A study on the development of a user-focused multi-functional convergence-smart-fashion product

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ABSTRACT

The attempts of combining fashion and technology together to provide digital functionalities at the closest distance users has been continued based on context-aware computing and wearable sensing. Through such convergence, the productive benefits of user-oriented computing and the expansion of traditional fashion functionality can be achieved. In this study, we aim to investigate the optimized way for the development of convergence-smart-fashion prototypes that provide user-oriented multi-functionality to increase the potential features of fashion and widen the application scope of related technologies. Through research and development (R&D), we developed four convergence prototypes which could provide four different functions: 1) Rear-detection, which detects vehicles or people approaching from rear-side and warns the user through vibrations. 2) Bluetooth hands-free provides remote-control functions, such as phone-call and sound-streaming. 3) Vital-signal monitoring, which measures and displays user's heart-beat rates and body heat through a built-in-screen and smartphone application for a user's health-care. The development was proceeded based on the following steps: the determination of the basic usability as a garment and its related practical digital functions, the mini-mization of the size of the system modules which could be easily assembled and disassembled to ease washability, and the system maintenance, which could help to diversify the usage of convergence fashion.

1. Introduction

The attempts of the convergence to adapt clothing as a media for providing digital functions to enhance human-abilities at the closest location from the human body has been proceeded from the late 20th century [1, 2]. These attempts are activated mainly by engineering areas and have influenced the IT-oriented convergence tendency in modern industry. This tendency can be represented by the emergence of 'wearable devices', typically composed in the form of fashion accessories: watches, glasses, or rings and electronic systems [3, 4, 5]. As mobile devices have been increasingly miniaturized, lightened, and low-priced since the 2000s, the potential of new roles and values in fashion have been sought by convergence [6, 7]. It was initially emerged by outdoor and sports fashion industries that are cooperating with IT industry in order to provide assistive functions of health or sports-care by using engineering technology, which users mostly use in unstable-outdoor or sports situations or purposes comparing to indoor-daily lives. These attempts presented feasible application combining fashion and electronics, and gradually showed commercial potential from late 2000s [8].

Following this tendency, historic luxury or high fashion brands also started to deal with smart accessories such as smartwatches or wristbands [9]. Moreover, new fashion brands such as Electric Foxy or Cute-Circuit had emerged, which reflect the convergence concept in their brand identities and engage various fashion products providing digital functions [10]. In modern industry, this convergence tendency becomes the significant topic that is not only for IT, but also for fashion industries in order to pioneer new promising values [6, 7].

The phenomenon that smart products with the convergence concept that have adapted the form of fashion implies the possibility of the expandability. Traditionally, fashion items, especially clothing, serve for the wearer's protective and expressive needs. However, both protective and aesthetic functions are readily augmented or extended through modern technology. Clothing is physically the most proximate medium to human body and spends the longest time with users comparing to other mobile stuff. The most significant benefit of fashion as the platform of the convergence with technology is its constant presence and mobility [11]. The development of IT-technology has caused the change of computing environment from indoor to outdoor spaces and the mobility was

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Increasingly grown as the essential concept on the usability of digital functions. Thus, it seems to be reasonable that fashion products, especially garments, are becoming the main agent of providing function as well as securement of the mobility [3, 4, 8, 10, 12].

Regarding the industrial convergence trends and the benefit of garments as the infra-structure for electronic functionality, the new roles and markets of smart fashion beyond the traditional recognition can be achieved through the convergence. However, there is a concerning point that the convergence fashion products should be differentiated from smartphones to establish the distinctive identity and value, by providing the traditional functions and values at the same time, since general computing or digital entertaining functions are provided by smartphones. When it comes to pursue the difference, the physical proximity of clothing and discriminative functionalities focused on certain users' particular needs which can be provided only by the clothing platforms will be the clue to establish valuable identity of convergence-smart-fashion.

In terms of the potential of fashion forms, convergence-smart-fashion has advantages to construct fully-user-focused multi-functionality with three properties; physical proximity, surface area, and social ubiquity. The physical proximity related factors allow clothing as a platform to interact closely with its user, the surface area of clothing allows to embrace or equip the electronic components as the containing platform to provide electronic functions with sophisticated investigation on construction, and social ubiquity is related to the constant presence of clothing to be worn and interactions with other users, social environments or requirements [19]. These advantages could play a key-role to produce pervasive multi-functional interaction with users; body, emotion, environment, and people, which provides useful convenience worn on its user's body and do not distract the user's attention, differing from ordinary mobile devices. Of course, there are complicated consideration points of the convergence which should meet the traditional requirements; wearability, activeness, comfortability and aesthetic impression [8, 13, 14].

Therefore, this study aims to develop convergence-smart-fashion prototypes providing user-oriented multi-functionality presented by the combination of traditional functionalities of fashion and engineering technologies. Through the research and development (hereunder, R&D) process, the way that disparate elements could be converged in order to broaden fashion's role and value is discussed. For this purpose, three topics of the convergence were considered; (1) the coexistence of traditional fashion's roles, functionality and concept with digital functions generated by the application of engineering technologies, (2) particular user needs to construct discriminative-pervasive functions which were effectively provided by the clothing form and not monopolize wearer's attention when used, and (3) the investigation on the converging methods which the fashion platforms and digital devices could be integrated visually, and able to assemble or disassemble for washability of platforms, system circuit updates, and maintenance.

Our proposed R&D process follows the below four steps, which is shown as in Figure 1.

First, in order to add multiple functionalities to garments, a survey investigating users' demands is initially carried out to find out user-oriented-functions based on participants' objectives. Then, four functions were extracted for the prototype: rear-detection that interacts with the environmental factors of user surroundings, Bluetooth hands-free that interacts with user's emotional factors, heart-beat monitoring and body heat protection that interacts with user's physical (health) factors.

Second, the direction for each design and the corresponding fashion platform and system functions are confirmed. Next, fashion platforms, electronic circuits, and system modules were developed by taking into account the aesthetic and systematic suitability. The prototypes were developed using 3D printing.

