

ABSTRACT

PARK, JUNG HYUN. Technical Considerations for the Design of Smart Apparel for the Overweight. (Under the direction of Dr. Hoon Joo Lee and Prof. Nancy Powell.)

According to the National Center for Health Statistics of the U.S. Department of Health and Human Services approximately 65% of adults in the United States were overweight in the period of 2003~2006. Overweight and obesity are associated with increased health risks and estimated medical expenditure attributed to obesity reached \$147 billion in 2008.

Various smart healthcare clothing, monitoring vital signs such as blood pressure, heart rate, electrocardiogram (ECG), respiration, and body temperature, have been presented by researchers and is in great demand owing to an increasing interest in health and well-being.

Waist circumference provides important information related to body fat and multiple health risks. This research is an investigation to develop smart apparel for the overweight, called Body Monitoring Smart Apparel (BMSA). BMSA was designed in order to measure waist circumference and convey the information to users participating weight management. A textile sensor, called elastic strain gauge, made of carbon black and polyurethane was developed in order to measure body circumference.

A BMSA consisting of leotard or bodysuit made of cotton and spandex was designed in order to fix the position of the elastic strain gauges around waist and to be fitted well on the body. In addition, BMSA selection options considering body shape, size, and garment preference were presented.

The relationship between electric resistance of elastic strain gauge developed in this research and its length was basically linear. In the washing durability test, the linear relationship remained after 20 times washing cycles. A prototype sample of BMSA having an elastic strain gauge was prepared. A 3D body scanner, Computer-aided Design (CAD), and Computer-aided Manufacturing (CAM) technologies were used in order to design a well fit BMSA.

Technical Considerations for the Design of Smart Apparel for the Overweight

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1 INTRODUCTION

According to the National Center for Health Statistics of the U.S. Department of Health and Human Services, approximately 65% of adults in the United States were found to be overweight in the period of 2003~2006 ("Health, United States, 2008 with Special Feature on the Health of Young Adults"). As the ratio of overweight and obesity continuously rises, obesity-related health problems such as hypertension, metabolic syndrome, type 2 diabetes, coronary heart disease, cancer, osteoarthritis, and sleep apnea also increases ("Do You Know the Health Risks of Being Overweight?"). In addition, overweight and obesity have a significant economic impact. According to one research, estimated medical expenditure attributed to obesity was \$147 billion (approximately 10% percent of all medical spending) in 2008 (Finkelstein et al.).

Although not necessarily an indicator of being overweight, waist measurement can clearly reveal excessive abdominal fat. It has been shown that abdominal fat, in particular, increases the risk of various health issues ("Do You Know the Health Risks of Being Overweight?"). Lakka et al. reported that middle-aged men with this excess are candidates for coronary heart disease, and that the amount of abdominal fat is even more important than overall obesity (Lakka et al.). Abdominal fat is a significant factor in various atherogenic conditions and is identified as a component of "metabolic syndrome" (Després, Lemieux and Prud'homme; Wajchenberg). Hypertension and blood lipid levels, risk factors for coronary heart disease, are accelerated by increasing waist circumference and the ratio of waist circumference to hip circumference (Willett, Dietz and Colditz).

Because of greater awareness of these health risks especially among an aging population, and an increasing interest in health and well-being, smart healthcare clothing has a special opportunity for development and expansion (Cho and Lee). Smart healthcare clothing monitoring vital signs such as blood pressure, heart rate, electrocardiogram (ECG), respiration, and body temperature have been developed by researchers. Research in this field is facing various challenging issues such as “biomedical sensors, scenarios of data security and confidentiality, risk analysis, user interface, medical knowledge/decision support, dissemination, user acceptance and awareness, and business models and exploitation” (Lymberis) (pg.no.3716). Smart healthcare clothing can be both comfortable and efficacious for disease prevention, a lifetime of continuous health monitoring, and home care versus hospital care (Axisa et al.).

According to the analysis of Venture Development Corporation (VDC) for wearable computing and smart fabric and interactive textile which can provide real-time vital and diagnostic information, the demand for these will be likely accelerated (Lymberis and De Rossi). Sensor and wireless communication technology highly developed will likely accelerate the smart healthcare clothing.

However, it is hard to find the smart clothing developed for helping people seeking practicing weight management. Waist measurement can be a useful indicator for health weight management. Continuous self-monitoring and physical activity play an important role in successful weight management (Burke et al.).

Therefore, this research focuses on developing smart apparel for the overweight, called Body-shape Monitoring Smart Apparel (BMSA), using a textile sensor which monitors waist circumference and finding potential possibility through making a BMSA prototype.

The overall research question for this research is: “How the Body-shape Monitoring Smart Apparel (BMSA) can be developed?”

Specific research questions are as follows:

Question 1: What are design constraints for BMSA?

Question 2: What users’ expects are?

Question 3: What technical issues should be considered?

Question 4: How can a BMSA prototype be prepared and tested?

Therefore, the specific objectives of this research are as follows:

Objective 1: develop a design concept of BMSA with technical considerations and end user considerations.

Objective 2: propose the BMSA selection options considering body shapes of overweight women.

Objective 3: develop a textile sensor, called the elastic strain gauge, in order to measure the waist circumference using carbon black and polyurethane and test the elastic strain gauge.

Objective 4: develop the prototype of BMSA containing elastic strain gauge and test the prototype.

2 REVIEW OF LITERATURE

In order to develop Body Monitoring Smart Apparel (BMSA), environmental and technical background considerations are required. Overweight and obesity, the reason for the development of BMSA, was investigated in aspects of definition, prevalence, health consequences, economic costs, waist circumference and health risk and figures of overweight adult women. The current status and potential of smart healthcare clothing was explored. The technology of textile sensor which can be especially used for the strain gauge was investigated in order to obtain knowledge for elastic strain gauge development. Computer-aided technical design technology was searched in order to find the potential of automatic production of BMSA.

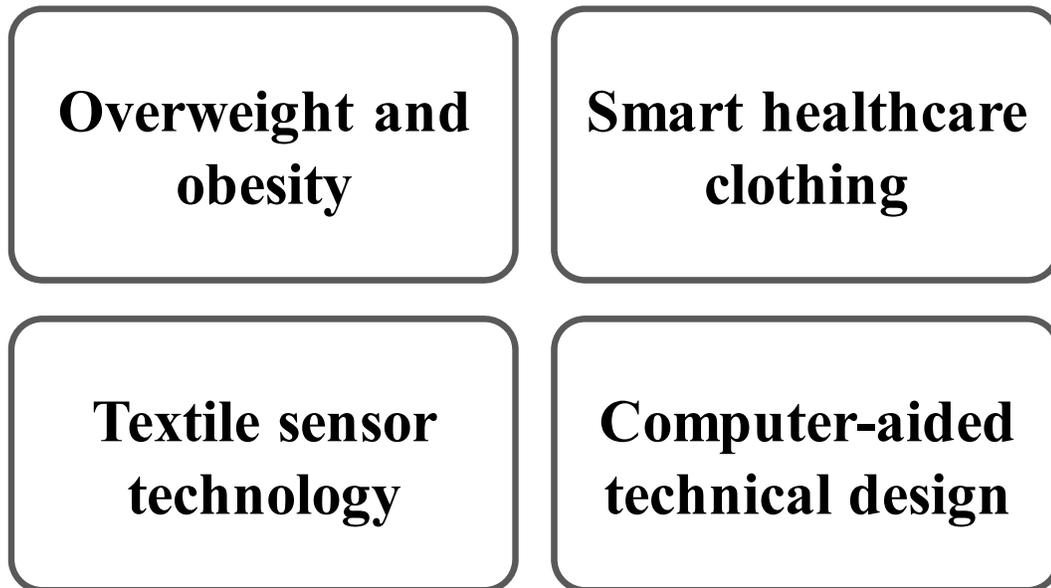


Figure 1. Considerations for development of BMSA.

2.1 Overweight and obesity

2.1.1 Definition of overweight and obesity

There are several methods for assessment of overweight and obesity. BMI, waist circumference, waist-to-hip ratio (WHR), weight and weight-for-height and skin-fold thickness are anthropometric methods. Magnetic resonance imaging (MRI), computerized tomography (CT) and bioelectrical impedance analysis (BIA) are direct measures.

2.1.1.1 Body mass index (BMI)

Body mass index (BMI) is a simple index of weight-for-height that is generally used in categorizing overweight and obesity in adult populations and individuals. It is defined as the weight in kilograms divided by the square of the height in meters (kg/m^2). Body mass index categories are defined according to the World Health Organization guidelines, as shown in Table 1. The World Health Organization (WHO) defines “overweight” as a BMI equal to or more than 25, and “obese” as a BMI equal to or more than 30. ("Obesity: Preventing and Managing the Global Epidemic. Report of a Who Consultation; World Health Organization, Obesity and Overweight") BMI is a measurement most often used to quantify body fat (Stein and Colditz), and BMI is closely associated with measurements of fat mass (Kopelman; Stein and Colditz). However, it does not discern fat mass from lean mass (Kopelman). Racial differences in the relationship between body fat and BMI have been observed. (Wang et al.; Fernandez et al.).

Table 1. Classification of overweight and obesity based on body mass index (BMI)

Classification	BMI (kg/m²)
Underweight	<18.50
Normal	18.50-24.99
Overweight:	≥25.0
Pre-obese	25.00-29.99
Obese class I	30.00-34.99
Obese class II	35.00-39.99
Obese class III	≥40.00

Source: Obesity: Preventing and Managing the Global Epidemic. Report of a Who

Consultation. 2000

2.1.1.2 Waist circumference (WC)

Waist circumference is an indirect measure of central adiposity and it is measured at minimum circumference between the iliac crest and the lowest ribs (Lobstein, Baur and Uauy). Waist circumference is closely related to BMI and waist to hip ratio (WHR). Waist circumference has a practical association with abdominal fat distribution, and it may be an approximate indicator of intra-abdominal fat mass and total body fat ("Obesity: Preventing and Managing the Global Epidemic. Report of a Who Consultation"). Central adiposity is mainly associated with risk for cardiovascular disease in adults (Ross, Fortier and Hudson). As waist circumference is a convenient and simple measurement with low measurement error (Lobstein, Baur and Uauy), it may be most helpful in clinical practice (Willett, Dietz and Colditz). Waist circumference is highly dependent on age (Power, Lake and Cole). Previous research suggested the baseline of waist circumference associated with health risk, as shown in Table 2 (Lean, Han and Morrison).

Table 2. Waist circumference and health risk

Health risk	Waist circumference (cm)	
	Men	Women
Increased	≥ 94	≥ 80
Considerably increased	≥ 102	≥ 88

Source: Waist Circumference as a Measure for Indicating Need for Weight Management,

Lean, M. E. J., T. S. Han, and C. E. Morrison, British Medical Journal 311.6998, 1995,

158-61.

2.1.1.3 Skin-fold thickness

Skin-fold thickness can be measured at multiple sites on the body with calipers. Fat mass and percentage fat can be estimated by prediction equations from skin-fold measurements (Power, Lake and Cole). There are significant variations among observers (Kopelman) and variations by age, sex, and race in skin-fold thickness measurements (Power, Lake and Cole).

2.1.2 World obesity

WHO stated that approximately 1.6 billion adults (age 15+) were overweight globally in 2005 and at least 400 million adults were obese. At least 20 million children under the age of 5 years were overweight globally in 2005. WHO predicts that by 2015, approximately 2.3 billion adults will be overweight and more than 700 million will be obese ("World Health Organization, Obesity and Overweight"). The USA, UK, and Canada are ranked 1st, 2nd, and 3rd in terms of obesity population, as shown in Figure 2.

("Oxford International Model United Nations, Oximun 2007 Study Guide, World Health Organization, Topic B: The Question of Obesity and Associated Health Complications").

