, as well as wireless communication with other cushions [11].



(**a**) (**b**)

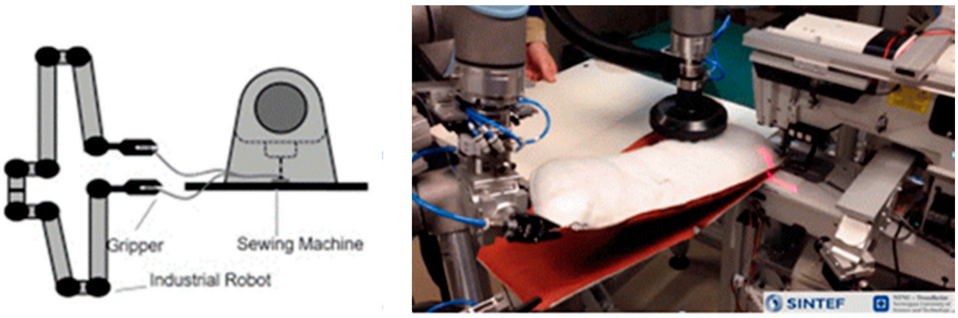
Figure 4. Micro-factory at Texprocess 2019: (**a**) smart cushion; (**b**) gripping robot system [11].

This smart textile micro-factory consists of a technical embroidery machine, an automatic cutting machine, a gripping robot system, and an automatic sewing machine. After materials, such as conductive thread and LED sequences, are embroidered on a large area of fabric through a technical embroidery machine, they were moved to an automatic cutting machine to cut the front and back panels of the cushion into a single-ply. The robot transfers the cut pattern materials to the frame of the sewing machine using a vacuum gripper, as shown in Figure 4b. When all cut materials are placed into the frame, sewing is performed automatically in a square shape.

This system is meaningful because it attempts to automate a series of processes for the manufacture of smart cushions using various existing equipment without human intervention.

2.3. Robotic-Guided Sewing Project in SINTEF Raufoss Manufacturing

The Norwegian company, SINTEF Raufoss Manufacturing AS, operates a laboratory for sewing automation research. They are working on robot-guided sewing projects in collaboration with the furniture company, Ekornes ASA, protective clothing manufacturer Hansen Protection AS, CAD and computer-aided manufacturing (CAM) supplier Amatec AS, Norwegian University of Science and Technology (NTNU), and the Research Council of Norway. Through this project, Johannes S. et al. [12] published a robot-guided sewing process that included an industrial C-frame sewing machine, two robotic arms to handle textiles to be sewn, one robotic arm to guide sewn textiles, and a sewing cell composed of a sensor and camera system to check the edge of the sewn textiles and adjust the moving direction, as shown in Figure 5. The two robotic arms that handle the textile to be sewn each grip the top and bottom of the workpiece. In addition, the robotic arm is equipped with mechanical grippers to monitor the tension on the textile and adjust it constantly. The fabric gripped by the robot is placed into the sewing machine, and the sewn textile is then inspected through the sensor. The overall robot motion is controlled in real-time through a Linux computer, a robot operating system, and various software. The system has a disadvantage in that the radius of the seam sewing is limited, and the working space is limited because of the robot guides. On the other hand, the robotic arm shows a new approach to robotic sewing—to guide the cut materials rather than the sewing head. Currently, they have developed prototype equipment for the robotic sewing of armchair covers and offshore survival suits, and further studies aimed at commercialization are underway.



(a) (b)

Figure 5. Robot-guided sewing process of SINTEF Raufoss Manufacturing AS: (**a**) scheme for the system; (**b**) operation [12].

3. Automatic Manufacturing Process for Smart Clothing

3.1. Making Process Framework

To build an automatic system, smart clothing with LED sequences was designed as an item. Smart clothing is suitable for an automatic production system because the raw and subsidiary materials used are relatively limited compared with fashion items, and the structure of clothing is simple. Considering the robot gripping and automatic sewing process, the design was simplified by reducing the cutting line and removing the fastening detail. In addition, to increase the efficiency of the production process, unlike the order of the general fashion clothing manufacturing process, the embroidery process for embedding smart functions was carried out in the fabric state and then cut. Figure 6 shows the entire production process.

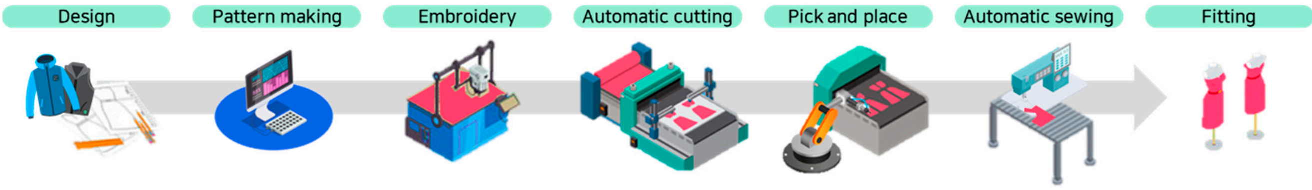


Figure 6. Automated manufacturing process for smart clothing.

Fabrics for making smart clothing in this study were provided by Woojoo Global (Korea). The fabrics were a tricot knitted fabric composed of 87% polyester and 13% spandex. The weight and thickness of the fabrics were 574 g/m^2 and 0.84 mm, respectively.