Third, the wearability and operability of the developed prototypes were tested to configure the platforms and systems to circumstances that are similar to the actual application situation or environment initially planned.

Finally, the prototypes were updated based on the results of the evaluations, and our proposed multi-functional convergence-smart-fashion prototypes are generated as a case of the convergence between fashion and technology.

2. Reviews on wearable technologies for convergence-smart-fashion

From the early 2000s, through the convergence between fashion and electronic technologies, the attempts to provide digital functions at the closest location from users have been activated in order to expand users' abilities [15]. Such smart garments providing the computing functions through embedded display, input device and other PC components, military uniforms providing the functions for communicating and surviving, and medical clothes checking patients' vital signals have been developed by various organizations such as academic institute, military, government and private industries [2, 8, 16]. By convergence-smart-fashion platform that develops the co-existence of the functionalities of fashion and engineering technologies, fashion products,
especially garments, can provide potential benefits on mobility (portability), connectivity and physical sensing that could be fully user-oriented [11, 17, 18, 19]. In many researches on the wearable technology, sensing from body, system interface and augmenting fashion's fundamental roles are considered as the research and development (hereunder, R&D) topics which could make use of benefits of the clothing forms [11, 17, 18].

2.1. Wearable sensing

Wearable sensing can allow to measure vital signals from a wider range of body parts and detect movements of the wearers at the same time [11, 17]. And, through the alternation of types or equipped locations of sensors, targets of sensing could be relocated from wearer's body conditions to the environmental situations around [20]. Wearable sensing, which is commonly recognized as health-care sensing, has been actively investigated to apply in medical health monitoring, sports, or gaming [21, 22]. From the initial periods of the wearable technology investigation, wearable sensing for medical purposes like the case of Vivometrics' LifeShirt® has been developed to measure and provide the data of patients or elderly's vital signals, such as heart-beat rates and body heats, to help wearers themselves or medical staff for the constant health management and monitoring [23, 24]. Most recently, wearable sensing has also been applied in tracking infants' vital conditions to help their parents or prevent SIDS (sudden infant death syndrome) [25, 26].

In cases of wearable sensing for sports-purposes, clothing sensor systems measure user's motion loads of physical exercising and provide the calculated data of Calorie consumption for the encouragement of physical exercising [21] or heat-stress for health-care to self-control the intensity of exercising [27]. Recently, through the advance of composite sensor technologies such as electromyogram, loads of muscles and body movements can be perceived and monitored for sports-care and coaching functions like Electicfox's smart yoga-suit, Bend series [28]. In the gaming sector, this technology has also gained much attention, such as Nintendo Wii's game pad equipping with the six-axis gyro-sensor [11], and usually sensors embedded in fashion platforms are connected to additional devices including smartphones and then used as game controllers in order to provide the experience of sensor-controlled gaming, as shown in the case of Lenovo's smart shoes that can be used as game controller reacting by wearers' feet movement instead of hands [22].

Garment-integrated sensors can use the same types of physiological and body movement sensors as medical or sports applications to deduce the location, activities, and even the emotional state of the user [29, 30]. The technologies for user-centered wearable sensing to perceive the environmental information can be comprehended as “context-aware computing” [11]. This sensing technology is composed of the process which analyzes the contextual situation between wearers and the environment and provides necessary outputs as the results of the analyzation on the environmental factor [20]. In general, although a sensor is produced to react to one sort of a stimulus, for example, a photo-diode sensor just reacts to the stimulus of “light” [11], the use of sensors for wearable sensing could be extended beyond technological limitations of ordinary sensors via directing the operating situations or principles with knowledge on the physical mechanisms of sensors and programming.

2.2. Context-aware computing and wearable interface

Context awareness is also a large part of ubiquitous computing. Space and objects become “intelligent,” while simultaneously demanding less attention and supervision [15, 19]. The concept of ubiquitous computing in the 2000s could be comprehended on the same direction as the current concept of the IoT (Internet of Things) [31, 32]. As the computing environment is transferred from desks to human bodies in wearable (context-aware computing), input-output interfaces which are suitable to be used in the status of “being worn” on user's body should be developed regarding the properties or purposes of contextual information or functions such as sensing user's body information or the environmental circumstances around [11]. To use the WIMP (window, icon, mouse, and pointer) interface of the general HCI (human computer interaction) users need to concentrate on the screens and icons to manipulate the pointer and control its functions by using the mouse or touchpad. Therefore, although WIMP interface is highly suitable to control complex computing platforms such as PCs or smartphones that have large number of menus or applications, it would not be completely suitable for the wearable computing that use clothing as a platform [11, 33].

During 2000s when the investigation of the wearable technology was diversified, previous researches of Toney et al. [34], De Rossi et al. [35], and Costanza et al. [36] suggested tactile (vibration) or gesture-based interfaces as the suitable input-output interfaces of context-aware computing for wearable systems. Since gesture based input and tactile based output feedbacks do not rely on user's visual sense comparing to traditional interfaces, users can intuitively react to the feedbacks doing other works or activities that need their visual senses.

As shown from the cases of the British convergence fashion brand, Cute circuit’s Hug-shirts, that provides a virtual hugging experience between two clothes without actually performing the real action, as well as a Dutch fashion designer Paulline van Dongen’s Isso, which provides a healing experience to the wearer through soft touches on the upper side of the back generated by tactile input-output interfaces that react to the wearers motions or stimuli [37, 38, 39], the optimized input-output interfaces of wearable systems’ mobility can be established by building mechanisms with existing input-output devices, such as sensors, conductive PCV panels, and vibration motors.