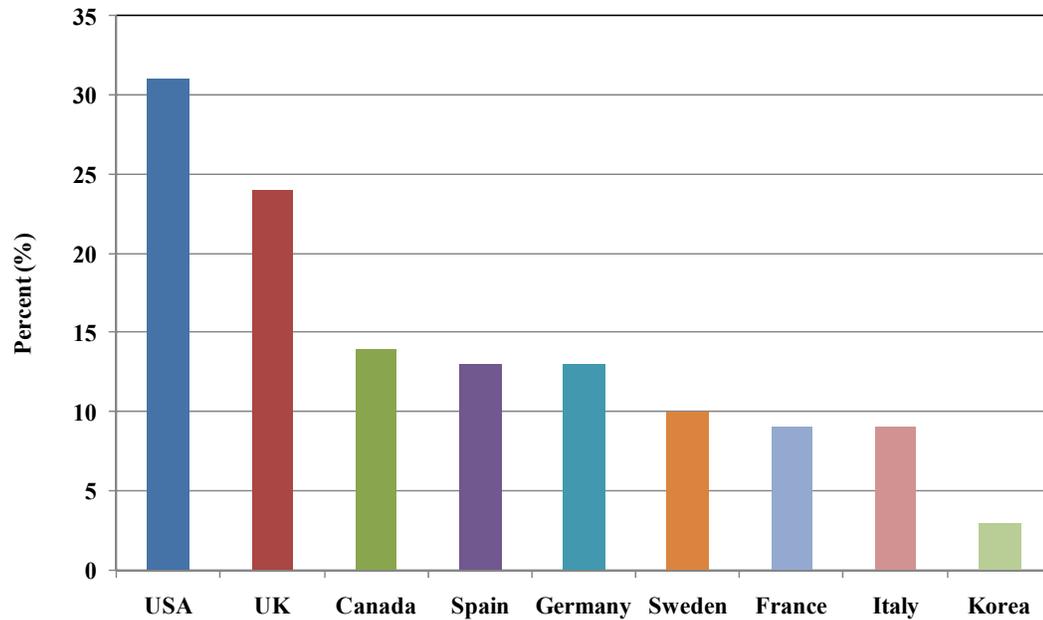


Figure 2. The percentage of the population older than 15 years with a BMI greater than 30 in each country.

Source: Oxford International Model United Nations, Oximun 2007 Study Guide, World Health Organization, Topic B: The Question of Obesity and Associated Health Complications. Oxford International Model United Nations, 2007, pg. no. 5.

2.1.3 Prevalence of overweight in the US

Figure 3 and Figure 4 present the overweight and obesity ratio of male and female adults living in the US. The significant increase over time is evident. Figure 3 shows as recently as ten years ago, the overweight population in the U.S. had reached over 65%.

Figure 5 and Figure 6 shows that the obesity ratio increases according to age. At 55~64 years the obesity ratio peaks and from 65 it decreases again.

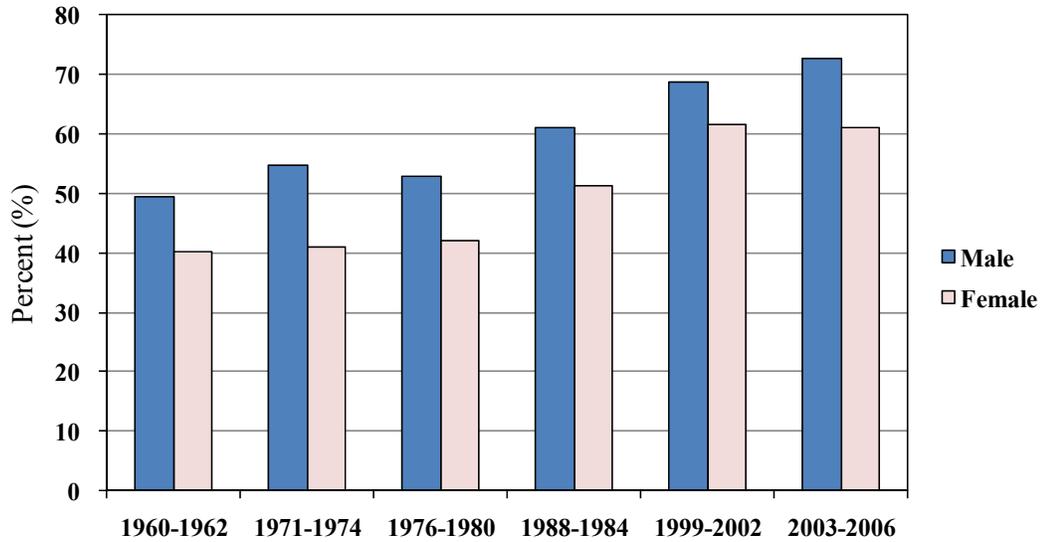


Figure 3. Overweight among persons 20 years of age and over: United States.

Source: Health, United States, 2008 with Special Feature on the Health of Young Adults.

2008, pg. no. 320-23.

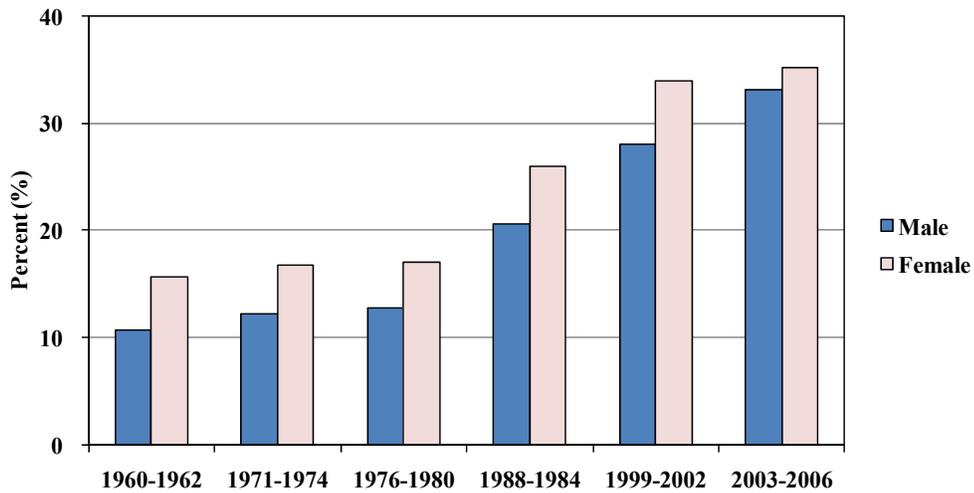


Figure 4. Obesity among persons 20 years of age and over: United States.

Source: Health, United States, 2008 with Special Feature on the Health of Young Adults.

2008, pg. no. 320-23.

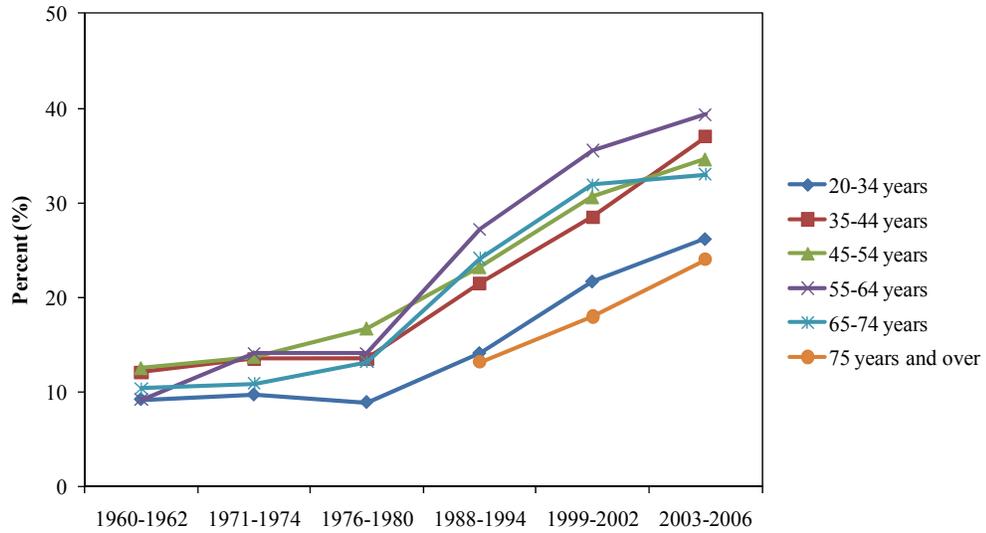


Figure 5. Male obesity ratio by age.

Source: Health, United States, 2008 with Special Feature on the Health of Young Adults.

2008, pg. no. 320-23.

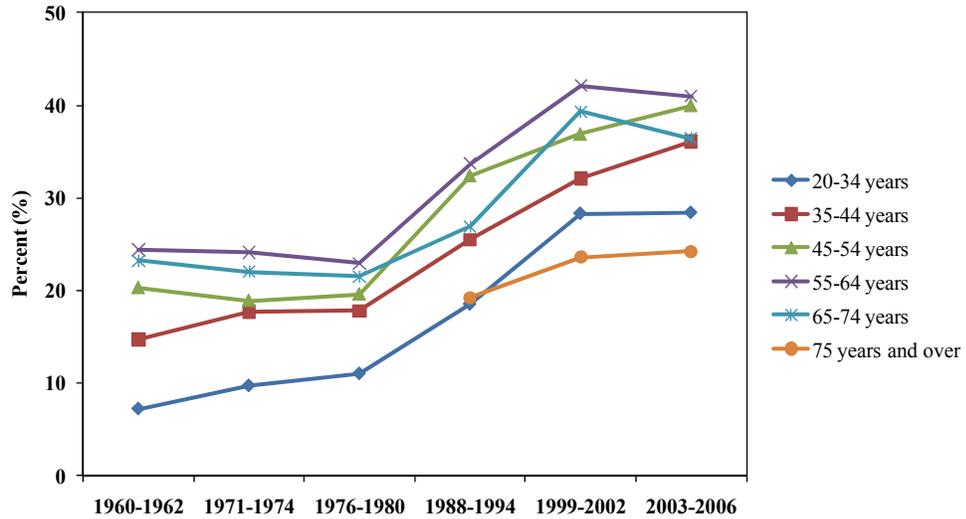


Figure 6. Female obesity ratio by age.

Source: Health, United States, 2008 with Special Feature on the Health of Young Adults.
2008, pg. no. 320-23.

2.1.4 Health consequences by overweight and obesity

Being overweight or obese results in serious negative health consequences. The negative influence on health increases progressively as BMI increases. Being considerably overweight can lead to various health problems, including cardiovascular disease (mainly heart disease and stroke), diabetes which has quickly become a worldwide epidemic, musculoskeletal disorders (particularly osteoarthritis), some cancers (endometrial, breast, and colon), high blood pressure, arthritis, indigestion, gallstones, snoring, sleep apnea, stress, anxiety, and depression ("Oxford International Model United Nations, Oximun 2007 Study Guide, World Health Organization, Topic B: The Question of Obesity and Associated Health Complications").

Chronic conditions caused by excess fat such as type 2 diabetes, hypertension, coronary heart disease, are closely related to high BMI. In subjects with a BMI less than 30, risk has an approximately linear correlation. However, the incidence of these disorders greatly increases in those with a BMI about 29, regardless of sex (Willett, Dietz and Colditz).

2.1.5 Economic lost of overweight and obesity in the US

As overweight and obesity have increased in the United States, the resulting health care costs, both direct and indirect, have increased. According to Finkelstein et al., estimated annual medical expenditure caused by overweight and obesity occupied 9.1% of U.S. medical expenditure in 1998 and was as high as \$78.5 billion (Finkelstein,

Fiebelkorn and Wang). That figure increased to approximately \$118.5 billion by 2006. The researchers hypothesized that obesity-related medical expenditures rose to \$147 billion (approximately 10% percent of all medical spending) a year by 2008. (Finkelstein et al.).

According to researchers, the total costs due to obesity were estimated to be \$99.2 billion dollars in 1995. Direct costs were approximately \$51.6 billion accounting for 7% of total health care spending and indirect costs were \$47.6 billion. Direct costs denote preventive, diagnostic, and treatment services such as physician visits, medications, and hospital and nursing home care, and indirect costs denote the value of wages lost by people unable to work because of illness or disability, as well as the value of future earnings lost by premature death (Wolf and Colditz).

Comparing 1998 and 1994 NHIS data, there has been a significant increase in the indirect cost of obesity. Lost productivity in 1994 cost the nation \$3.9 billion as evidenced by the following: 39.22 million days of lost work (50% increase), 239 million restricted activity days (36% increase), 89.5 million bed days (28% increase) (Wolf and Colditz).

2.1.6 Waist circumference and health risk

According to previous research, waist circumference helps to identify people at increased risk for disease such as hypertension, metabolic syndrome, type 2 diabetes mellitus, and dyslipidemia. 14,924 adult participants of the Third National Health and Nutrition Examination Survey were divided by BMI and waist circumference using the

National Institute of Health cutoff points, and the prevalence of the above disorders was compared in people with normal vs. high waist circumference within normal-weight, overweight, and class I obese BMI categories. Both men and women with high waist circumferences had an increased health risk within the same BMI category compared with those with normal waist circumference. Considerable association between the prevalence of health risk and waist circumference was shown in their research. (Janssen, Katzmarzyk and Ross)

According to Zhu et al., waist circumference is useful for indentifying obesity-associated risk factors. Using a sample study of 9,019 white participants (men=4338, women=4631), they investigated the relationship between either waist circumference or BMI and the following obesity-associated risk factors: high LDL cholesterol (LDL cholesterol \geq 4.14 mmol/L), low HDL cholesterol (HDL cholesterol $<$ 0.91 mmol/L for men and $<$ 1.17 mmol/L for women), high blood pressure (diastolic blood pressure \geq 140mmHg or systolic blood pressure \geq 90mmHg), and high glucose (plasma glucose $>$ 6.94 mmol/L). Except for HDL, correlations between waist circumference and risk factors were considerably higher than correlations between BMI and risk factors. (Zhu et al.)