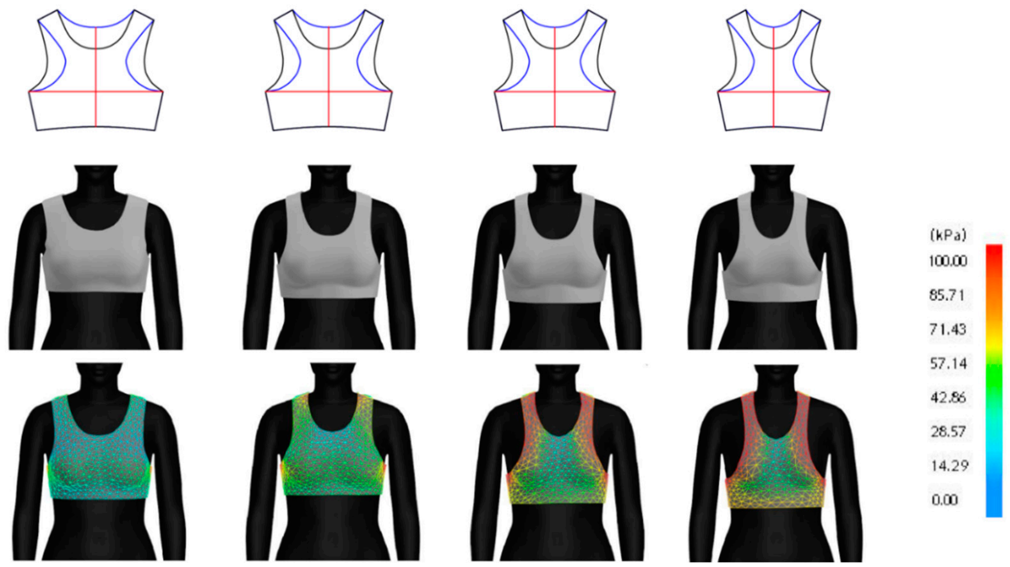
3.2. Design and Pattern Making through CAD/CAM Systems

Computer-aided design (CAD) is a design and development process based on computer technology, and has been utilized in various fields. In the textile and apparel industries, CAD uses software, such as Gerber, Lectra, Apparel CAD, Illustrator and Photoshop, and Optitex to design clothing and accessories, pattern design, grading, and virtual simulation. The computer-aided manufacturing (CAM) system performs substantially related to manufacturing, such as marker planning, spreading, and cutting. In the actual clothing production process, CAD/CAM systems, such as pattern design, grading, 3D virtual simulation, and markers, improve overall productivity, accuracy, and efficiency by reducing sample production, shortening the time required for the entire work, and reducing fabric waste [3,13,14]. In this study, as a part of the automated manufacturing process of smart clothing, the CAD/CAM system was used to establish pattern making, simulation of virtual fit, and marker planning.

The sports bra was selected as a prototype for this study. The pattern was formed based on the average size of women in their twenties (height = 160.8 cm, bust circumference = 85.1 cm, waist circumference = 71.9 cm, and shoulder width = 35.7 cm) from the seventh SIZE KOREA data provided by the Korean Agency for Technology and Standards [15]. The pattern was designed using YUKA CAD (Yuka & Alpha Co., Ltd., Tokyo, Japan), and the pattern of the sports bra was based on the bodice pattern from ESMOD [16]. After removing the ease of the bust circumference and darts on the shoulder from the bodice pattern, the sports bra was designed with a neck width of 9.6 cm, a front neck depth of 10 cm, a shoulder length of 6 cm, and a side line of 10 cm. In addition, according to the characteristics of the sewing equipment that sews while each piece is placed flat on the template of the sewing machine, the front and back pieces were set identically, and the length and angle of the shoulder and side lines of the front and back panels were designed to be the same.

The fabric was made of flexible material and required a consideration of the reduction rate of the pattern. The reduction rate of 0%, 10%, 20%, and 30% was applied to the sports bra pattern in a weft direction, referring to the pattern reduction rate for the development of tight-fitting clothing by Jeong [17]. For the four patterns, the conditions of virtual fitting were simulated by CLO (CLO 3D version 5.2, CLO Virtual Fashion Inc., Seoul, Korea), and the properties of the fabric were used after converting the elongation of 18% in the warp direction and 32% in the weft direction through the CLO fabric emulator function. Figure 7 shows each pattern and the wearing state. The color of the virtual clothing in Figure 7 simulated the clothing pressure that can occur depending on the size reduction rate. The pattern without the reduction rate showed a lifting phenomenon in the armhole. The pattern with the 30% reduction rate showed that the armhole area was stretched due to the insufficient ease of the bust circumference. The measured values are difficult to compare from the actual clothing pressure, but examination of the clothing pressure distribution ratio according to the pattern reduction rate on the CLO showed that the pattern applying 20% and 30% reduction ratios in the weft direction showed a high clothing pressure of

100 kPa to the human body when designed and virtually worn through the CAD program. Therefore, a pattern with a 10% reduction ratio in the weft direction was selected.



(**a**) (**b**) (**c**) (**d**)

Figure 7. Sports bra pattern and virtual fit by pattern reduction rate: (**a**) 0% reduction; (**b**) 10% reduction; (**c**) 20% reduction; (**d**) 30% reduction. The black line is the front panel; the blue line is the back panel; the red line is the base-line.