2.3. Augmentation of traditional Fashion's functionality

Along with the applications of wearable technologies, combination with technology can augment the fundamental property and functionality of fashion such as basic protection and aesthetics [11, 15, 40]. Like as the case of electronic-heating function developed to augment thermal protection of clothing during middle of 20th century, 1968, through the grafting technologies on clothing platforms, users could replace the inconvenience of repetitively putting on and out thick clothes according to the changes of the temperature with the simple action of manipulating function control switches. As shown in the cases of Northface, Dewalt or Bosch’s similar approaches, driven thermal protection of clothing is improved by user-controlled electronic-heating functions [41, 42]. Also, the property of aesthetics of fashion can be expended through the same principle of the protection aspect; an individual’s expressive or aesthetic preferences can change dramatically over the course of a day. With electronic technologies, the user may be able to control the visual properties of a garment, including its shape, texture, color, or graphic [11].

From early 2000s, designer Hussein Chalayan presented a series of fashion applications applying kinetic technologies through his fashion collections. Electronic technologies were adapted to augment the aesthetic or adorning role of fashion garments. Chalayan was the first person to attempt presenting technology through fashion design by using kinetic technologies, such as motors and shape-memory metals, as well as illuminating technologies, such as LEDs and lasers, which were used to animate the garments during presentations [15, 43, 46]. British fashion brand Cute circuit is also an essential brand to discuss the applications of the convergence. The brand has presented sophisticated concepts of the applications between fashion and electronics, such as wireless connectivity and interactivity with external devices or networks to diversify the illuminating expressions. For instance, their “Twitter dress” displays wearer’s messages on Twitter through a wireless connection between the dress and the Social-Network-Service [44, 45].

When it comes to consider the properties of the wearable technology and the applications into the fashion platforms, the direction of the progress of the convergence between fashion and technology could be summarized as the combination of the advance of engineering technologies and materials more applicable in fashion, and the expansion of
traditional fashion’s functionalities. Therefore, to meet the traditional requirements and the technological usability, the convergence products should be made to ensure the basic needs of clothing such as physical comfort and the stability or durability as electronic mobile devices [11].

2.4. Current technical methodology to construct flexible circuits for wearable technology

In the development of the convergence fashion products, it has been recognized that general fabrics (flexible substrates) and electronic components are integrated to affix system components onto the surface of fabric inside or outside of clothing products [47, 48]. The components of electronic circuits could be dispersedly located in pockets of the garment platforms through the connection of electronic wires. Conductors, in general, electronic wires or circuit path could be alternatively replaced with conductive yarns or inks and they could be combined by sewing, drawing or printing techniques according to the feature of each material [47, 48, 49]. Comparing to the traditional manufacturing methodology of electronic instruments, the development of convergence fashion products is complicated and took more time to produce due to the complex integration of garments and electronics. Thus, in diverse areas including academic, compelling researches on the variety of wearable as well as mechanical technologies of the rapid construction of flexible circuitries have been presented [11, 50, 51, 61]. Recently, due to the advance of the multi-layered-complex printing methods including 3D-printing, the mechanical printing methodologies to fabricate electronic-circuitries have been investigated for the convergence between clothing platforms and electronic components [47, 48]. Those technologies are invented to print circuitries on flexible substrates and are mainly classified into two categories; contact-printing and non-contact-printing, as stated in below Table 1 and Table 2, respectively (See Figures 2, 3, 4, 5, 6 and 7).

In company with the mechanical printing techniques, researches on printing technologies and elements for 3D-printing to print electronic circuitries three-dimensionally were also started [62, 63]. However, in general, the flexibility or property of conductive elements, such as filaments for 3D-printing, is not yet to apply in clothing platforms which need highly or extremely formative or structural fluidity and durability of systems readiness, in which the components should be concretely attached on the surface of circuitries.

Also, although the above circuit printing technologies including 3D-printing, which could be used to print conductive circuits on flexible media or directly print circuit structures, have been paid attention to and recognized as the technology of additive manufacturing for rapid prototyping [47, 48], expensive printing machines, materials, and high engineering skills are essentially required to use the mechanical printing methodologies. Also, there would be difficulties in the construction of sophisticated structured processor units, as the electric resistance of the alternative materials used in these printing methodologies are generally higher than traditional conductors, such as copper-wires or metallic path on circuit boards. Moreover, as the printed path of circuits, on which the electric currents run, are exposed compared to insulated wires, there is a concern that wearers may experience shock without proper insulation [11]. Thus, thorough consideration of the circuit path structure, surface insulation, and locations of the circuit installation are required to use printing technologies to develop a wearable system.

Table 1. The principle of contact printing in mechanical printing techniques [47, 48].

| Printing Technique | Printing mechanism |
|--------------------|--------------------|
| Contact Printing   | Flexographic printing |
|                    | Ink is conveyed from an ink bath to a designated substrate by an anilox roller. Subsequently, a printing plate transfers controlled amounts of ink from the anilox roller to the substrate by adjusting the pressure between the printing plate and an impression cylinder [47, 48]. |
| Gravure printing   | The gravure cylinder collects inks from the ink chamber. The width and thickness of printed patterns can be adjusted by the dimension of gravure cells, ink viscosity, ink-substrate surface energy, and printing speed. |
| Offset printing    | Inks are firstly transferred from a metal plate to a medium substrate and then to the printed surface. The repulsion between oil and water, is applied to print the designed pattern. |

Table 2. The principle of non-contact printing in mechanical printing techniques [47, 48].

| Printing Technique | Printing mechanism |
|--------------------|--------------------|
| Non-contact printing | Drop-on-demand (DOD) inkjet printing |
| Aerosol-jet printing | “Aerosol” (the suspension of fine liquid droplets in a gas) is generated in this printing system to carry ink droplets to substrates. The technique is capable of handling a wide variety of materials to print patterns at high resolutions (line width <10 μm, layer thickness of 0.1-2 μm). In many researches, this technique is used to fabricate electronic components that require fine details and high precision such as capacitors, sensors, antennas, silicon solar-cells and so on. This technique is the most recent, however, a main challenge for wide adaptation and development of it is its high cost [55, 54, 55, 56]. |
| Organic vapor-jet printing (OVJP) | A hot inert carrier gas is used to carry molecules of organic vapor to the substrate. The resolution of the deposited patterns can be controlled by the pressure and type of carrier gas, nozzle properties, and the distance between the nozzle and the substrate [57, 58, 59, 60]. |

In thermal DOD printing, the printing mechanism involves pressure generated by the bubble. By applying power through the heater in the fluid chamber, the ink is heated to form a bubble. Electrostatic inkjet uses electrostatic force to push the droplets out. The force is generated when applying a high voltage between conductive ink and a plate electrode. For printing electronics, the piezoelectric technology has higher potential in printing both passive and active electronic components compared to the thermal technology.