There are studies related heart disease such as cardiovascular risk factors (total cholesterol \geq 6.5mmol/L, high density lipoprotein cholesterol \leq 0.9mmol/L, diastolic blood pressure \geq 160mmHg, and systolic blood pressure \geq 95mmHg) in groups divided by waist circumference to determine whether waist circumference can be used for identification of cardiovascular risk factors or not. As waist circumference increased, cardiovascular risk factors were shown about in 2183 men and 2698 women (Han et al.).

In order to evaluate association of the anthropometric measures of obesity and cardiovascular disease risk factors, Reeder et al. conducted correlation analysis between the anthropometric measures - body mass index (BMI), waist circumference (WC), hip circumference (HC), ratio of waist to hip circumference (WHR) - and cardiovascular risk factors - diastolic blood pressure (DBP), systolic blood pressure (SBP), levels of total cholesterol (TC), low density lipoprotein (LDL) cholesterol, high density lipoprotein (HDL) cholesterol and triglycerides (TRIG) and the TC/HDL ratio. Waist circumference was most closely related with cardiovascular risk factors. The stronger association was shown in younger groups than older groups. (Reeder et al.)

Waist circumference is a useful indicator of coronary heart disease. Through analysis of correlation coefficients between height and waist circumference, they found that waist circumference was not significantly influenced by height, especially in people requiring weight management (Han, Lean and Seidell).

2.1.7 Waist circumference as an indicator of accumulation of visceral adipose tissue

It is suggested that the value of measuring waist circumference for identification of ("Glossary of Hiv/Aids-Related Terms")tissue which surrounds internal organs in the abdominal cavity. In order to verify the association between the visceral adipose tissue accumulation and each measurement, they calculated correlation coefficients between the visceral adipose tissue accumulation measured by computerized tomography and waist, WHR, BMI, or sagittal diameter of subjects of 213 men and 190 women. Correlation

coefficients between the visceral adipose tissue and waist circumference, WHR or sagittal diameter were highly significant in both men and women (Lemieux et al.).

Table 3. Correlation coefficients between the visceral adipose tissue accumulation measured by computerized tomography and waist, WHR, BMI, or sagittal diameter

	waist	WHR	BMI	Sagittal diameter
men	0.82	0.80	0.75	<i>r</i> = 0.84
women	0.73	0.61	0.60	<i>r</i> = 0.77

Source: A Single Threshold Value of Waist Girth Identifies Normal-Weight and Overweight Subjects with Excess Visceral Adipose Tissue. Lemieux, S., et al., Am J Clin Nutr 64.5, 1996, 685-93.

Waist circumference and WHR values corresponding to two critical values of visceral adipose tissue (100 cm²: Subjects are generally free from metabolic complications below this amount, 130 cm²: Substantial alterations in plasma glucose-insulin homeostasis and plasma lipoprotein-lipid profile are shown above this amount) were computed in men and women in order to determine critical values of waist circumference and WHR. They conducted analysis to verify whether the waist circumference and WHR values are influenced by age, menopausal status and obesity status. It was shown that the relation between waist circumference or WHR and visceral adipose tissue is influenced by age and menopausal status. Waist circumference and WHR values were generally higher in younger groups than older groups (

Table 4). It was shown that the relation of waist circumference and visceral adipose tissue is not significantly influenced by obesity status, but the relation of WHR to visceral

adipose tissue is influenced by obesity status. The difference between the normal-weight group and the overweight group is evident in the WHR values in the

Table 4. It was shown that waist circumference is an easier and better indicator for accumulation of visceral adipose tissue WHR. According to Lemieux et al. the, waist circumference and the waist-to-hip ratio (WHR) are most commonly used as anthropometric indexes for the prediction of visceral adipose tissue. Critical waist circumference values relating to visceral adipose tissue in different age and sex groups was proposed (Table5) (Lemieux et al.).

Table 4. Waist circumference and WHR associated VAT volume

	Waist circumference		WHR	
	VAT area 100 cm ²	VAT area 130 cm ²	VAT area 100 cm ²	VAT area 130 cm ²
Men	87.8 cm	95.3 cm	0.89	0.94
Women	84.2 cm	94.0 cm	0.82	0.88
Men <40y (n=140)	90.3 cm	98.9 cm	0.90	0.96
≥40y (n=73)	83.4 cm	90.9 cm	0.88	0.92
Women <40y, (n=124)	89.9 cm	101.2 cm	0.86	0.94
≥40y, Premenopausal (n=29)	79.9 cm	88.5 cm	0.78	0.84
≥40y, Postmenopausal (n=37)	75.3 cm	83.9 cm	0.77	0.83
Men <25 kg/m ² (n=77)	87.3	93.9	0.94	1.02
≥27 kg/m ² (n=83)	88.9	96.2	0.89	0.93
Women <27 kg/m ² (n=88)	85.0	94.2	0.94	1.06
≥27 kg/m ² (n=56)	88.0	98.4	0.78	0.96

Source: A Single Threshold Value of Waist Girth Identifies Normal-Weight and

Overweight Subjects with Excess Visceral Adipose Tissue. Lemieux, S., et al., Am J Clin

Nutr 64.5, 1996, 685-93.

Table 5. Waist circumference relating health risks

	Men		Women		
	<40y	≥40y	<40y, Premenopausal	≥40y, Premenopausal	≥40y, Postmenopausal
Desirable (<100cm²)	<90cm	<80cm	<90cm	<80cm	<75cm
Increased risk (>130 cm²)	>100cm	>90cm	>100cm	>90cm	>85cm

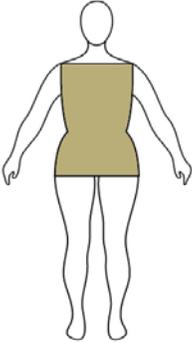
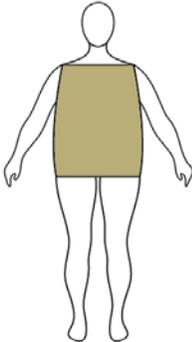
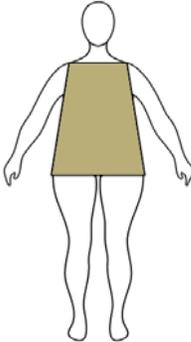
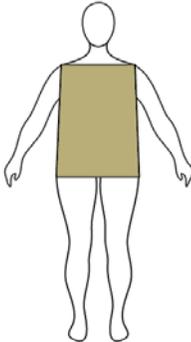
Source: A Single Threshold Value of Waist Girth Identifies Normal-Weight and Overweight Subjects with Excess Visceral Adipose Tissue. Lemieux, S., et al., Am J Clin Nutr 64.5, 1996, 685-93.

2.1.8 Body shapes of overweight adults women

The body shapes of overweight women are different with body shapes of normal weight women, and knowing body shapes is required for well-fitting garment patterns.

Body shapes of overweight women can be divided into 4 types. First, the rectangular-8 body shape is considered to be the most even in scale. This shape is characterized by well formed shoulders and well proportioned gentle curves. Second, the waist is thicker in the middle than at the hips in the barrel body shape. Third, the pear body shape has a narrow top and usually a narrow-shouldered torso that continues to the waist area, where it meets round hips or large bulging thighs. Next, the box body shape has a thick and wide torso, wide hips, and usually long legs with no visible waistline indentation (Zangrillo).

Table 6. Body shapes of overweight women

Rectangular-8 shape	Barrel shape	Pear shape	Box shape
			

Source : Frances Leto. Fashion Design for the Plus-Size. Zangrillo, New York: Fairchild Publications, 1990.

Some researchers divided body shapes of 222 women subjects into 9 categories (Figure 7): bottom hourglass (40%) hourglass (21.6%), spoon (17.1%), rectangular (15.8%), oval(3.6), triangle(1.8). Average weight was presented in each shape category: oval (150.6), triangle (143.1), spoon (141), rectangular (140.4), bottom hourglass (135.8), hourglass (132.9) (Simmons, Istook and Devarajan). Oval shape can be matched with barrel shape in body shape of overweight women of Zangrillo, triangle with pear, spoon with rectangular-8, and rectangular with Box (Zangrillo).

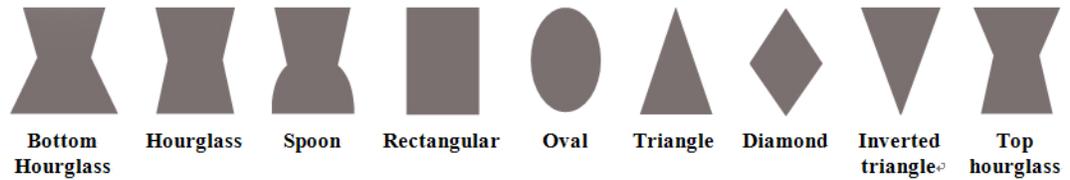


Figure 7. Body shapes of women.

Source: Female Figure Identification Technique (Ffit) for Apparel Part Ii: Development of Shape Sorting Software. Simmons, Karla, Cynthia Istook, and Priya Devarajan. *Journal of Textile and Apparel, Technology and Management* 4.1, 2004, 1-15.

2.2 Smart healthcare clothing

Smart Clothing can be defined as all clothing manufactured with “intelligent” or “smart” materials with the ability to sense stimuli from the surroundings and to respond to the conditions (Baurley). Smart textiles can be classified into three groups: passive smart, active smart and very smart determined by the behavior of the response (Van Langenhove and Hertleer; Zhang and Tao). Passive smart textiles only have the ability to sense stimuli from the surroundings; active smart textiles have the ability to sense and respond; very smart textiles have the ability to sense, respond and adjust themselves to the situations of the surroundings (Ariyatun, Holland and Harrison).

Smart healthcare clothing in particular has an opportunity for growth in the future because of the aging society (Cho and Lee). Moreover, the nation’s health care crisis encourages a greater interest health and well-being. Researchers have been designing smart healthcare clothing that monitors blood pressure, heart rate, temperature, respiration and electrocardiogram (ECG), but many issues must be worked out.

Challenges include “biomedical sensors, scenarios of data security and confidentiality, risk analysis, user interface, medical knowledge/decision support, dissemination, user acceptance and awareness, business models and exploitation” (Lymberis) (pg. no. 3716). As smart healthcare clothing is refined, it may allow users to stave off disease, avoid hospitalization and comfortably monitor their health on a continuing basis (Axisa et al.).

The wearable motherboard, called a ‘smart shirt’, using interactive textile through integration of traditional textile and sensors and sensor networks was developed in Georgia Tech (Figure 8). The smart shirt use multiple sensors and interconnects to monitor soldier’s vital signs such as heart rate, respiration rate, electrocardiogram, and body temperature and uses optical fibers to detect the penetration of bullet wounds. The smart shirt has the function of collecting, storing and transmitting data and is comfortable, lightweight, washable and durable. In addition, it can be used for monitoring babies prone to SIDS (sudden infant death syndrome). It can be used for patients recovering at home from heart surgery by monitoring the vital signs and transmitting the data to the hospital and alarming in an emergency situation (Jayaraman et al.; Geogia Tech Wearable Motherboard (Gtwm)").



Figure 8. Georgia Tech Wearable Motherboard (GTWM).

Source: Georgia Tech Wearable Motherboard (Gtvm). 2009

The department of Textiles at Ghent University developed the smart textile ‘Textrodes’ measuring heart rate and an electrocardiogram (ECG). The Textrodes have direct contact with the skin, so they allow long term monitoring without problems such as skin irritation. The elasticity of the knitted structure of the Textodes provides close contact between the garment and the thorax. Stainless steel fibers were selected as the material of the Textrodes due to good conductivity, soft touch, low toxicity, washability and its ability to be manipulated as a textile material (Van Langenhove and Hertleer).

LifeShirt® has developed for continuous ambulatory monitoring of respiration, the electrocardiogram, posture and motility. Sensors are embedded in the sleeveless under garment made of washable, reusable, stretchable textiles and connected to a handheld personal computer. The raw data are stored in the flash memory card and are analyzed by software. Raw waveform signals and over 35 derived parameters are displayed (Wilhelm, Roth and Sackner; Pda Cortex").



Figure 9. LifeShirt

Source: Pda Cortex. 2009.