A marker was produced using the AutoNest (Yuka & Alpha Co., Ltd., Tokyo, Japan) program. Marking is an automatic placement of patterns with an optimization of the fabric yield, enabling efficient markers to be produced in a short time using the CAM system [3]. In this study, however, manual placement was carried out so that the robot arm can move within the range not affected by the cutting machine and sewing machine, A distance of at least 3 cm between each pattern was placed to prevent interference with vision recognition during gripping (Figure 8).

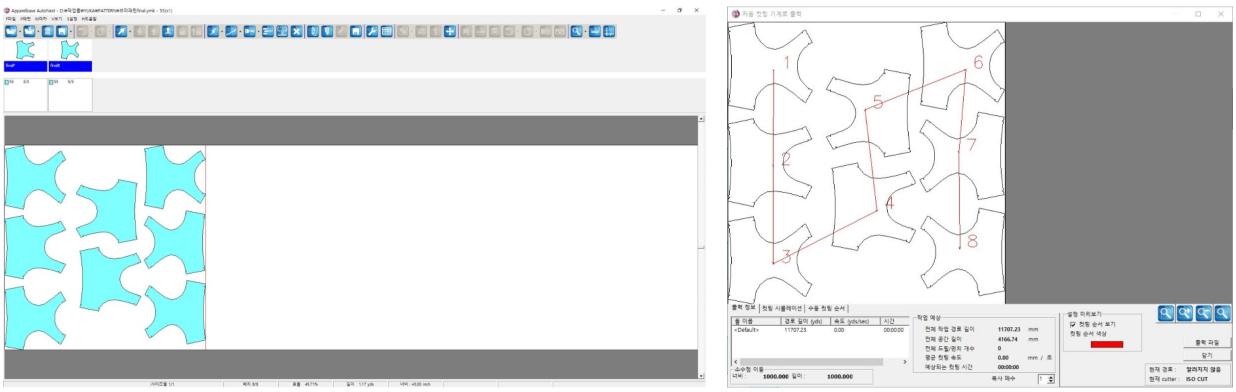
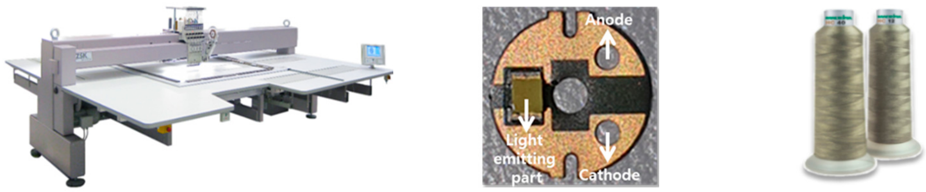


Figure 8. Sports bra marker by AutoNest.

3.3. *Embroidery for Smart Function*

Embroidery was originally a handicraft. On the other hand, during the Industrial Revolution, embroidery machines began to be developed, and digitized-pattern software is used in modern times [18,19]. Technical embroidery technology uses conductive materials (thread, wire, fiber, and LED) with an embroidery machine to make embroidery products with electrical properties. Digitized embroidery patterns can include machine motion-control functions (e.g., thread color change, embroidery speed change, thread cut, machine stop, and sequin device control), enabling almost automatic embroidery. Many researchers are developing various fiber-type conductive wires, sensors, and antennas using technical embroidery technology [20–23].

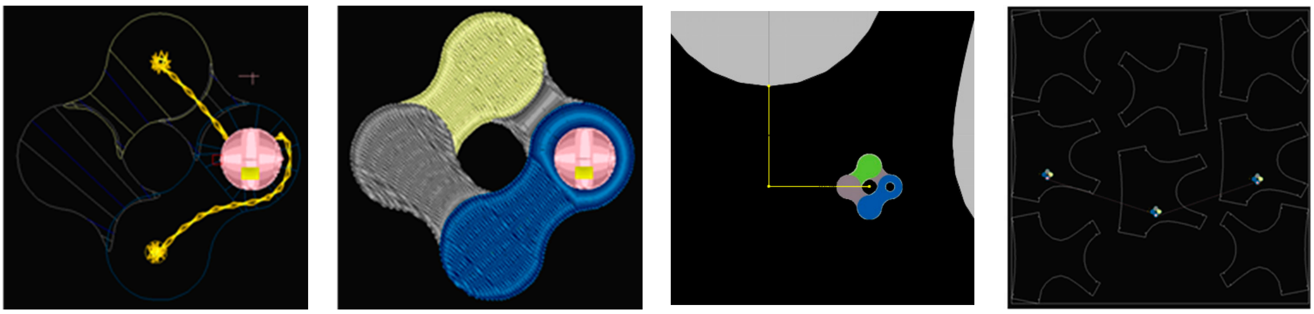
In this study, the KITECH logo was designed over the sports bra pattern using technical embroidery techniques. For this, a technical embroidery machine (SGVA 0109-825, ZSK Stickmaschinen, Krefeld, Germany) was used, as shown in Figure 9a. The EPC_win program (ZSK Stickmaschinen, Germany) was used to design the size and shape of the logo for embroidery. In particular, an LED circuit was inserted with an LED and silver-coated conductive thread in the logo to give a light-emitting function to the sports bra. As shown in Figure 9b, an LED sequin consisted of a light-emitting part and an electrode part. The LED circuit was made by connecting the anode and cathode with conductive thread. HC-12 from Maderia (Germany) was used as a conductive thread, as shown in Figure 9c.