In the piezoelectric DOD printing mechanism, the pressure pulse is generated directly by the mechanism of the piezoelectric transducer. On applying current through the piezoelectric transducer, its shape and volume change, which leads to the production of the pressure pulse [52].
3. The development of the multi-functional convergence-smart-fashion-prototypes

In the development of convergence-smart-fashion products, flexibility of the platforms and durability of the systems are important [64]. In the development of convergence-smart-fashion products, flexibility of the platforms and durability of the systems are important [64]. In general, electronic circuits and components of electrical devices are connected by rigid connectors and contained by hardware covers in order to be durable from external impacts. However, usage of rigid wire connections would not be appropriate in garment platforms because of the concerns regarding the garment’s wearability and durability. Thick silhouettes and stiff materials have been adapted to address these issues. However, it may not be enough to address the problems regarding garments, specifically with respect to their washability. Also, there have been other difficulties in the development process. The training, traditions, and approach of different designers can often have conflicts with the use of traditional electronic techniques and methods being grafted onto traditional apparel construction. So, an interdisciplinary perspective is required to overcome the differences between traditional approaches and electronic techniques [11].

Regarding the above-mentioned issue and difficulty, Nike’s Nike+ could be referred as an example of the effective direction of the development of convergence-smart-fashion products to meet the conditions as garments and minimize the collision of the producing techniques between fashion design and electronic engineering. Nike+ system is divided into the minimum sized system module of GPS and gyro-sensor and training shoe platforms. The small system module is inserted in the tiny hole inside the shoes to track the overall information of its user’s physical exercising and send the data to smartphones to display the information such as calorie consumption and distance coverage [21]. Although Nike’s case is not the approach to construct multi-functionality for diverse purposes, it was compelling, which the basic requirements and interactive functionality generated by the integration could be met by the minimized alteration of the traditional making technique with the structural and formative design consideration. Therefore, the split-and-merge methods of device modules and visually balanced platform designs to optimize garment platforms’ wearability, comfort, aesthetics and system modules’ operability are investigated our R&D.

3.1. R&D concept configuration

In this study, based on the previous researches we aim to present the cases of the development of convergence-smart-fashion products that provide user-oriented multi-functionality using the concepts of context-aware and wearable sensing. Garment categories that are worn more consistently throughout a day such as jean pants or shirts are generally also more disposable and interchangeable than garments worn more sporadically like outerwear. Less disposability or interchangeability is beneficial for expensive technologies designed to last considerably longer than a T-shirt [11]. Therefore, it is also significant to select the category of the clothing platform to apply digital technologies according to the property and purpose of target functionality in the actual usage of wearable systems.

Accordingly, at the initial stage of this study, it was considered that bottom wear, such as pants or skirts, would be less appropriate. The human leg has the highest intensity of movements, which could damage the electrical circuits in the wearable devices. In contrast, upper wear such as jackets or coats can embrace the system because it is less affected by the body movements. And the upper body part also has more advantages as it is closer to the user’s head which is responsible for the greater part of the human’s perception. Thus, the scope for investigating the application of electronic technologies to a fashion platform is more suitable to upper wear. Accordingly, in this study, an upper wear was used as the platform of the convergence for the multi-functionality.

Generally, most computing and entertaining functions can be provided by smartphones. Thus, we aim to develop the differentiated user-focused-multi-functionality that could be effectively provided by the form of garments and each functionality was applied in different parts of a garment platform. In order to improve interactions between user’s body and functional systems which would be separately located in each different part of the platform, appearance of the platform was planned to be designed based on the anatomical chart of the human body, as shown in Figure 8. And the whole system modules of prototypes were then designed to be able to be assembled and disassembled from the garment platforms.

As the goal of this study was the development of multi-functional convergence-smart-fashion prototypes through the application of the

![Figure 2. The mechanism of Flexographic printing (Table 1).](image)

![Figure 3. The mechanism of Gravure printing (Table 1).](image)

![Figure 4. The mechanism of Offset printing (Table 1).](image)
functional systems in each different part of the platforms, the ideation on the suitable functionalities which would be applied into each part was initially conducted. Thereafter, the result of the ideation was put into a diagram based on the anatomical chart of the human body and a survey of users’ needs based on Graffiti-wall technique was then conducted by the hypothetical users consisting of 50 of fashion design and engineering majors (see Figure 9).

Through the survey, the four functions were selected for R&D stated in Table 3.

Rear-detection function, based on the modified wearable sensing and context-aware computing concepts of wearable technologies, was selected to locate on the back part of the garment platform, which the system consistently monitors user's rear-side and notice the approach of bicycles, vehicles or people for user safety. Bluetooth hands-free function for user's emotional needs was selected to located on the head part of the hooded garment platforms, by which the system provides the controlling function of phone call and listening sound contents when it is connected to IT devices such as smartphones. Vital-sign monitoring function based on wearable sensing concept was selected to locate on the lower arm part of the platforms, which the system measures and displays its user's heart-rate data by the system itself and a smartphone application. Heating function augmenting fundamental functionality of clothing on thermal protections was selected to locate in the inside of the bodice part of the platforms, which the system operates to sustain user's body heat. The actual scenario of above functions are stated in Table 4.

After the idea evaluation and selection, the specific direction of R&D was configured. In order to investigate the stable wearability, usability of each system module as well as the interaction of the visual impression between the garment platform and system modules when the platform and systems were combined, we planned the development of four different prototypes; type 1 equipping all functions, type 2 equipping three functions, type 3 equipping two functions and type 4 equipping only one function.