Cho & Lee (2007) developed smart healthcare clothing having bio-medical sensors which monitor basic vital signs of cardiac disorder and respiratory disease. The prototype is composed of an outer layer and an inner layer. The outer layer is similar in appearance to common clothing. The inner layer has a temperature sensor, an electrocardiogram (ECG) sensor, an RFID tag with the wearer's medical history and identification data and a battery. The signals of electrocardiogram, respiration, heartbeat, and temperature can be measured. The wireless transaction part transmits the vital signs to the computer for real time monitoring. This clothing also has an alarm function in emergency situations (Cho and Lee)

2.3 Technology of the textile sensor as a strain gauge

The idea of a strain gauge is based on the principles of the changing of electric resistance of the conducting wire related to stretching of the wire. The electric resistance of conducting wire, R , is proportional to the length, L , and is inversely proportional to its cross-section area, A . Resistivity, ρ , is an inherent value of the material. Therefore,

stretching of the strain gauge results in an increase of the length, L , and reduction of the cross-section area, A . The electric resistance increases according to the equation (1).

$$R = \frac{\rho \cdot L}{A} \quad (1)$$

where R is the electric resistance; L is the length of the wire; ρ is the resistivity; A is cross-section area of the wire. (Cochrane et al.) pg. no. 485

A strain sensor has been developed based on a thermoplastic elastomer (Evoprene®) and carbon black nanoparticle composite in previous research. The researchers used two different methods, the melt-mixing process and the solvent process, to prepare conductive polymer composite sensors with filler contents variations. Mixed polymer pellets were made into film types with a hot press. Resistivity of conductive composites made by the melt-mixing process and the solvent process rapidly decreased in 7.3 vol% filler contents. The transition from insulating to conducting appears at the rapidly decreasing point. The solvent process shows better conductivity because of good dispersion of the particles. The researchers attached the conductive polymer composite sensor to the lightweight nylon fabric and covered the sensor with latex film for protection. When they measured the electric resistance of 27.6 vol% strain sensor, a non-linear relationship was observed below 15% relative strain, and a linear relationship was observed above 15%. They observed that the electrical performance of the sensor was particularly influenced by the existence of high humidity due to the sensitivity of the carbon black filler particles to water (Cochrane et al.).

Mattmann et al. used 50wt% thermoplastic elastomer (TPE) and 50wt% carbon black particles to make strain sensors using a melt process and extrusion. The strain sensor was placed on the fabric, and then silver coated conductive yarn was attached to both ends using conductive epoxy. The sensor was covered with silicon film, enhancing flexibility and elasticity. They performed measurement on a sensor of 2cm length in order to characterize the sensor's dynamic behavior. They provided waiting times at the point of extension and retraction in order to observe relaxation behavior. Relaxation of the sensor results an inaccuracy of 8.8%. Electric resistance response for the strain was not observed at a strain below 10% due to textile deformation. Mean hypothesis error in response to a strain was $\pm 2.25\%$. When the strain was decreased, the response of the sensor was stable. On the other hand, when increasing strain was applied, the response property of the sensor was not consistent. Therefore, pre-stretching is required to keep the constant sensor characteristics. The increase of the strain rate results in a small rise in the electric resistance. The sensors showed the stable properties over time and were not affected by aging or washing. Twenty-one strain sensors were applied to a tight-fitting garment in order to recognize upper body postures, and a recognition rate of 97% was achieved (Mattmann, Clemens and Tröster).

In other research, the dissolving-coating method for carbon black-coated conductive fiber was introduced, and it was compared with the traditional coating method. The traditional coating method is to coat fiber with carbon black particles using adhesive molecules (polyurethane) and solvent of adhesive. The dissolving-coating method is to coat fiber with carbon black particles using fiber solvent. Carbon black particles are

saturated into layers of fiber swollen by solvent and then the solvent is removed. Polycaprolactam (PA6) fibers are used as fiber substrate and formic acid is used as solvent. In a washing test, volume resistivity of CB-coated PA6 fibers by the dissolving-coating method showed no significant change (before washing: $4.94 \times 10^0 \Omega \text{ cm}$, after 50 washings: $8.36 \times 10^0 \Omega \text{ cm}$ stable), but volume resistivity of CB-coated PA6 fibers by the traditional coating method showed a significant increase (before washing: $1.20 \times 10^1 \Omega \text{ cm}$ after 50 washings: $3.58 \times 10^8 \Omega \text{ cm}$). For CB-coated PA6 fibers by the dissolving-coating method, electric resistance presented a linear increase in strain below 35% and a nonlinear increase in strain above 35%. For CB-coated PA6 fibers by the traditional coating method, electric resistance presented a gentle increase in strain below 15% and a nonlinear and rapid increase in strain above 15% as a result of a break in the conductive coating. It was observed in SEM photographs that the coating durability of CB-coated PA6 fibers by the dissolving-coating method is better than CB-coated PA6 fibers by the traditional coating method. (Jin et al.)

PPy (polypyrrole, a π -electron conjugated conducting polymer)-based strain sensor was integrated by coating the fabrics with a thin layer of PPy. The gauge factor of PPy-based strain sensor is -13 and error signal is about 3%. The gauge factor is a negative value and is similar to nickel. PPy-based strain sensor has a high gauge factor, but response time is long. CFR (Carbon-filled rubber)-based strain sensor was made by printing the mixture of rubber and carbon. The CFR-based strain sensor has a gauge factor of 2.5 and 2.5% error signal. Both the PPy-based sensor and CFR-based sensor

show different values between stretching and restoration in electric resistance upon strain (Federico Lorussi et al.).

Scilingo et al. presented the properties of Polypyrrole (PPy) coated fabrics for strain-sensing. Electric resistance of the PPy fabric sensor having an initial electric resistance 0.9kΩ/cm was measured for 60 days to verify its sensor aging property. A linear increase tendency in electric resistance was observed over time. In order to know the effect of temperature, electric resistance of the PPy fabric sensor was measured in temperatures of 10~50°C. The value of the temperature coefficient of resistance (TCR) was -0.018 °C⁻¹. Temperature did not have a significant effect on the resistance of the PPy strain sensor (Scilingo et al.).

$$TCR = \frac{(R_t - R_{t_0}) / R_{t_0}}{(T - T_0)} \quad (2)$$

where R_t is the resistance at temperature T ; R_{t_0} is the resistance at reference temperature T_0 . (Scilingo et al.) pg. no. 462.

Li et al. investigated the method to acquire high strain sensitivity and good environmental stability for PPy-coated strain sensor. They used the chemical vapor deposition method to acquire a thin PPy coating on the Tactal(83%)/Lycra(17%) fabrics. PPy-coated fabric obtained by a chemical vapor deposition process presented an improved strain sensitivity of 80 for a deformation of 50%, compared to a strain sensitivity of 6 when PPy-coated fabric was obtained by solution polymerization. Scanning microscopy(SEM) photography showed that PPy-coated fabrics obtained by the

chemical vapor deposition process at a low temperature(-26°C) have a smooth surface which, along with density, has been shown to improve stability. Li et al. showed that annealing of the PPy-coated fabrics improves strain sensitivity and stability. They propose that the inclusion of dodecyl benzene sulfonate anions will improve the stability of the PPy-coated strain sensors.(Li et al.)

$$\text{Strain sensitivity} = \frac{\Delta R}{\epsilon R_0} \quad (3)$$

where ΔR is the resistance change of the fabric under extension; ϵ is the deformation; R_0 is the original resistance. (Li et al.) pg. no. 90.

Gibbs and Asada developed a wearable joint monitoring device using strain sensors. They applied conductive fiber sensors to a knee support for measuring the single-axis joint angle of a knee. They used the principle that when a joint moves, electric resistance of conductive fibers fitted to the skin changes according to its skin extension and restoration. Silver plated nylon having electric resistance values less than $10\Omega/\text{cm}$ for a 100-denier fiber was used as sensor fibers. Sensor fibers were placed across a knee joint along the length and were connected with elastic cord helping the relaxing and expanding of the conductive fibers. Testing conductive fibers in three different positions on the knee, they showed how the electric resistance changed in response to the joint angle acquired which was measured by a rotary potentiometer goniometer. Electric resistance changes in the conductive fibers caused by joint movement showed fairly linear relationships with joint angles. They conducted modeling of the knee joint applying the extended Kalman

filtering for a one-time calibration which will correct subsequent sensor misplacement (P. Gibbs and H. H. Asada).

For rehabilitation purposes, Gibbs and Asada developed wearable conductive fiber sensors for multi-axis joint angle measurement for continuous monitoring of joint motion. They applied the conductive fiber sensors to skin-tight pants for measuring the joint angles of the lower body. Silver plated nylon 66 yarn having an impedance of approximately $3.6\Omega/\text{cm}$ was used as the sensor. They formulated an automated registration algorithm considering a sensitivity shift and arrangement of sensors. They showed that the quadratic predictor is better than the linear predictor through comparing the results of goniometer output, linear model estimation and quadratic model estimation in a single-axis knee joint angle. Sensing output errors caused by repetitive dressing and undressing of the sensing garment were observed. Sensors monitored the movement of a double axis hip joint. There was no significant difference between the quadratic predictor and the linear predictor for the output in the double axis hip joint (P. T. Gibbs and H. H. Asada).

Tognetti et al. used conductive elastomer composites having piezoresistive properties upon deformation for strain sensing. Lycra® fabric with an adhesive mask was coated with conductive elastomer composites material. When the mask is removed, the sensor remains in the shape of the mask. The fabric is then treated in an oven at a temperature of about 130°C for 10 minutes to speed up the cross-linking procedure. The strain sensor has a gauge factor of 2.8. When the sensor registered the strain, electric resistance increased

rapidly and decreased gently after the peak point. Electric resistance showed a small leap and slow decrease at restoration of the length (Tognetti et al.; F. Lorussi et al.)

Farrington et al. integrated knitted stretch sensors on a jacket in order to measure upper arm and body movement and posture. The sensor shows increasing electric resistance as it is stretched. Knitted sensors are placed at the elbow, on top of the shoulder, at the armpit, on the upper back etc. A connections terminal on the jacket can be attached to other wearable devices providing data concerning limb movement and body position. (Farrington et al.)

2.4 Role of computer-aided technical design

2.4.1 Needs of computer-aided technical design

Body size and shape varies according to the individual. Even though some people have the same bust size, their circumference of waist and hip might differ. Even if they have the same measurement in the specific parts of the body, the flat degree and the sectional cross area may be different. The obese and seniors especially show different body shapes as compared to general body types. However, the conventional pattern making system is based on regression formulas indicating the average relationship between measurements and bust circumference (Yunchu and Weiyuan). Therefore, mass production that maintains the conventional pattern system cannot satisfy customers' fit expectations. Satisfaction of consumer can be dependent on their fit preferences such as loose fit, relaxed fit, and slim fit or on use of the garment such as outdoor activity and indoor activity. In the case of on-line purchases, problems with fit occur at a high rate because customers cannot try on clothes. In the case of structured suits or tight-fitting

garments especially, pattern fit is a critical factor of evaluation. A two dimensional (2D) pattern generation system reflecting the curved surface information of a body by using individual 3 dimensional (3D) body scan data could be a solution to the problem.

After a technical designer generates garment patterns according to the design, samples are manufactured in order to identify the real shape of the garments in space and the final pattern is obtained by correcting faults. Such processes consume much time and cost. If it were possible to simulate 2D into patterns for a 3D garment, it would be a useful system. Connections between such simulation systems and current pattern computer-aided design (CAD) systems might be useful for technical design. Such systems can also be applied to a customized design system in which customers select design components by means of a database.

OptiTex offers 3D Runway Suite of Tools software integrating the 2D flat pattern and 3D virtual realistic clothing simulation. Pattern designers can see 3D shapes draped of 2D flat patterns on the body model. OptiTex software provides a function of transformation of 3D surface of garment into 2D flat patterns ("Optitex").



Figure 10. OptiTex offers 3D Runway Suite of Tools.

Source: Optitex, 2009

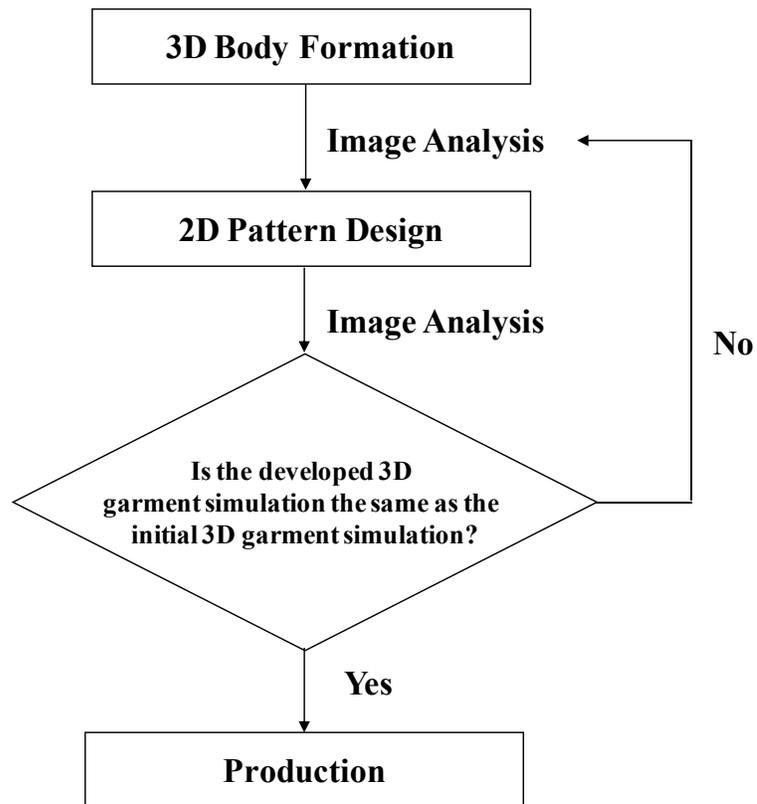


Figure 11. Computer-aided manufacturing (CAM) process (developed by J. H. Park).