(**a**) (**b**) (**c**)

Figure 9. Apparatus and materials for the embroidery process: (**a**) technical embroidery machine; (**b**) light-emitting diode (LED) sequin; (**c**) conductive thread.

The procedure for producing an embroidery pattern was as follows. First, the LED circuit was designed, as shown in Figure 10a. The pink part and yellow line are the LED sequin and conductive circuit line, respectively. After that the KITECH logo was designed on the LED circuit to hide the conductive lines with the LED sequin, as shown in Figure 10b. The final design and size of the embroidery pattern were determined by a simulation through virtual fitting using a 3D CLO program (Figure 10c). Finally, the position to embroider among the sports bra patterns was designated, as shown in Figure 10d. After adjusting the position of the logo to be embroidered on the front of the sports bra using the marker file, the position coordinates were obtained for the embroidery process.



(**a**) (**b**) (**c**) (**d**)

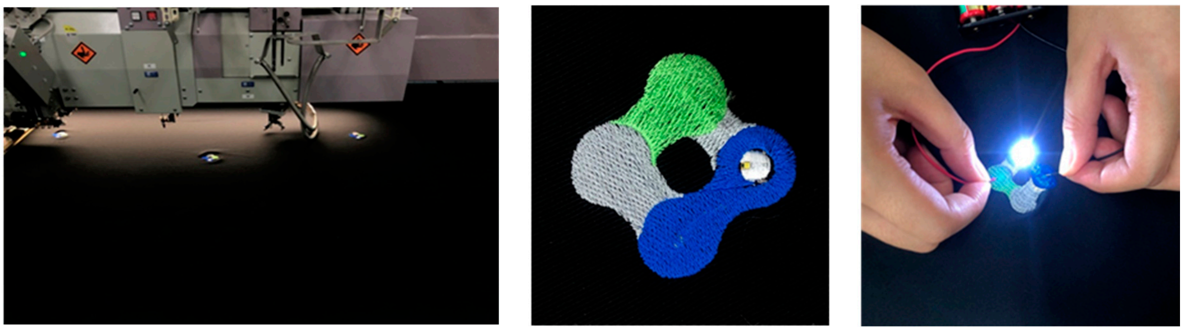
Figure 10. Procedure for designing embroidery pattern of KITECH logo with LED circuit: (**a**) LED with a circuit line; (**b**) final logo pattern; (**c**) virtual fitting with final logo pattern; (**d**) sports bra pattern with the designed logo on the marker.

Embroidery patterns files designed in the EPC_win program were moved to a technical embroidery machine for embroidery. As shown in Figure 11, the connection between the LED and the conductive thread was not embroidered well, and the logo embroidery did not proceed smoothly. The connection problem between the LED and the conductive thread caused a malfunction of the LED and damaged the needle of the embroidery machine. The appearance of the logo work was not good, reducing its value as a product. This is because the good elasticity of the fabric used for embroidery allows the fabric to be stretched easily by the needle and thread during embroidery. Furthermore, the short stitch lengths were packed into each inch of stitching, producing a puckering and spacing appearance because the stitches with short stitch lengths hold the fabric with high tension [24].

(**a**) (**b**)

Figure 11. Technical problem during the embroidery process: (**a**) LED circuit; (**b**) logo.

To reduce the deformation of the fabric, a nonwoven fabric was placed under the fabric and embroidered together to minimize the movement of the fabric during embroidery. In addition, the stitch length was increased from 3.0 mm to 4.5 mm to reduce the puckering problem. As a result, the embroidered product and process were improved, as shown in Figure 12. After the continuous embroidery process, the LED operation on the KITECH logo was confirmed by connecting the battery.



(**a**) (**b**) (**c**)

Figure 12. Improving embroidery products by minimizing the movement of the fabric: (**a**) work with technical embroidery machine; (**b**) final embroidered product; (**c**) LED operation.

3.4. Automatic Cutting Process

A cutting process is an important area where garment components are cut from fabrics. Automatic cutting machines can cut single or multiple plies of a wide variety of fabrics, from lightweight apparel fabric to high-performance industrial fabrics. Cutting can be performed using a laser, knife, or water-jet. The advantages of automatic cutting are the increased efficiency and accuracy, ease of cutting single and multiple plies, and perfect cutting the first time [3].

In this study, several embroidered fabrics were placed on the automatic cutting machine (P-CAM 161, Shima Seiki, Wakayama, Japan) for cutting into the patterns. For matching the embroidered logo on the accurate position, a full-size pattern piece was projected on the fabric as it was spread over the cutting surface using an overhead projector, as shown in Figure 13a. The cutting process was performed using a multi-ply knife cutter. After the cutting was complete, the cut fabrics were transferred approximately 1.7 m through a conveyor belt attached to the cutting machine for pattern recognition through a vision sensor and gripping by a robot.

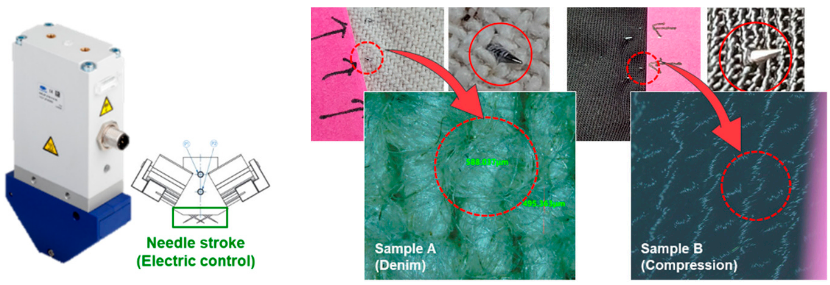
(a) (b)

Figure 13. Automatic cutting process: (**a**) preparation for cutting; (**b**) transfer of cut fabrics for robot gripping.