Regarding the traditional concepts of the usage of garments, R&D of system devices was planned to be modularized which could be assembled-and-disassembled from the garments for the washability of the platforms. For the modularization of the systems, it was considered to adapt 3D-printing technology in the development of module containers, system bases and module anchors for garments platforms.

As a result of the primary investigation, we decided two design concepts of garment platforms: the first concept was to construct light-outdoor or sportswear style regarding the public's acknowledge or recognition on convergence fashion products, since the functionalities of our study have been actively applied in the outdoor-sports-fashion areas. And the second concept was to visualize the concept of the anatomical interaction between each part of human body and the functionalities applied in each part of garment platforms separately.

Also, two different concepts of the technology-development were also set up: the first was to investigate the ways of the circuit construction and equipment of the circuits which could make system modules operated and applied independently in each part of the platforms. And the second was to achieve the minimization of the sizes, volumes and weights of the system modules without negatively affect the wearability and comfort-ability of the prototypes as garments.
3.2. Garment platform development

3.2.1. Platform design process

When sensors are embedded in garment platforms, inaccurate results of vital-sign sensing which need to be close to user's skin could be occurred [65]. Consequently, as the loose fit structure and elasticized material of garment platforms cannot sustain the enough and concrete form, in many cases, garment platforms were composed of skin-tight silhouette to maintain the proximity between user’s body and sensors to minimize the external variables in the sensing [66]. However, skin-tight shapes would not be physically and socially comfortable [11]. Thus, in this study, we investigate the appropriate fit of the garment platforms and means of the equipment of devices to ensure the physical and social comfort.

Regarding the above points, the ideation in order to extract the garment design concept was conducted in the initial step. To express the relation of the functions applied in each different part of the garment based on the feature of the human body and its movement visually, the design concept was configured as “Anatomy”. Therefore, the diagrams of the human musculoskeletal system has been digitally synthesized using

![Diagram of human musculoskeletal system](image1)

**Figure 8.** The anatomical images for design concepts.

![Diagram for user's needs survey and the results](image2)

**Figure 9.** The diagram for user’s needs survey and the results.
graphic tool such as Adobe Photoshop CS5 initially, and the first design draft based on the structures and lines of the anatomical image was then generated. Thereafter, to investigate the visual balance between the platform design and four system modules, the extracted design draft was adjusted to refine excessive lines and diversify variations of the design. As a result, the A and B, two types of second design drafts were developed and they were also diversified into two variations; hooded and unhooded, as shown in Figure 10 and Figure 11.

The style design of both two types were carried out to express outdoor and sports style and details such as loose fitted silhouettes and sleeve hemlines covering the back of hands completely. It was the design strategy to emphasize the concept of the technology development focused on the assistive functions of outdoor-activities.

| Location        | The most preferred functions in each location of the jacket |
|-----------------|------------------------------------------------------------|
| Head            | Bluetooth hands-free which could be connected to smartphones wirelessly |
| Bodice front    | Heating function to sustain body-heat                      |
| Bodice rear     | Rear-detection to avoid dangers from user's rear-side       |
| Sleeve          | Vital sign monitoring function for self-health-care        |

The selected ideas on prototype functions in each part of the garment platform.

| Function               | Function usage scenario in each idea |
|------------------------|--------------------------------------|
| Rear detection         | For two sorts of target users who tend to put ear-phones or head-sets on their ears when they move around in daily lives or have difficulties on hearing, the system consistently perceive the circumstance of its user's rear-side and give warning signals when something or someone are approaching to the users in less than 10 m to assist their safe activities in the crowded spaces. |
| Bluetooth hands-free   | For outdoor or sports activities or situations which people will not be able to use their hands freely to manipulate smartphone, the system allow its user to use and control phone call or sound streaming without putting out the devices from pockets or bags. |
| Vital-sign monitoring  | For people who have physical problems or disease on the cardiovascular system or do physically intensive sports or outdoor activities in irregular places comparing to city environments, the system measures and displays its user's heart-beat rates on a built-in-screen. The users can also check the statistical data through the smartphone application when they connect to each other through Bluetooth wireless connection. |
| Heating                | For emergency situations such as the distress in the outdoor environment or harsh climate in the winter, the system provides the thermal generation function to sustain user's body heat. |

Both of type A and B designs are consisted of the similar silhouette and cutting lines inspired from the human's musculoskeletal system, the designs for the structures and cutting lines of the shoulder parts between bodices and sleeves. And cutting lines of stomach parts were differentiated from each other.

Also, the color strategy of the two types of the garment designs was considered to emphasize the divisions of the clothing generated by the design lines. The divided parts of the jacket were grouped into three color groups, the colors of which were separately applied to differentiate and underline the lines as shown in Figure 12 and Figure 13.

The development of each system circuit was designed to be installed in the container modules made by 3D-printing technology, where the system modules could be independently operated and detachable from the garment platforms to achieve the washability as in Table 5.

We investigated the precise locations to install the systems on the garment according to the operating scenarios of the system. As a result, we planned that rear-detection system should be located on the upper-center-back part of the platform regarding the requirement that the module should not be affected and interrupted by the user’s motions commonly. The location of Bluetooth hands-free system was configured to be attached on the side part of the hoods by considering the repetitiveness property of it; listening and talking would be high enough as the user’s head as possible. The Vital-sign monitoring system was decided to be attached on the lower part of sleeves allowing the module and the heart-beat sensor part to perform well since hearth-beat sensor achieves its best performance when it is attached on the parts of central chest, armpits or inner-side of wrists among human body. As the heating function needs the large amount of the electric current comparing to other systems, it was considered that heating sheets were located on

| Function               | Function usage scenario in each idea |
|------------------------|--------------------------------------|
| Rear detection         | For two sorts of target users who tend to put ear-phones or head-sets on their ears when they move around in daily lives or have difficulties on hearing, the system consistently perceive the circumstance of its user's rear-side and give warning signals when something or someone are approaching to the users in less than 10 m to assist their safe activities in the crowded spaces. |
| Bluetooth hands-free   | For outdoor or sports activities or situations which people will not be able to use their hands freely to manipulate smartphone, the system allow its user to use and control phone call or sound streaming without putting out the devices from pockets or bags. |
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| Heating                | For emergency situations such as the distress in the outdoor environment or harsh climate in the winter, the system provides the thermal generation function to sustain user's body heat. |
around the heart in the inner place of the garments to optimize the efficiency of heating by using the limited numbers of sheets and user’s body movements (see Figure 14).