A 3D virtual individual body model is required in order to create patterns from body scan data. Cho *et al.* (2005) created a 3D ‘interactive body model’ in which lengths and perimeters are adjusted according to individual body size (Youngsook Cho et al.). Some researchers utilized only linear data from the 3D scan data to construct patterns (Chan, Fan and Yu; Griffey and Ashdown). Others used a mesh method in which triangular and quadrilateral mesh are used to flatten 3D surfaces onto a plane (Choi et al.; Daanen and Hong; Jeong, Hong and Kim; Kang and Kim; Kim and Park; Kim and Kang). S. M. Kim & Kang (2002) developed a ‘body model’ and a ‘garment model’, modifying the garment model on the body model by means of convex hull generation and multi-resolution. They proposed a projection algorithm based on the ‘strain minimization technique’ (Kim and Kang). Jeong *et al* (2006) utilized Garland’s method of triangle simplification for pattern design of tight-fitting garments of stretch fabric (Jeong, Hong and Kim). Kim & Park (2007) introduced ‘the fit zone’ and ‘the fashion zone’ and showed various style variations using ‘the fashion zone’ which is modified by shape parameters and is combined with the fit zone (Kim and Park). Yunchu & Weiyuan (2007) showed geometrical transformation of 3D surface into 2D pattern through constructing a 3D wireframe (Yunchu and Weiyuan). Sul & Kang (2006) developed a ‘virtual scissoring method’ by NURBS cutting curve and a mesh cutting algorithm imitating draping techniques (Sul and Kang). Cho et al. also brought draping techniques into their method in which shearing behavior of woven fabric was considered (Youngsook Cho et al.).

We focus on technical CAD systems in today’s use. In 3D to 2D technology, virtual body surface generation is required. 3D body scan data, B-Spline curve, and convex hull

are used for body formation. The uniform mesh type such as quadrilateral mesh and triangular mesh and triangulation will be explained. In the image analysis sections, various flattening systems and virtual draping systems will be mainly dealt with. Accuracy is described in the evaluation section.

Table 7. 3D to 2D technology for computer-aided technical design (developed by J.H. Park)

3D Body Formation	Virtual Body Surface Generation 3D Body Scan Data B-Spline Curve Convex Hull
Image Analysis	Meshing Uniform Mesh Triangulation
	Flattening System Dart Generation Algorithm Wireframe Transform
	Draping System Virtual Scissoring Method Geometric Draping Modeling
Evaluation	Accuracy of Fit

2.4.2 Body generation

Cho et al. developed ‘virtual interactive body model’. They made a body model made of ‘cross-sectional lines’ at regularly spaced intervals from scan data of a dress form. They determined 9 perimeter parameters such as bust, waist, and hip and 3 length parameters such as bodice length in the body model. Therefore, if parameter values are

input into the body model, the body model is modified according to the individual body size. However, this method cannot represent each body curve shape because only perimeters and lengths are controlled, but body shape may follow the standard body shape (Youngsook Cho et al.).

Kang & Kim (2000); Kim & Kang (2002) adopted the way to create ‘body model’ and ‘garment model’. After appropriate sorting of points obtained from 3D body scanner for data reduction or obtaining data from a sliding gauge, they developed the body model composed of cross-sectional points in the cylindrical coordinate system. Landmarks such as neck points, shoulder points, and armhole points of the body model which are located at the maximum, minimum, or extreme points and maximum curvature are determined using the Fourier series expansion. Because garments usually do not follow complex body surfaces directly or cover the body smoothly, they generated the garment model into convex shape using a general dress form by stereoscopy. The body model and the garment model are matched and the garment model shape is transformed into a convex shape covering the body model (Kang and Kim; Kim and Kang) .

Kim & Park (2007) offered the way to divide ‘fit zone’ and ‘fashion zone’. ‘Fit zone’ means the parts fitting closely to the body shape such as the upper part of bodice’s bust level and the upper part of skirt’s hip level. ‘Fit zone’ is acquired by mapping surface of a dress form and is expressed as B-Spline surface. To easily acquire the ‘fit zones’ without a complicated formation process from each body scan data, the method to adjust parameters, such as key lengths and angles, in the initial ‘fit zone’ is used . ‘Fashion zone’ indicates the changeable parts according to various garment design. ‘Fashion

zones' also can be deformed using 'shape parameters' such as lengths, widths, and the number of folds. 'Fit zone' and 'fashion zone' are joined in order to compose the entire shape of the garment (Kim and Park).

2.4.3 Mesh generation

To transform three dimensional surfaces into two dimensional flat patterns, a mesh generation method is generally adopted. The surface is divided as small pieces in space and the pieces are recombined on a plane. Two primary mesh generation methods have been used. In the pre-partition method, the surface is first separated into several zones by specified lines (center line, bust circumference line, princess line, and shoulder line etc) and then each section is divided into tiny pieces (Choi et al.; Kang and Kim). In the other method, the surface is entirely divided into small pieces (Kim and Kang). Of these two methods, the former does not create darts, and the latter generally does create darts during the flattening process. In the pre-partition case, dividing lines can be used as dart lines (Kang and Kim) or design lines such as a princess line and a yoke line.

Uniform mesh generation methods keep the size and arrangement of meshes constant. That is, the width and height of zones are separated at regular intervals (Choi et al.) and such processes generate quadrilateral elements or triangular elements taken diagonally from rectangles. The structure which is well aligned horizontally and vertically is related to the mesh size control (Kim and Kang). It is important to decide the optimum size of elements in that the high grid resolution has a tendency to create many darts despite its detail expression (Kim and Kang). Multiple darts is inappropriate not only for typical garment patterns but also for sewing production (Kang and Kim).

Triangulation is a method used to create meshes with points from 3D scan data and to consider curvature. That is, large meshes are generated in low curvature surfaces and comparatively small meshes are generated in high curved surfaces (Daanen and Hong). The more triangles there are, the more detailed expression there is. However, since it takes a long time to deal with data in the case of many triangles, it is important to decide the optimum size of triangles to hold shape well and to have minimum of data. The Garland simplification method makes it possible to reduce the number of triangles without strong deformation (Jeong, Hong and Kim).

2.4.4 Flattening system

Each mesh element undergoes deformation during the flattening process from three dimensional surfaces into a two dimensional plane. Because the degree of deformation is related to accuracy, the key point is how to minimize deformation in the flattening process. Kang & Kim (2000) presented a pattern projection method considering the elastic and shear properties of the fabric. To minimize deformation of mesh structure obtained by projecting, the lengths of the quadrilateral mesh elements are adjusted. If the differences in the lengths and angles of quadrilateral elements between 3D and 2D as calculated in Equations (4) and (5) reach the specified elastic allowance and the shear allowance, the adjusting process of lengths is stopped (Kang and Kim).

$$A_{Modulus} = 100 \times \sum_{i=1}^N \sum_{j=1}^4 \frac{|L_{ij}^{2D} - L_{ij}^{3D}|}{L_{ij}^{2D}} (\%) \quad (4)$$

$$A_{Shear} = 100 \times \sum_{i=1}^N \sum_{j=1}^4 \frac{|\theta_{ij}^{2D} - \theta_{ij}^{3D}|}{\theta_{ij}^{2D}} (\%) \quad (5)$$

where N is the number of elements; L_{ij} is the length of j^{th} side on i^{th} element; Y_{ij} is the size of j^{th} angle on i^{th} element. (Kang and Kim) pg. no. 251

Kim & Kang (2002) introduced a dart generation algorithm using triangular elements derived from uniform rectangles split diagonally. Triangles are more determinative than rectangles because shape can be determined with merely three lengths. Therefore, when using a triangular structure, it is possible to reduce the number of control factors considered in order to develop an algorithm and to make an uncomplicated algorithm. When triangular elements are combined one by one, the subsequent element is forced to attach to neighboring elements until the difference between angles before and after distortion does not exceed the predefined shear tolerance value. If the angle difference exceeds the tolerance, a dart is formed by detaching elements (Figure 12). This algorithm creates darts in the perpendicular direction with boundary lines of the pattern and shows a tendency to have a smaller number of darts with larger shear angle allowance (Kim and Kang). Kim & Park (2007) compared patterns having user-defined darts with patterns having automatic darts. They showed that the former is more practical and more suitable than the latter (Kim and Park).

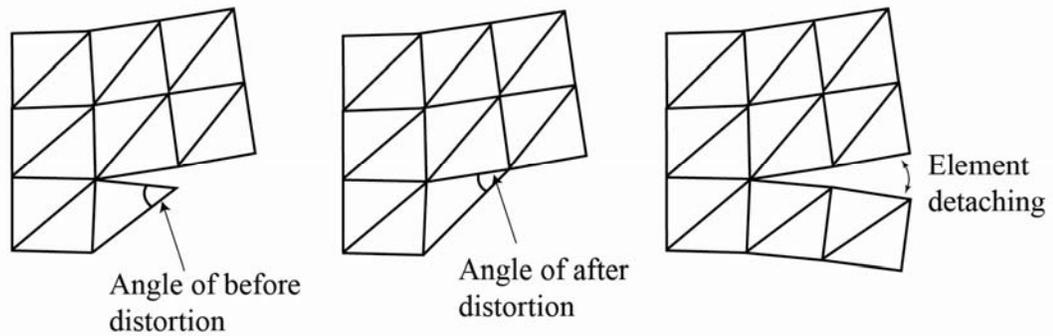


Figure 12. Dart generation algorithm.

Source : Garment Pattern Generation from Body Scan Data. Kim, Sung Min, and Tae Jin

Kang. *Computer-Aided Design* 35, 2002, pg. no. 616

In the case of triangulation, there are flat triangles which are different from curved triangles requiring the flattening process in the uniform mesh structure. Therefore, triangles are separately reflected on the plane with their original shape and connecting lines between triangles and then triangles are combined by application software. A gap and an overlap exist between triangles in a merged pattern owing to the three-dimensional shape (Jeong, Hong and Kim).

Yunchu & Weiyuan (2007) developed a geometric flattening method using a three dimensional wireframe tool. First, the half bodice of the 3D body surface is divided into 10 zones in space according to the geometric features of the surface, referencing a structure of pattern prototype developed by Japanese Bunka Women's University. In order to transform the 3D surface into a 2D pattern, each zone was subdivided horizontally or vertically, mainly in a longish quadrilateral shape (Figure 13). The 3D

wireframe which is composed of such structural lines is transformed into a 2D pattern by geometric means. Controlling direction and position of specific outer lines such as the center front line, center back line, and bust circumference line, each quadrilateral element is flattened in regular sequence. In the case of a quadrilateral, if the positions of two neighboring lines are determined, the intersection of arcs drawn by the two remaining lines becomes the final point of quadrilateral (Figure 13). Using the above rule, the final 2D flat pattern having similar structure to a conventional pattern prototype is obtained. This method has the possibility of application to various styles of garments due to such pattern construction (Yunchu and Weiyuan).

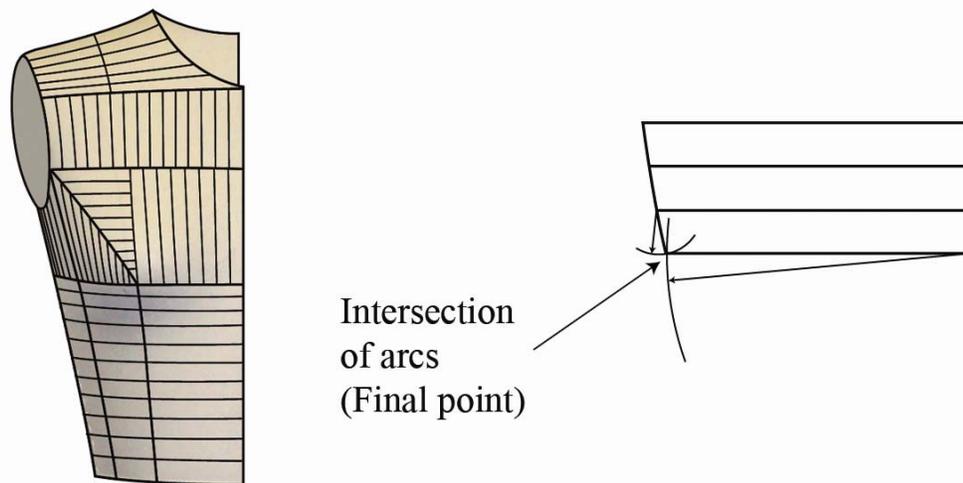


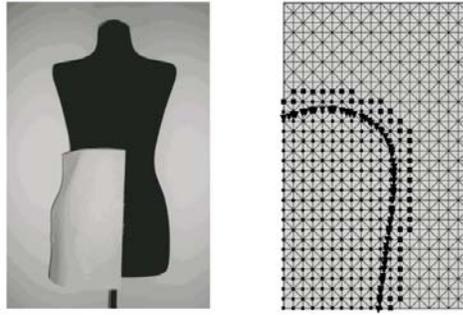
Figure 13. 3D wireframe and the principles of geometric transformation.