3.5. Robot Handling with a Gripping System

3.5.1. Adaptive Fabric Gripping Module

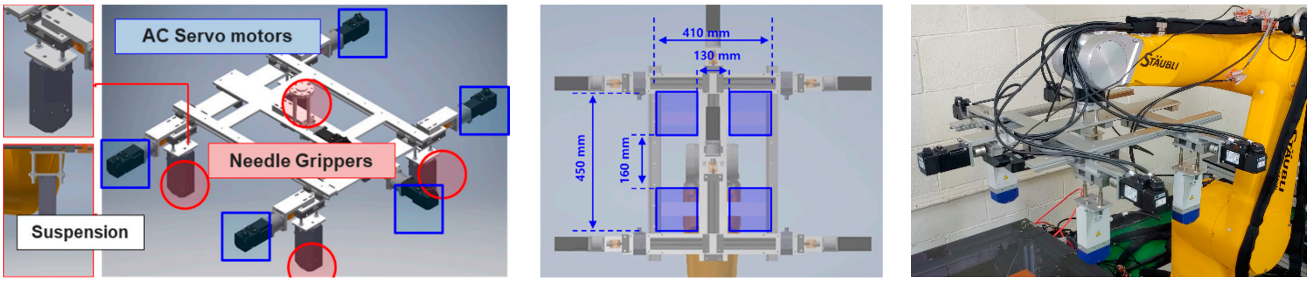
Grippers handling garment parts should be differentiated from general robot grippers because of the unique characteristics of fabric materials, such as flexibility and air-permeability. Koustoumpardis and Aspragathos [25] classified the valid types of fabric handling grippers, and several studies have proposed several novel fabric-grippers, including an electrostatic gripper [6,26–28]. On the other hand, when integrating the fabric gripping process with the cutting or sewing process for the garment manufacturing automation, it is very important to hold the fabric firmly and grip it without sagging and wrinkles. To this end, the grippers must hold the suitable points of the target fabric according to its shape. Therefore, in this study, an adaptive gripping system was developed to respond appropriately to various fabric shapes. First, several commercialized grippers based on pneumatic and penetrating principles have been studied to determine if they could be applied to an adaptive and automatic fabric grip. Pneumatic grippers could hold the fabric without damage, but it was almost impossible to grasp only a single fabric sheet because precise control of the pneumatic variables was difficult. On the other hand, the penetration types, including a needle gripper, had a potential risk of fabric damage, but they could pick up the precise number of fabric sheets by adjusting the penetration depth. As a result, an electric needle gripper (SNGi-AE, Schmalz, Glatten, Germany), which can electrically adjust the length of the edle stroke, was chosen for this study; it showed robust performance for numerous fabric types without noticeable damage. Figure 14a presents photographs of the selected electric needle gripper. Figure 14b presents optical microscopy images of denim and stretched fabrics for compression wear after the need to penetrate them. A quantitative examination of the images in Figure 14b showed no noticeable damage to the fabrics after the penetration.



(a) (b)

Figure 14. Selected gripper model and fabric damage evaluation after needle penetration: (**a**) electric needle gripper (Schmalz); (**b**) fabric damage evaluation due to needle penetration.

Second, an adaptive gripper jig system was designed to move the grippers to the appropriate positions depending on the shape of the grip object. Figure 15a shows the designed equipment containing four needle grippers that move along the linear motion (LM) guides with four alternating current (AC) servomotors. In addition, the spring suspensions were installed between each gripper and the jig structure to minimize the impact forces in the direction of fabric stacking when gripping the fabric. Consequently, fabrics with various shapes within the area range from 160 × 130 mm to 450 × 410 mm could be gripped stably, as shown in Figure 15b. The developed gripper jig system has been mounted into the six-degree of freedom (DOF) industrial robot arm, as shown in Figure 15c.

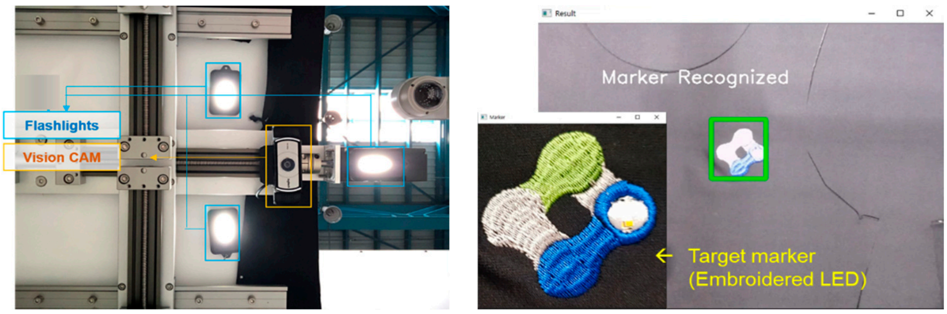


(**a**) (**b**) (**c**)

Figure 15. Design and development of the adaptive gripper jig structure: (**a**) gripper jig structure design; (**b**) gripper feed range; (**c**) robot-mounted gripper system.