3.2.2. Platform construction process

After overall garment design tasks were completed, flat pattern design and muslin basting in each type of platform were initially conducted as in Figure 15. The size spec and target wearers of the prototypes were configured as unisex for general physique of men and women to examine the usability of the prototype by diverse testers. At the process of flat pattern making, the locations and real sizes of the system modules were marked on the patterns to apply the thin and flexible anchors of the system modules, which would be developed by 3D-printing exquisitely. Thereafter during the basting making, the errors on realization of the sophisticated design lines which were found out at the process, were corrected for final garment platform making.

During the pattern making and basting process, 3D modeling of each system module container and module anchor was conducted at the same time in order to clarify the numeral interaction between the shape lines of each system module container and the marked boundaries of the module anchors on the flat patterns.

The system modules and the anchors were designed to be assembled and disassembled through the joint structures, as illustrated in Figure 16, which could easily attach or detach the modules from the platform by the one-snap-button action. The thickness of the module anchors was to 2 mm. The plan was to sew them in the middle layer between the outer and inner fabric. Also, in order to obtain the flexibility and washability of the garment platforms, TPU (thermoplastic polyurethane) filaments, which is a flexible and tough material, was selected to 3D-print the anchor units. After the 3D-modeling, the anchors were printed and assembled in the prearranged locations as shown in Figure 17 and Figure 18.

Four garment platforms of two design, A and B, were developed by integrating the fabric parts and 3D-printed anchor units. This was sorted into hooded and unhooded, as demonstrated in Figure 19 and Figure 20.

3.3. System modules development

3.3.1. System design process

In order to develop the system, electronic components were researched to minimize the volume of the system modules based on previous researches and cases. Then, the smallest processor, sensors, batteries, and other components, which could be procured in academic areas realistically, were selected. In general, for R&D of wearable technologies in fashion design, Arduino uno or nano, which are the open sourcing micro-processors, have been equipped in inner parts of garment or accessory platforms. In this study, we used the super-micro-processor, “Tiduino” provided by Tiny circuit, which is compatible for tuning boards of Arduino. As the size of Tiduino is smaller than Arduino nano by 2 X 2 cm, the processor was generally accepted as suitable to condense the volume of the wearable systems. Therefore, we used Tiduino units in the construction of the main control boards of each functional system, while the other input, output, and power devices were differently constructed according to the purpose of each function. The specific details of the selected devices are stated in below Table 6.

In the case of rear-detection system, to realize the function of the distance perceiving of center-rear, right-rear and left-rear and the intensity of the vibration was planned to be getting stronger when the approaching object is getting closer.

Table 5. The outlines of the operation principle of the functions in each module.

| Function            | Function usage scenario in each idea                                                                                                                                 |
|---------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Rear-detection      | The system equipped on the back part of the garment consistently perceive circumstance of its user’s rear-side and notice the approach of things or people through vibrations by three phases; 10, 8 and 5 m. The intensity of the vibration was planned to be getting stronger when the approaching object is getting closer. |
| Bluetooth hands-free| For the situation of outdoor leisure or sports activities and carry stuff such as mountaineering sticks, system modules equipped on the side part of the hoods provide the control function of phone-call or sound-streaming through buttons on the surface of the module cover when the it is connected to a smartphone by Bluetooth. |
| Vital-sign monitoring| The system module measures user’s heart-rate in real time and displays it through the built-in OLED screen. If the system is connected to smartphones by Bluetooth 4.0 LE, users can check the daily or monthly average data, the highest or lowest rates, through a smartphone application. |
| Heating             | For the circumstance or environment of freeze-up, the system provides heating function to sustain its user’s body heat once the user put the push-stop switch to turn on the function. |

Figure 12. The configured color groups and sample color variations.

Figure 13. Flat sketches on color variations of type A and B.
vibration warning by three phases based on the detected object’s distance, function control is carried out by Tinuino, while distance recognition is done by three of infrared light DMS, and warning signals were generated by three cylinder type vibration motors. We used 5V battery for the power supply and designed battery recharging module.

In the case of Bluetooth hands-free system, to realize the functions of phone call and sound-streaming control, the application of the system control by Tiduino, the wireless connection with smartphones by the all-in-one-circuit of sound transceiver and Bluetooth, voice input for phone call by a micro phone, sound output by stereo speakers, 3.7V battery for power supply and changing module for battery recharging were designed.

In the case of vital-sign monitoring system, to realize the function of sensing, displaying heart-rates, and interaction with smartphones, the application of the system control by Tiduion, heart-beat measuring by heart-beat sensor, direct displaying of the signals by Tiny-screen, wireless connection with smartphones by Bluetooth 4.0, 3.7V LE battery for power supply, and charging module for battery recharging were designed.

In the case of heating system, since the function was focused on the health-care, the extension of the length of using hours and the reliability of the system operation were preferentially considered the most important. Thus, the input system was designed to use push-stop-switch to activate the function manually which would be the most reliable and stable input method on the activation of digital systems. This was because the automatic system control needs sensors and processors to be constructed, which had to be consistently turned on to release the activation orders to output devices automatically. So, the automatic control was assessed as unnecessarily consuming electricity for the purpose. Accordingly, differing from the other systems, we adapted the manual control principle in heating system. Heating system was designed consisting of eight heating sheets surrounding the user’s chest parts as the output devices, a push-stop-switch as the input device and high-capacity 5V supplementary battery for mobile devices as power supply.