Source: Prototype Garment Pattern Flattening Based on Individual 3d Virtual Dummy.

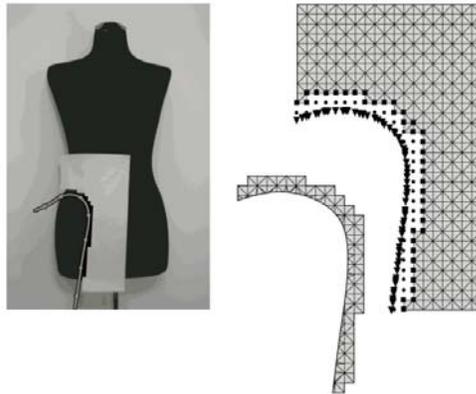
Yunchu, Yang, and Zhang Weiyuan, International Journal of Clothing Science and Technology 19.5, 2007, pg. no. 343~344

2.4.5 Virtual draping system

Sul & Kang (2006) developed a virtual scissoring method imitating the draping technique, directly modeling garment shape on a dress form with pinning and cutting fabric. They constructed 3D triangular meshes. The 3D mesh is reflected on the 2D image surface and cutting lines are drawn on the 2D image plane showing the 3D mesh at the same time. Cutting lines such as dart lines, necklines, and hemlines are drawn on the fabric by NURBS curves obtained by connecting points located by mouse clicks. Fabric is cut according to cutting lines by detaching, deleting and recombining meshes associated with a cutting line. Intersection points of meshes and cutting lines are basic reference points for the cutting process. Since the 2D mesh and the 3D cloth mesh are transformed at the same time, the virtual scissoring method doesn't require a flattening process to generate patterns, as shown in Figure 14. Sul & Kang (2006) also developed a mesh adding technique which is to add and connect a new mesh at the edge of an existing mesh. Fabric cannot be expanded or created in real draping, but fabric can be inserted in virtual draping by changing design lines. A new mesh's node coordinates are estimated by surrounding meshes. A pinning technique is used to fix fabric at a specific position and to prevent dropping of the fabric piece. Sul & Kang (2006) demonstrated the generation of garment patterns by using the previous methods. A bodice pattern with underarm darts and waist darts acquired by pinning and cutting lines and pattern pieces are virtually sewn together. Texture mapping is shown, and it also allows users to predict final garment appearance closely (Sul and Kang).



(a) Initial 3D mesh and 2D mesh



(b) Detaching and deleting of mesh

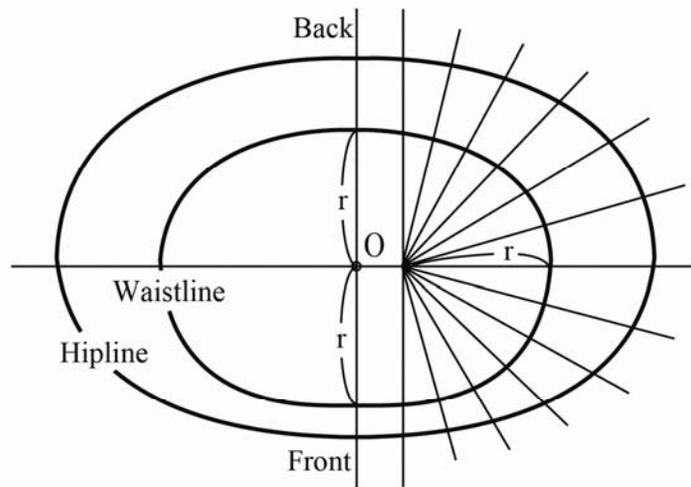


(c) Recombined mesh

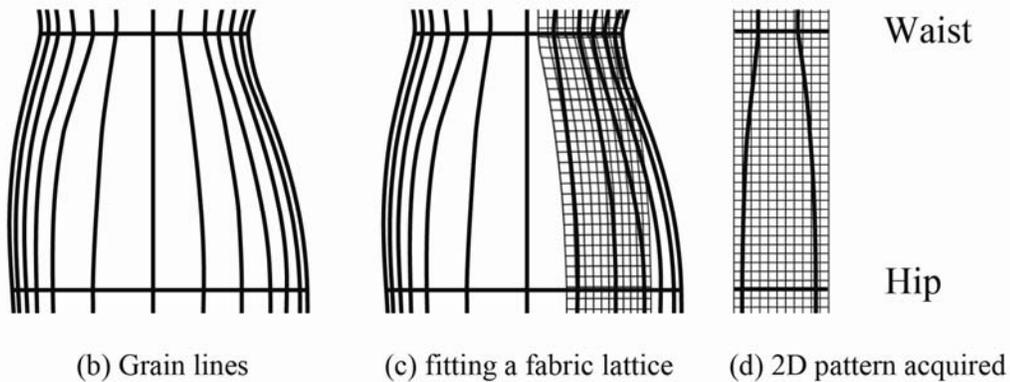
Figure 14. 3D mesh cutting algorithm.

Source: Interactive Garment Pattern Design Using Virtual Scissoring Method. Sul, In Hwan, and Tae Jin Kang. International Journal of Clothing Science and Technology 18.1, 2006, 31-42. pg.no. 36

Cho et al. also presented a CAD pattern making method using draping principles and tight skirt patterns acquired. First, the 3D curved surface of a dress form is prepared with triangular patches, and grain lines are drawn on the 3D surface to match with grain lines of fabric as in draping. Cross-sections of waist and hip levels are superimposed and grain lines are placed at 15° intervals. Grain lines become dividing lines of 3D surfaces, and grain lines can be applied to design lines or dart lines. Therefore, allocating some grain lines in high curvature to dart lines, they fitted a fabric lattice on the 3D surface while considering fabric shear angle. For example, if the shear angle is 64°, the fitting process proceeds only until a threshold of 64 degrees. The fabric lattice is cut according to reference lines of 3D surface and is spread on the 2D plane keeping the lattice at right angles, as shown Figure 15. (Youngsook Cho et al.).



(a) Cross sections of waist and hip levels



(b) Grain lines

(c) fitting a fabric lattice

(d) 2D pattern acquired

Figure 15. Geometric draping modeling process.

Source: Individual Pattern Making Using Computerized Draping Method for Clothing.

Cho, Youngsook , et al. Textile Research Journal 76.8, 2006, 646-54.

2.4.6 Accuracy of fit

To verify a pattern generation method reflecting 3 dimensional data, researchers use various ways that comparing lengths and areas, analysis of the space between clothing and body, analysis of virtual fit and self sensory-test. Jeong et al. compared areas of 2D pattern pieces developed from 3D data with original areas of 3D manikin and also showed differences in lengths of significant parts of a garment between the 2D pattern and 3D manikin (Jeong, Hong and Kim). Choi et al. analyzed the space between clothing manufactured by 3 dimensional data and body form. The pictures from the 3D scanner indicated the amount of space between clothing and body form by variation of color, and the silhouette of vertical sections also indicated the fit of clothing (Choi et al.). Daanen & Hong (2008) virtually sewed their made-to-measure patterns and showed virtual try-on images that illustrate strain, ease amount, and relative pressure in order to evaluate fit (Daanen and Hong). Jeong et al. conducted self sensory-test indicating satisfaction of fit by numerical value about their tight-fitting garments by a participant after wearing for five days. However, it is difficult to present objective results in the case of too few participants (Jeong, Hong and Kim).

2.5 Summary of literature review

Overweight and obesity justify the development of BMSA. The overweight and obesity are continuously increasing, so that related health problems and costs are also increasing. Since waist circumference is associated with BMI and abdominal fat, it is a

useful health indicator for obesity. Therefore, self-monitoring on waist circumference using BMSA may lead people to manage weight successfully.

The current status and potential of smart healthcare clothing were reviewed in previous sections. Smart healthcare clothing monitoring vital signs have been developed by researchers, and it mainly consists of three parts: sensor, transaction, and display. The demands of smart healthcare clothing are continuously increasing, but it is hard to find studies on obesity related to smart healthcare clothing or waist circumference monitoring. Therefore, the investigation which is related on smart healthcare clothing provides valuable data for developing prototype of BMSA.

The textile sensors technology applied to strain gauges was reviewed to obtain technical background knowledge for developing the elastic strain gauge of BMSA. Traditionally carbon black based strain sensors, PPy-based strain sensors, and silver plated nylon sensors have been used for development of an elastic strain gauge. Sensors were applied to a garment to recognize and monitor body posture and joint movement. In this research the carbon black-based strain sensor and melt process have been adopted to develop an elastic strain gauge.

In order to discover a potential production process for a BMSA and to develop a well-fitting BMSA, current automatic computer-aided technical design technology was reviewed. Various techniques such as meshing, flattening, and virtual draping were used for transformation from 3D surface to 2D flat patterns. Computer-aided technical design technology can be a useful and efficient tool for designing the BMSA.

Furthermore, the development of the optimum BMSA system needs to be verified for accuracy.

3 METHODOLOGY

3.1 Design of research

The major objective of this research is to design Body Monitoring Smart Apparel (BMSA) for the overweight which measures changes in body circumference and informs the users with relevant data. Figure 16 presents the methodology for this research which has been developed to create a textile sensor and prototype of BMSA monitoring waist circumference for weight management.

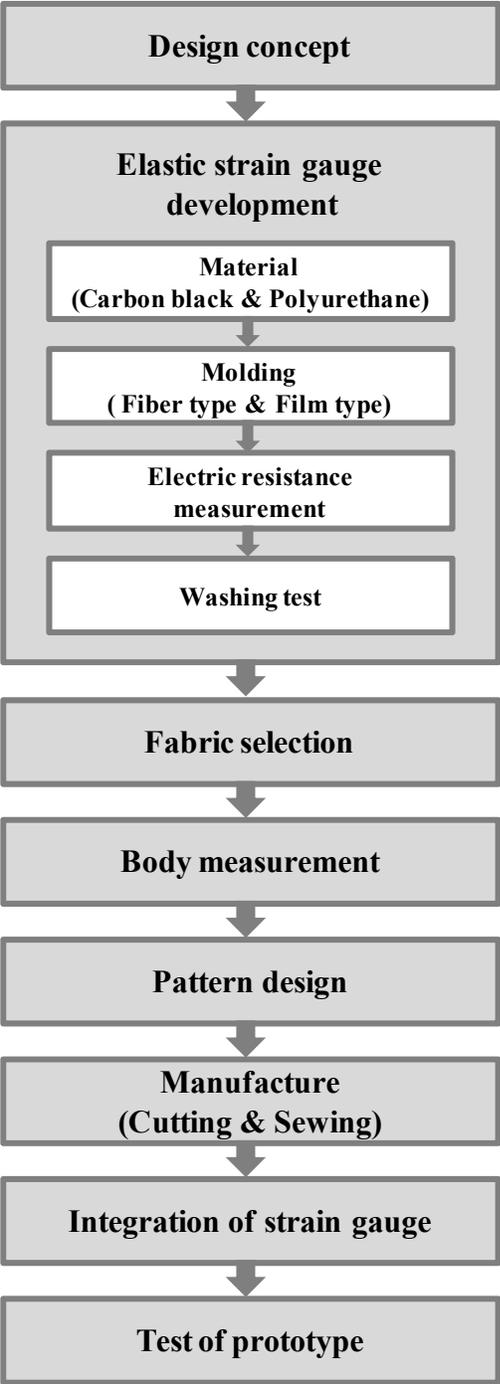


Figure 16. Process of BMSA prototype development (adapted from (McCann, Hurford and Martin).

The design concept of BMSA includes the garment design and the positioning of technical devices on the garment. A textile sensor, which is called ‘elastic strain gauge’ in this research, was developed using carbon black and polyurethane, and its performance was tested by measuring the electric resistance. Cotton/spandex jersey knit fabric was selected for the BMSA prototype. Body measurements of the dress form were extracted using a 3D body scanner, and patterns were generated using CAD. Fabric was automatically cut using CAM and garment was constructed by sewing. After strain gauge was integrated in the prototype, BMSA prototype was tested on the dress form.