3.5.2. Vision-Based Shape Recognition Module

The vision-image processing technique was applied to recognize the shape of a fabric object automatically and to make a proper decision for optimal gripping of the object. The vision camera (CAM) was attached below the gripper jig structure with a flashlight, as shown in Figure 16a. OpenCV, the most popular and powerful open-source computer vision library, was used to construct the vision-based shape recognition algorithm.



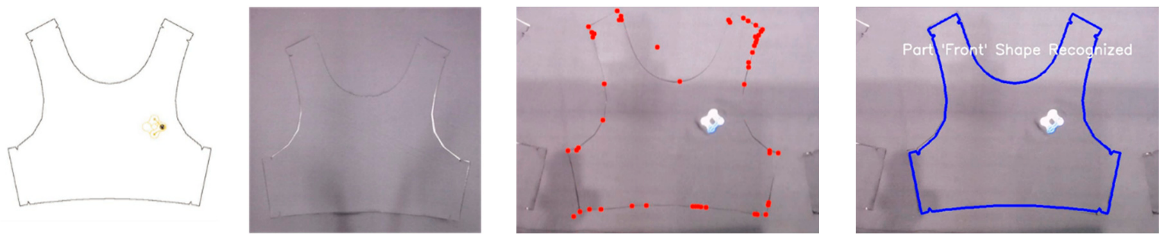
(**a**) (**b**)

Figure 16. Photograph of vision-based shape recognition module and marker recognition result: (**a**) vision computer-aided manufacturing (CAM) and flashlights; (**b**) marker (embroidered LED) recognition result.

The final vision-based recognition module has two functions: marker recognition and shape recognition. The marker recognition was required to determine whether to start the automatic fabric handling processes, including gripping, transferring, and releasing steps. The speed-up robust features (SURF) algorithm was used to detect the pre-specified marker in a fabric object in a real-time manner with a CAM image at a rate of 30 frames per second (fps). Figure 16b shows the result of recognizing the embroidered LED marker in the fabric object. The next step begins once the SURF-based algorithm confirms the marker position for two seconds (60 frames) within the CAM screen.

The second step is to match the real-time CAM images with the pre-designed CAD pattern (2D) images. As a second step in the vision system, the fabric shape-recognition algorithm works by matching the pre-designed CAD pattern image to real-time vision

CAM images. To increase the recognition accuracy, several types of image features were considered and tested, such as the contour, edges, and corner, and the corner-based features were finally chosen as the features of the CAM images. Figure 17 presents the results of detecting the correct shape of the sports bra (front parts) by mapping the CAD image with the corner-based features of the CAM image. Subsequently, the detected shape information was converted to the quantified geometrical information for the robotic motion, such as (1) the position of the recognized shape's center point in the local robot coordinate system to move the gripper jig to the target fabric and (2) the distance between the center point and each gripping point to which the grippers should move using AC servomotors.



(**a**) (**b**) (**c**) (**d**)

Figure 17. Vision system-based shape recognition procedure for gripping target: (**a**) computer-aided design (CAD) image; (**b**) CAM image (original); (**c**) corner detection; (**d**) shape recognition.

3.5.3. Data Communication Module and Total System Development

The heterogeneous communication network environment for the robot, AC servomotors, and grippers should be established to transfer the information obtained from the shape recognition module. Figure 18 presents a schematic view of the data communication framework, including the following three communication protocols.

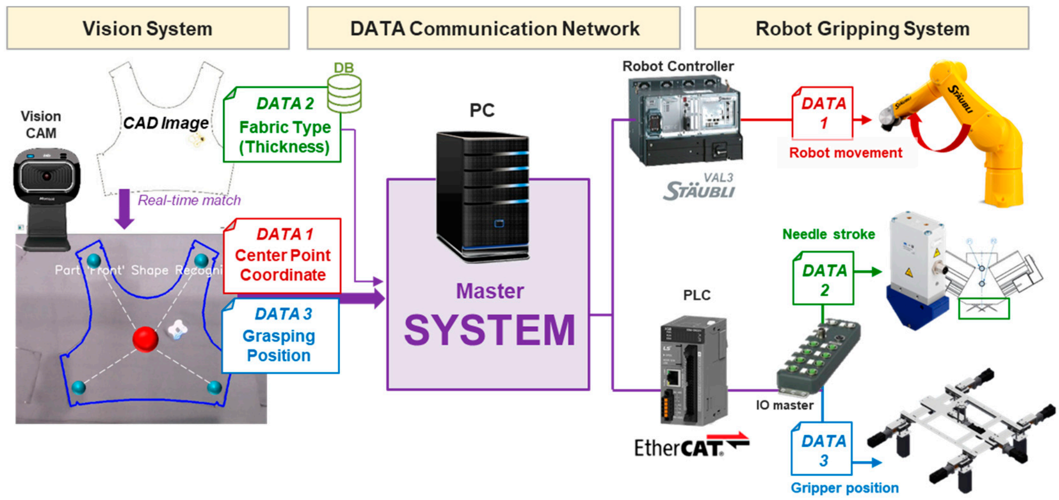


Figure 18. Scheme of the data communication network for the robot-based fabric handling system.