To realize our proposed system, experiments using breadboards as well as program coding were initially performed, and only the successful results of the experiments were then organized in the circuit diagrams to prepare the system module development (refer Figure 21).
3.3.2. System construction process

Although the mechanical printing techniques and 3D-printing technology were investigated to construct electronic circuits for wearable technologies in the previous researches on rapid prototyping [47, 63], there are several difficulties and limitations to use the techniques in our R&D process. Since this study’s R&D was conducted in an academic institute with limited budget, the high-cost printing techniques was not available to adapt in circuit making. And the durability of the conductive materials of 3D-printing was also not suitable for our proposed systems to be worn, since the conductive materials for 3D-printing was easily cracked by physical shocks. However, 3D-printing technology was adapted for the other purpose in this study, since the other non-conductive materials by it have enough solidity and it was an appropriate means of rapid-prototyping to produce circuit hosing or device hardware covers. To develop 3D-models of each system module, the sizes of each assembled circuits were measured and overall forms and specific details of the modules were then designed based on the measured data. The 3D-printed modules were planned to protect the system circuits from external shocks.

Thereafter, the 3D-models of the system modules were printed by two types of 3D-printers: Cubicon Single Plus (FDM) and Form2 (SLA), Figure 22 and Figure 23.

At the 3D-modeled system module development phase, it was found out that the system modules printed by SLA type could be directly applied to assemble the modules without any post-cleaning treatments since the

![Figure 18. The developed 3D-modeling of each system module.](image1)

![Figure 19. The developed Prototype of Design type A.](image2)

![Figure 20. The developed Prototype of Design type B.](image3)
printing resolution was high at about 0.02 mm by the printing principle of the light-polymerized. In contrast, the modules printed by FDM type showed lower printing resolutions and coarse surface conditions by the printing principle of high-temperature extrusion. Thus, the post-cleaning tasks; putty coating, sanding, and coloring were progressed to improve the quality of the surface conditions of the modules printed by FDM. Thereafter, every device module container and system circuit were assembled temporarily. The whole development processes are illustrated in below Figure 24.

Rear-detection system module was developed to locate the processor and battery units in the center part of the module and DMSs which were the biggest components among the system located around the central units in a triangular form; left-upper-side, right-upper-side and center-bottom-side of the module in each. In the below layer of the three DMSs, three vibration motors were embedded to allow that the vibration warning could be delivered to user's body effectively. Finally, the system wires which connects the central units (processor) and the DMSs were cut to be of the shortest length to minimize the system, as in Figure 25.

Bluetooth hands-free system module was developed to allow its users to control the system power, volume, and attending phone calls without manipulating the smartphones directly through the three short-cut switches located on the module container that were directly connected to Bluetooth-sound-amplifying-board. Speakers and a micro-phone without the system module equipped in the inner side of the hood were also developed, which can be attached or detached to additional inner pockets and Velcro-line applications. All the components were connected to each other through the pin-socket-joint-system for efficient maintenance and washability, as shown in Figure 26.

Vital-sign monitoring system module were developed to install the screen indicating the measured heart-beat rates diagonally in the module.

| Functional systems                  | Control    | Input                               | Output                              | Power                 |
|-------------------------------------|------------|-------------------------------------|-------------------------------------|-----------------------|
| Rear-detection                      | Tiduino    | Infared light DMSs                   | Cylinder type vibration motors      | 5 V Lithium-ion battery |
| Bluetooth wireless head-set         | Tiduino    | Push switches, Bluetooth sound control module & micro-phone | Speakers               | 3.7 V Lithium-ion battery |
| Vital-sign measuring & monitoring  | Tiduino    | Heart-beat sensor & Bluetooth 4.0 module | Tiny screen & Bluetooth connection with smartphones | 3.7 V Lithium-ion battery |
| Heating                             | None       | Switches                            | Heating sheets                      | 5 V battery pack      |

Table 6. The selected and applied devices in each system development.

![Figure 21](image1.png)  Rear-detection system  Bluetooth hands-free system  Heart-beat measuring & monitoring system  Heating system

Figure 21. The diagram of the system circuits in each functional system module.

![Figure 22](image2.png)  Rear-Detection module  Bluetooth hands-free module  Vital-sign monitoring module

Figure 22. The designed 3D-models of each device container.

![Figure 23](image3.png)  Rear-Detection module  Bluetooth hands-free module  Vital-sign monitoring module

Figure 23. The 3D-printed of each device container.
cover to allow that users could easily check their vital-signs through a simple action such as putting their arms up. And the main system module and the heart-beat sensor were developed detachable and attachable from each other through the micro-pin-socket-joint-system in order to make the input sensor adhered on user’s skin of the wrist independently, which was equipped in the inner rib-hem part inside the left wrist part of the platforms, as shown Figure 27.

Heating-system was developed to be directly installed in the inner space between outer and inner fabric of the garment platform differing from the other system modules. As heating sheets were located on Velcro-lines inside of the garment to improve the efficiency of the heat transmission, the electric wires supplying electricity to the sheets were also embedded in the Velcro-lines to anchor them concretely and detach them from the platforms for the durability of the circuit, as well as wearability and washability of the garment platforms. Each component of the system; heating sheets, switch and wires were also connected by the pin-socket-joint-system and the high-capacity battery was developed as rechargeable through USB ports as shown in Figure 28 and Figure 29.

Except the heating-system, batteries of the three system modules could be easily recharged by using five-pin charger cables, which has been the most popular standard of charging mobile devices. Also, in each system module, the main power control button, which equipped with LEDs inside the structures, was applied to allow users to comprehend whether or not the systems were turned on through the LED lighting in order to reduce the unnecessary battery consumption as in Figure 30.

In the last phase, the developed system modules were pre-assembled with the garment platforms temporarily for the wearing test (evaluation) (see Figure 19, Figure 20).

3.4. Test and finalize

The evaluation on the wearability of the platforms and operability of the systems were followed to improve the completeness of the prototypes’ usability. To test the functions in similar circumstances with the initial plans, evaluations were conducted in the outdoor environment.