3.2 Design concept of BMSA

A design concept of smart apparel for the overweight was proposed with consideration of components such as technical devices and garment design. In this case, BMSA is defined as clothing monitoring the change of body circumference. It consists of a textile sensor to measure body circumference, a wireless transmission device for convenient data transfer, a display to provide information, and batteries supplying power and secondary functional devices such as an accelerometer, Radio Frequency Identification (RFID) and Global Positioning System (GPS). Elastic strain gauges were made as the textile sensor was horizontally placed on the important body parts.

3.3 BMSA selections

In order to measure the body circumference correctly, the garment needs to fit closely on the body. Therefore, customized patterns for individuals are good for fitting the garment. However, current technology to make these customized patterns has low

efficiency compared to cost. Therefore, a way to select body types in the shape categories of torso, arms and legs was proposed as a workable solution. The users can be fitted using not only their size, but also their body type and garment preference. The way to create patterns for each different torso type was described.

3.4 Development of textile sensor

Two types of elastic strain gauges were developed for use as textile sensors. Carbon black was used for conductivity and polyurethane was used for elasticity which allows for body circumference changes. An elastic strain gauge of fiber type was produced using Hakke MiniLab having the twin screw, and an elastic strain gauge of film type was produced using a heat pressure machine.

3.4.1 Materials

3.4.1.1 Carbon black

Carbon black, furnace black, with the density 1.7-1.9g/cm³ was supplied by Cabot Corporation.

3.4.1.2 Polyurethane

Pellethane® 2355-80AE polyurethane elastomer provided by Dow Chemical is polyester polyadipate based thermoplastic polyurethane elastomer. It offers 'memory' and elasticity and blends easily with other thermoplastic resins. **Table 8** shows its properties.

Table 8. Properties of Pellethane® 2355-80AE polyurethane elastomer

Property	
Melt temperature	193-204°C (379-399°F)
Density	1.18 g/cc

Melt Flow	7.00 g/ 10min
Elongation at break	550%

3.4.2 *Molding elastic strain gauge*

3.4.2.1 *Compounding and Extrusion using Hakke MiniLab*

Carbon black powders and polyurethane pellets were mixed using the Hakke MiniLab ("Thermo Scientific "). 90wt% polyurethane (6.25g) and 10wt% carbon black (0.75g) were loaded on the Hakke MiniLab having 7cc capacity of volume. (See Figure 17 and Figure 18) twin screws were rotated for 10 minutes with a rotating speed of 100 rpm at a temperature of 200°C for good dispersion of carbon black powders in polyurethane elastomer. Polymer composite was extruded through a 2mm cylindrical die in order to acquire carbon black polyurethane composite fiber.

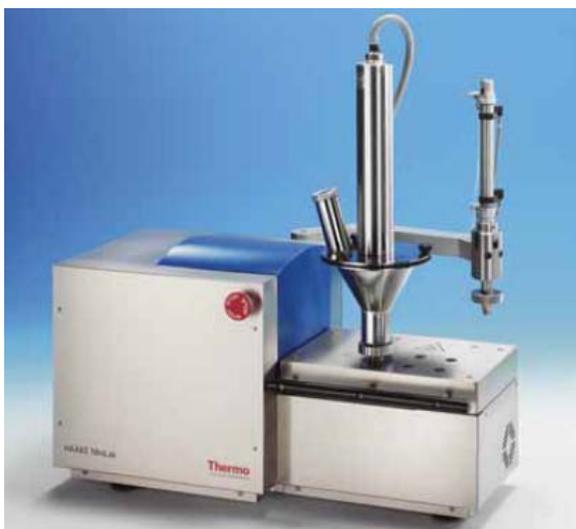


Figure 17. Hakke Minilab.

Source: Thermo Scientific. 2009



Figure 18. Twin screws of MiniLab.

Source: Thermo Scientific. 2009

3.4.2.2 Heat Pressing

Carbon black powders and polyurethane pellets cut into tiny pieces were pre-mixed by hand. 50wt%, 40wt%, 30wt%, 20wt% and 10wt% carbon black concentrations were tried, but films were easily broken at more than 20wt% and showed low conductivity at 10wt%. Thus, carbon black concentration used was 15wt%. The mixture was pressed between Teflon® sheets of 0.05 inch thickness under 1500 lbs of pressure at a temperature of 200°C for 15 minutes in order to acquire a film consisting of carbon black and polyurethane using a heat pressure machine in Figure 19.



Figure 19. Heat pressure machine (taken by J. H. Park in the filament lab).

3.4.3 Test of elastic strain gauge

Film strain gauges were used for measurement of electric resistance, because a fiber strain gauge showed too weak signals.

3.4.3.1 Scanning Electron Microscopy (SEM)

The surface and cross-sectional area of the fiber strain gauge were examined with a scanning electron microscope (SEM), Hitachi S-3200N, operated at 5 kV and magnifications of 100x, 200x, 25000x, and 100000x. 4pi Revolution® software (4pi Analysis©) was used for image analysis of SEM pictures. The diameters were measured in scattered carbon black powders using this program.

3.4.3.2 Electric resistance

The electric resistance of strain gauge of 4 samples which have a length of 2cm, width of 0.25cm, and thickness of 0.04cm was measured. All measurements were performed with an EXTECH multimeter 420. Strain gauges were stretched to a strain of 2.5%, 5%, 7.5%, 10%, 12.5%, and 15%. Repetitive stretching and restoration of the strain gauge was conducted respectively for each strain. The electric resistance was measured using a multimeter for each strain. Measurements were repeated 5 times at each level of strain and at each subsequent relaxation. The waiting times at each strain measurement were about 15 seconds.

3.4.3.3 Washing test

Washing tests were conducted following AATCC test method 61-2006 test no.2A, using an AATCC Standard Instrument Atlas Launder-Ometer LEF®. One cycle in the Atlas Launder-Ometer LEF® is equivalent to home machine washing of five times, and it takes 45 minutes for each cycle. Twenty washings were conducted for the samples used in electric resistance measurements. The 1993 AATCC standard reference detergent WOB (without optical brightener) was used, and detergent was 0.15% in total liquor volume of 150 ml. Washing temperature was 49°C, and 50 steel balls were used for each sample container. (AATCC Test Method 61-2003, AATCC technical manual, 2005)

3.5 Manufacturing and testing of BMSA prototype

A prototype of smart apparel for the obese was manufactured in order to test the performance of the elastic strain gauge developed. The prototype of a leotard type

garment has the strain gauge in the waist, and it was connected to a multimeter. The prototype garment was fitted on a dress form, and an air package was used for simulation of change of body circumference in a dress form test. Body scanning was used for customized patterns. Patterns were designed in Gerber Accumark® Pattern Design System (PDS) with consideration of stretch ratio of chosen knit fabric, and fabric was automatically cut using Gerber Cutting Edge Cutter. After dressing the prototype on the dress form, the electric resistance of the elastic strain gauge was measured.

3.5.1 Construction of BMSA prototype

BMSA prototype was designed with the bodice and pant clothes connected as a leotard type with sleeves in order to place the elastic strain gauges at the consistent position in the waist. 95% Cotton/5% Spandex knit fabric was used. The elastic strain gauge was inserted in the waist which is the minimum circumference between the iliac crest and the lowest ribs (Lobstein, Baur and Uauy). The elastic strain gauge which is 60×12 (W×L in centimeters) is fixed on the inside by a running stitch using an elastic thread with fabric tape casing. A zipper opening was located in the center back for preventing damage of the elastic strain gauge due to stretching and for convenience of in putting on or taking off the clothing. The strain gauge was connected to a multimeter in order to measure electric resistance of it through a small hole around center back. An air package which is 1.5×22.5×3.5 (W×L×H in centimeters) was used for simulation of change of waist circumference fitted on a dress form. An air package has a rubber air

pump which allows inject air. A prototype was made to be fitted to the dress form of size 10 (Figure 20).

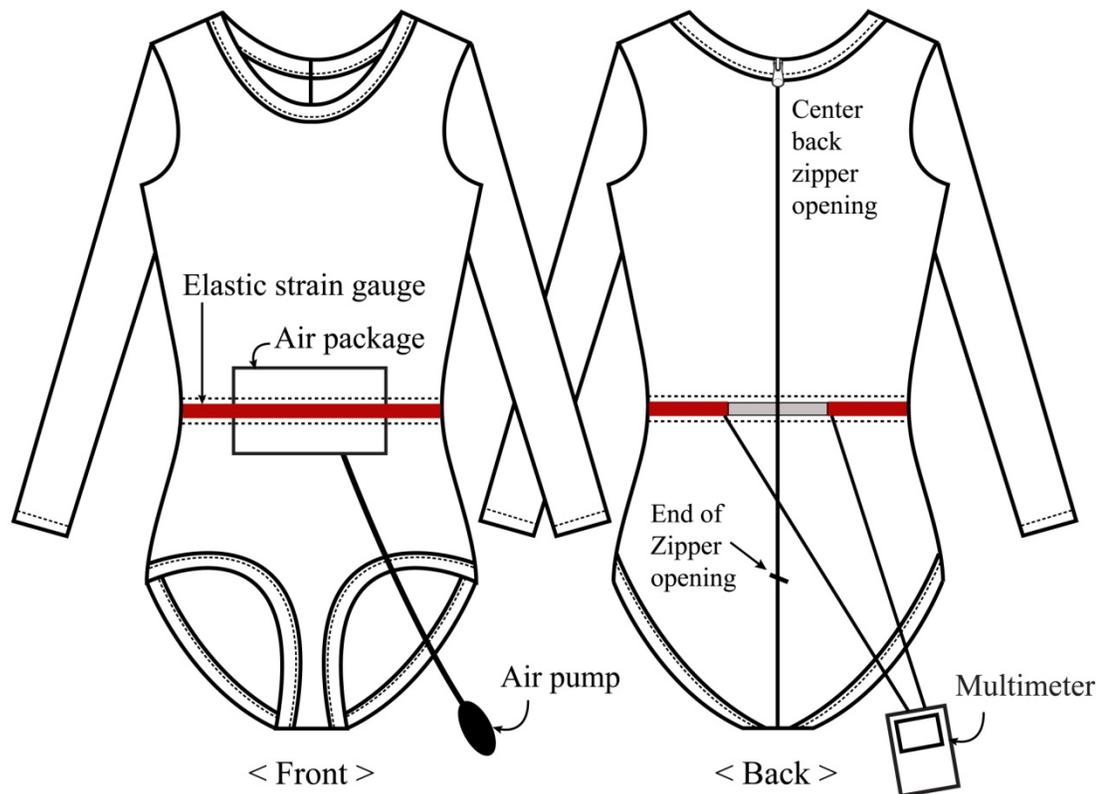


Figure 20. Prototype of DMSA.

3.5.2 Fabric selection

95% Cotton/5% spandex jersey knit fabric was used for a prototype of tight fitting apparel, taking in consideration moisture management. Cotton fabric is comfortable, and the subject's skin due to property absorbing water vapor skin does not become wet (Hatch). High elongation of spandex covers changes of the body and allows the body to move. Jersey knit, a type of weft knit, creates relatively lightweight fabric compared to

the fabrics constructed by other stitches, and Jersey knit fabric stretched more in the width than in the length. On the other hand, double-knit fabrics are generally firm, stable, wrinkle-resistant and durable and have similar drape to woven fabrics. Warp knit knits also have good stability. Warp knit fabrics do not ravel and more abrasion – resistance, as compared with weft knits (Corbman and Potter).

3.5.2.1 Direction of stretch of the fabric

One-way stretch knit fabric stretches only in one direction - across the material. Two-way stretch knit fabric stretches across the width as well as the length of the material. Four-way stretch knit fabric stretches across the fabric as well as lengthwise, and spandex/Lycra® added to the fibers before knitting supplies supplementary stretch. It returns to its original measurements after release (Richardson).

3.5.3 Ratio of reduction according to the stretch fabric types

Knit fabric is divided into stable knits, moderate knits, stretchy knits, super-stretch knits and two-way & four-way stretch knits according to range of possible stretch, as shown in table 9. A different reduction ratio of measurement for sloper drafting is applied for each type of knit. The reduction of measurements is only applied in skirts, pants, tops, dresses, and oversized tops for one-way stretch knits. The reduction ratio for these garments is the same for both super-stretch knits and two-way & four-way stretch knits. Ten percent reduction was applied in both directions - across and lengthwise - in catsuits, leotards, and bikini for two-way & four-way stretch knits (Richardson).