- PC to Robot: Transmits the x, y coordinates of the target's center point by Ethernet-based socket communication
- PC to Grippers: Transfers the specified stroke length of needle gripper using Ethernet/IP communication
- PC to Jig (AC servomotors): Sends the determined gripper positions through Ethernet for control automation technology(EtherCAT) communication

As shown in Figure 18, the processed data 1 and 3 from the vision-based shape recognition module and data 2 were transferred to the PC, and the data on the robot movement, needle stroke, and gripper position were generated and given to each device: the robot arm, grippers, and AC servomotors. The 6-DOF robot equipped with the gripping sub-system could grasp the fabric at its optimal points and move it to the target position precisely. Figure 19 presents photographs of moving to the target fabric, grasping the fabric, and transferring the fabric in a sequence. To estimate the transferring accuracy, the difference between the target position and actual position capture by the CAM was calculated by considering the pixels of the entire fabric (cloth) area. The final accuracy was calculated to be 96.64%, as shown in Figure 20.

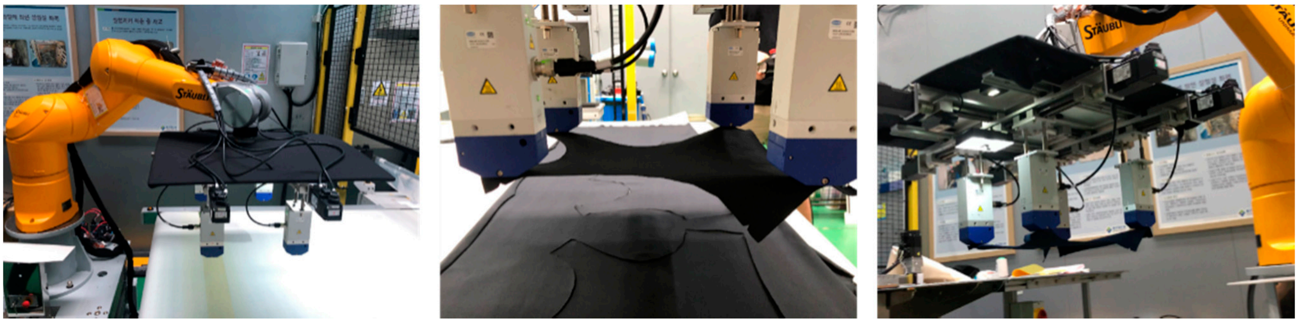


Figure 19. Photographs of the robot-based gripping system sequential operations of moving to, grasping, and transferring the target fabric object.

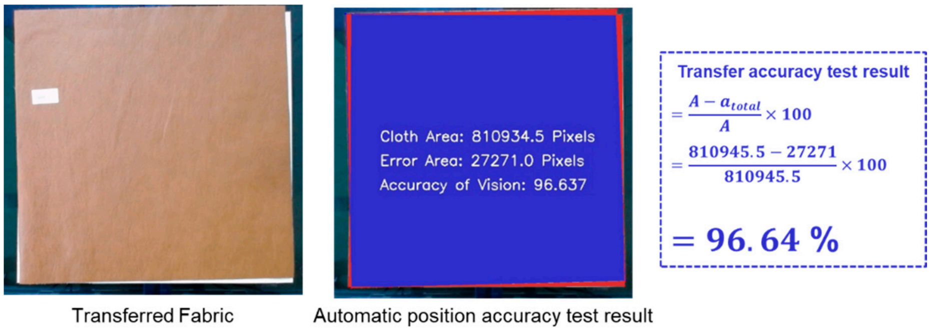
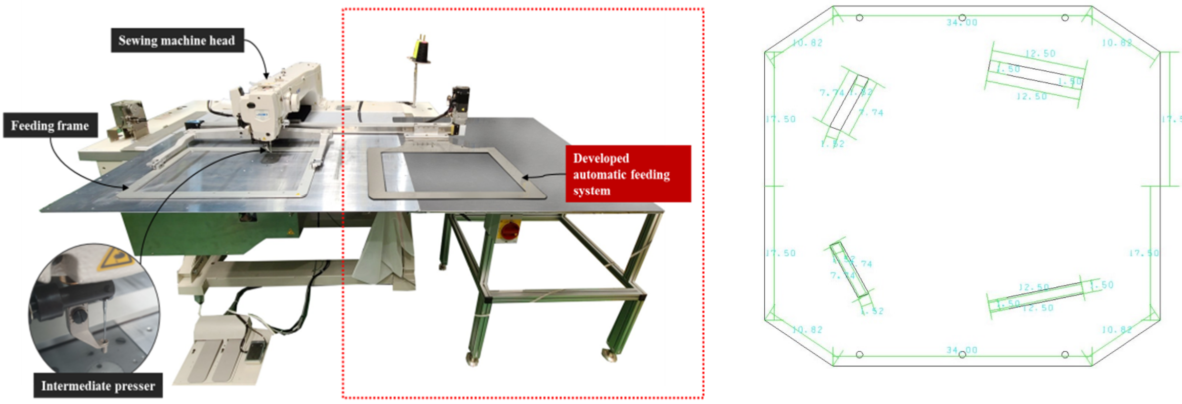


Figure 20. Calculated transferring accuracy of the robot-based gripping system.