First, for the test of rear-detection system, subjects were instructed to use earplugs when testing the warning function in order to exclude errors generated by auditory stimuli. In this scenario, testers were led to walk around the street and use their fingers to point directions when they felt vibrations. Second, the tests of Bluetooth hands-free were conducted to evaluate three points: whether the system could be smoothly paired to testers’ smartphones or not, whether the quality of phone-call would be good, and whether the short-cut-buttons would accurately function. Third, the test of vital-sign monitoring and heating systems were conducted simultaneously with the rear-detection system test as there was a need to assess their operability when users perform activities that affect both the heart rate and the body temperature. In the test of vital-sign monitoring system, we examined whether the system could precisely measure and display its user’s heart-beat data through the built-in-screen or the phone application. In the test of heating system, it was focused to confirm whether the temperature of heating sheets was appropriately
heated up and the circuit did not affect wearer’s body movements (see Figure 31).

As a result, in rear-detection system, it was found that the three DMSs and vibration motors consumed more amount of electric currents than the initial expectation extracted by the breadboard experiments, since the devices were needed to be consistently activated for the purpose. The similar issue was also observed in heating system that applied 5000 mAh battery. Therefore, the refinement to lengthen the using time of both two functional modules was decided. On the other hand, in vital-sign monitoring system, two points of the refinement were discovered that the heart-beat sensor equipped in the wrist band inside of the sleeve had to be closer to user's skin to improve the efficiency of the vital-sign measurement. Regarding these findings, the refining tasks of each system, excepting Bluetooth hands-free, were performed and specific works are stated below.

First, as rear-detection function could be operated for about 50 min by adapting the one-cell-battery, two-cell-battery system which were parallelly connected to each other was applied in the system module to increase the using time twice. The refined battery was made to equip in the same system module container in order to maintain the minimized sizes and weight.

Second, in heating system, the new supplementary battery was searched, which had the similar size and weight with the previously adapted battery that sustained for about two-and-half hours. As a result, the new high-capacity-battery which could store 15000 mAh of the current and had almost the same size and weight for 300 g was found and applied to extend the using time for about 3 times.

Third, the input device module of vital-sign monitoring system was refined to be worn on user's wrists directly like watches, for stable heart-
In this study, we conducted an R&D of convergence smart jacket prototypes, which could provide both electronic and traditional functions of garments. The study was conducted to seek the extended role of fashion in industrial convergence. As a result, four prototypes with four function; rear-detection, Bluetooth hands-free, vital-sign monitoring, and heating at the same time were developed. In order to proceed with this R&D we first considered the usability of the garments and the application of technology, then we considered minimizing the system modules so that they can be attached or detached as necessary, and then the washability of the garments.

Through the experience of this study’s R&D, the factors which had to be necessarily considered to develop convergence-smart-clothing were found out. First, the interaction among joints of human body, range of body movement, as well as each part of clothing platforms related to it and the property of digital functions should be investigated to find out the correct location of system applications which can be operated stably.

| Design type   | Feature of platform | Applied system                                      |
|---------------|---------------------|-----------------------------------------------------|
| Design type A hooded | Hooded design, Color variation 1 | Rear-detection, Bluetooth head-set, Vital sign measuring, & monitoring, |
| Design type A unhooded | Unhooded design, Color variation 3 | Heating                                              |
| Design type B hooded | Hooded design, Color variation 2 | Rear-detection, Bluetooth head-set, Heating          |
| Design type B unhooded | Unhooded design, Color variation 4 | Rear-detection, Vital sign measuring, & monitoring |
Second, to construct multi-functionality, the systems should be developed independently since there will be unnecessary wire connections or power units which can introduce negative effects on wearability, durability and operability of wearable systems, if several system circuits share components such as wires or powers in one clothing platform. And, to improve the stability of system modules and the wearability of clothing platforms commonly, the components of the circuits should be directly assembled, ensuring the systems as minimum and substantial like mass-produced one-board circuits. If there is the inevitable necessity of the wire application, they should be cut as short as possible and the joints connecting boards with the wires should also be coated by reinforcing materials such as flexible Silicon to prevent the disconnection of wires.

Therefore, as the result of R&D in this study, the direction of future research was discovered as to enhance the completeness as garments and reliability to use digital functions of convergence smart fashion.

The first direction of future research is the elaborated and aesthetic system modularization, which can be attachable and detachable from clothing platforms. In this study, 3D-printing technology was employed to construct the main frames of the modular systems. The modules were durable and substantial, but there was also the disadvantage of using 3D-printing for rapid prototyping of the modules, and that the module consisted of unfamiliar materials and forms from the traditional fashion perspectives. Thus, there should be deep consideration and experiments to design the external system module components, which can be visually coordinated and balanced with designs of garments.

The second direction was to modularize the components themselves, especially input and output devices of the system modules, which could be changeable like RAM-chipssets on the PC motherboards. If the whole circuit components could be modularized, each key-device such as input devices could be adjusted according to the changes in situations or environments. For example, in the case of this study's vital-sign monitoring system, its function can be extended or changed to measure other vital signs such as body temperature, if its input sensor can be replaced by temperature-sensors through the changeable modular system and the five pin ports for updating the program. Therefore, there is more potential to expand the use of the systems and functionality of the wearable systems through this study's principle.

It will be expected that the achievement of the two research topics cannot only contribute the construction of aesthetic appearances of platforms, but also affect the reinforcement of the diversity of usages of the wearable systems, which can be ultimately connected to the improvement of the use and values of convergence-smart fashion. Through this study's R&D principle based on split-and-merge mechanism of system modules, developers of convergence-smart-garments can readily expand the variations of the garments' functions or upgrade the performances of existing systems by only additional development of supplementary system modules. Also, there will be benefits for users that the users can select, change, add or dispose functions according to their daily needs or social conditions.

Declarations

Author contribution statement

Hyunsung Lee: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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