3.6. Automatic Sewing

Sewing technology has not changed radically since thousands of years ago when people first put needles and threads into fabric. Despite the tremendous engineering advances, including mechanized looms and sewing machines, the methods of producing sewing products today are as labor-intensive as they were 100 years ago. In addition, sewing represents the most important textile joining technology, accounting for 85% of all joining methods [29]. Textile manufacturing skills, such as sewing, are essential process steps of manufacturing garments, comprising approximately 35–40% of the total cost and the added value of textile products [3]. For the above reasons, factories have been relocated to developing countries where wages are low. On the other hand, as a fundamental solution, research to automate the sewing process is urgent.

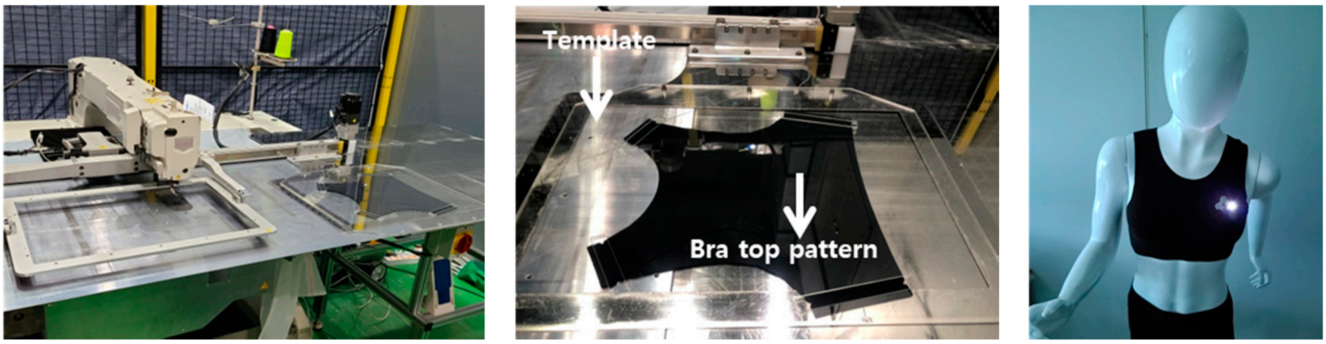
In this study, two tasks were performed to realize automatic sewing technology. First, an automatic feeding system was developed to develop an automatic sewing process using a motor and acceleration sensor. The automatic feeding system was located on the right side of the industrial pattern sewing machine (ASM-224, JUKI, Tokyo, Japan), as shown in Figure 21a, and was designed to move the cut material to the sewing position. Two templates were then produced, as shown in Figure 21b. Each was placed above and below the pattern that will be sewn to be moved using an automatic feeding system. The template was designed using two polycarbonate materials by drilling two shoulder lines and two lines next to the bust sewn 15 mm thick.



(a) (b)

Figure 21. Picture of the automatic sewing machine with a self-modified feeding system and template: (**a**) sewing machine with the feeding system; (**b**) polycarbonate template for sports bra.

The sewing stitch design was produced using the PM-1 program (JUKI, Japan). The shoulder line and the body side line were designed as a straight lock-stitch pattern with a stitch distance of 2 mm. The sewing pattern file was transferred to the sewing machine and saved. The robot grasped the cut fabric and placed it on the templates of the sewing machine. Sewing preparation was completed when the front and back panels of the sports bra pattern were superimposed on the templates through the repetitive work. Figure 22a shows the sewing readiness. Two patterns placed between the two templates exist in the automatic feeding system, as shown in Figure 22b. Sewing was performed in the order of the right shoulder line, right body side line, left body side line, and left shoulder line for the efficiency of the work. Figure 22c shows the final product. The mannequin wore the light-emitting sports bra through the automatic manufacturing process.



(a) (b) (c)

Figure 22. Image of the sewing process for manufacturing a smart functional sports bra using a self-developed feeding system and a polycarbonate template: (**a**) position ready for sewing; (**b**) cut patterns in the templates; (**c**) final product.

4. Conclusions and Future Work

The innovation of smart factory construction through the automation system and garment manufacturing technologies is already progressing in the academic and industrial fields. Following this movement, this paper proposed a system to establish an automated process for smart sports-bra manufacturing with various machines and technologies, such as 2D CAD and 3D virtual programs, technical embroidery machines, automatic cutting machines, vision sensors, industrial robot arms with a gripping system, and automatic sewing machines. This process showed the possibility of manufacturing the smart sports bra automatically with digital systems and automated equipment through the simplified process and sequence change. In particular, human intervention could be minimized by connecting cutting, moving, and sewing processes that were performed by humans previously. On the other hand, the design, pattern, and cut lines of the target item were very limited to implement the automated manufacturing process. In addition, the function of the smart sports bra is simple, with an LED light attached using the embroidery method. Therefore, it is necessary to continuously study the establishment of a process for manufacturing smart clothing with more diverse functions and designs.

To realize the automation of the garment manufacturing industry, the following two issues must be solved. The first is quality. Garments made through an automated process must maintain the same quality as garments made by human resources. In particular, the sewing processes still depend on humans, and the extremely low quality of robot sewing has limited commercialization. On the other hand, it is expected that further developments of pattern sewing, 3D sewing technology, and automation systems will produce superior quality products in the near future. The second is flexibility of the process. The system must buffer among the fast and frequent pattern modification, shifting and sorting, and transport systems. In this respect, smart clothing is one of the most suitable items for an automated manufacturing process.

Future research will explore methods for the development and commercialization of an automated garment manufacturing process for smart clothing using more diverse designs and materials.

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