Table 9. Ratio of reduction according to the stretch fabric types

	Stable knits	Moderate knits	Stretchy knits	Super-stretch knits	Two-way & four-way stretch knits
Stretch range	18-25%	26-50%	51-75%	76-100%	100% in both directions
Amount of expansion	5" stretches to 6 ¼"	5" stretches to 7 ¼"	5" stretches to 8 ¾"	5" stretches to 10"	5" stretches to 10" in both directions
Reduction ratio for sloper drafting	0% smaller for across measurements	2% smaller for across measurements	3.5% smaller for across measurements	5% smaller for across measurements	10% smaller for both directions
Percentage of original measurement : Skirts, pants, top, dress, and oversized top	100%	98%	96.5%	95%	95% (Same as super-stretch)
Percentage of original measurement : Catsuits, leotard, and bikini	N/A	N/A	N/A	N/A	90% for both directions

Source: Designing and Patternmaking for Stretch Fabrics. Richardson, Keith. New York:

Fairchild Books, 2008. pg. no. 4 and pg. no. 75

Cotton/spandex knit fabric (jersey) for the prototype sample stretches 85% crosswise and 80% lengthwise. The fabric length comes back to its original measurement after release. Therefore, the knit fabric is regarded as four-way stretch fabric. However,

because it stretches only 80~85%, a 5% reduction in measurements was applied for both directions in order to create the leotard sloper.

3.5.4 *Body scanning of dress form*

A body scanner was used in order to acquire accurate measurements of the dress form and to make the garment fit well. One dress form was scanned by a NX-16 three dimensional body scanner of Textile Clothing Technology Corporation ([TC]²) in Figure 21. The key measurements were extracted and used for pattern design. Three-dimensional (3D) body scanners captured the outside surface without contact. Body scanning systems employ one or more light sources, one or more vision or capturing devices, software, computer systems and monitoring screens. Light-based and laser-based systems are major types of body scanning systems. A body scanner from [TC]² is a light-based system. ([TC]²; Simmons and Istook; Istook and Hwang)



Figure 21. NX-16 3D body scanner.

Source: [TC]², 2009

Table 10. Specifications of NX-16 3D body scanner

Scan time	8 sec
Scan volume	1.20.6×2.1 (W×D×H in meters)
Operation system	Windows XP, Vista
Data density	600,000-1 million points
Sensor	16 independent sensors, 4 angles at 4 heights
Data file format	BIN, RBD, OBJ, and VRML

Source: 3d Body Scanning Systems with Application to the Apparel Industry. Istook,

Cynthia L., and Su-Jeong Hwang. Journal of Fashion Marketing and Management 5.2

(2001): 120-32.

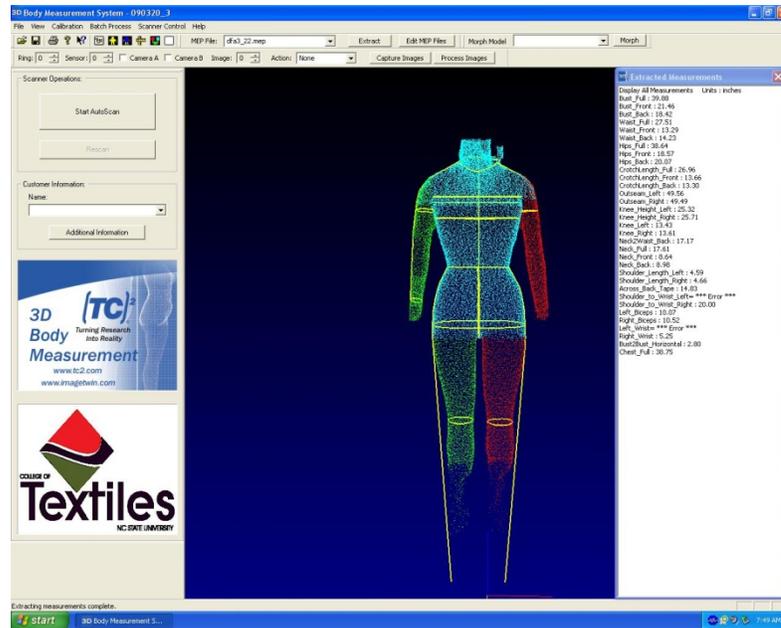


Figure 22. Extraction of body measurements (taken by J. H. Park with NCSU 3D body scanner).

3.5.5 List of measurements

Body measurements required for leotard sloper are shown in Table 11. Body measurements of a dress form were automatically acquired using the [TC]² 3D body scanner.

Table 11. Body measurements required for leotard sloper

Bust circumference	measure all the way around the fullest part of the chest
Waist circumference	measure around the smallest part of the waist
Hip circumference	measure around the widest part of the hip
Nape to waist	measure straight down from the nape, the point where the neck intersects with the center back
Neck circumference	measure around base of neck
Shoulder length	measure from the intersection point of the neck and shoulders to the intersection point of the shoulder and arms
Across back	measure between the two bones at the top of the armhole
Crotch length	measure from the crotch up to the waist level using an “L” square

Source: Designing and Patternmaking for Stretch Fabrics. Richardson, Keith. New York:

Fairchild Books, 2008.

Specific body measurements for pattern drafting were calculated and measurements were reduced to 95%, as shown in Table 12. However, reduction is not applied to shoulder pitch, neck, back neck, back neck rise, shoulder length, and across back (Richardson).

Table 12. Specific measurements of dress form for prototype

	Original measurement	95% of original measurement
(1) ¼ Bust circumference	9.848	9.355
(2) ¼ waist circumference	6.905	6.559
(3) ¼ Hip circumference	9.640	9.158
(4) Nape to waist	17.120	16.264
(5) Shoulder pitch= $1/11 \times$ Nape to waist	1.556	No reduction
(6) Neck	15.310	No reduction
(7) Back neck= $1/6 \times$ Neck	2.552	No reduction
(8) Back neck rise= $1/18 \times$ Neck	0.851	No reduction
(9) Shoulder length	5.110	No reduction
(10) ½ Across back	7.340	No reduction
(11) ½ Crotch length	27.01	25.660

3.5.6 Pattern Design using CAD

The pattern of smart apparel was developed using Gerber Technology's Accumark® Pattern Design System (PDS). Gerber Technology's PDS allows the user to create new patterns or transform existing ones to satisfy new designs. Functions such as darts, fullness, and pleats can be conducted in PDS. Seam allowances can be easily added to multiple patterns at once, and grading can be applied to patterns (Sharp and Elsasser). The system can remember the position of patterns on the workspace so that they are placed in the original position when recalled (Istook). The system allows the user to make facing and interfacing in a short time. Copying, tracing, shrinking and enlargement of the patterns can be conducted quickly. Notches, drill holes, and annotations can be simply added to the pattern pieces. Using PDS reduces the time required for pattern developments. Convenience of storage and modification and accuracy are other advantages of a Pattern Design system, computer-aided design (CAD) system. (Espinoza-Alvarado)

Fabric was assigned to each pattern piece created and the number of pieces to be cut was determined using Model Editor®. After creating the order for the maker using Order Editor®, the order was processed and the marker was created. Pattern pieces were placed on the fabric in Marker Making. Pattern pieces can be rotated and moved in order to determine optimum layout on the fabric. The maker was sent to cutter through Marker Plot®.

3.5.6.1 Drafting a leotard sloper

Figure 23 describes the process to develop leotard patterns (Armstrong; Richardson). The technical design method has been modified for this research. Raw data has been obtained from a 3D body scanner and the patterns have been developed using Gerber Accumark® PDS.

Back

- Draw a line AB, $AB=(4)$
- Divide a line AB in half to get a point C
- Draw horizontal lines at points A,B, and C
- Mark a point D, $AD=(7)$
- Draw a line DE, $DE=(8)$. Draw a back neck line A~E as illustrated.
- Mark a point F, $AF=(5)$. Draw a horizontal lines at a point F.
- Draw a line EG, $EG=(9)$. A point G is same level with a point F.
- Mark a point H, $CH=(10)$. Draw a vertical line HI at a point H.
- Mark a point J, $CJ=(1)$. Draw a armhole line G~J as illustrated.
- Mark a point K, $BK=(2)$. Draw a side seam JK.
- Draw a line BL, $BL=(11)$
- Draw a line LM, $LM=(3)$. Draw a vertical line MN at a point M.
- Divide a line MN into 3 equal parts and mark a point O. Draw a horizontal line at a point O.
- Draw a hip line K~O as illustrated.

- Divide line MN in half and mark a point P 1" above the point separating line MN.
Draw a horizontal line PQ at a point P.
- Mark a point R at intersection of a hip line KO and a line PQ.
- Mark a point S, LS=1 1/2". Draw a vertical line at point S.
- Draw line RS, mark point T, draw R~T~S.
- Draw center back line as illustrated considering the back body shape.

Front

- Copy of a back pattern
- Mark U, AU=1 1/2". Draw neck line E~U as illustrated.
- Move guideline IH for armhole line as much as 1/4" in center front direction.
- Draw armhole line as illustrated.
- Adjust a side seam line JK into a curve line as illustrated considering body shape.
- Divide a line RQ in half and mark a point V.
- Draw a curve line R~V~S as illustrated.

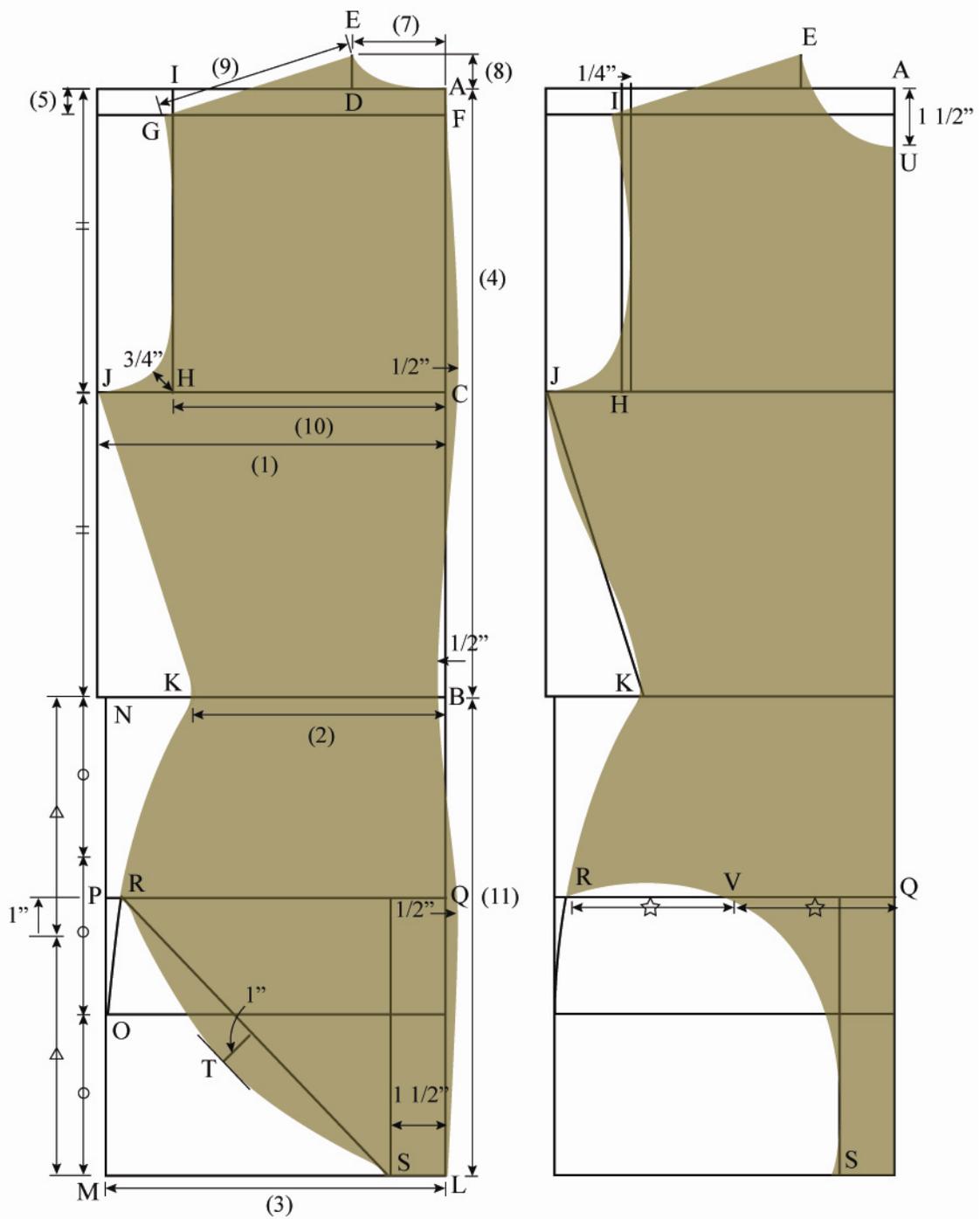


Figure 23. The way to draft a leotard sloper.

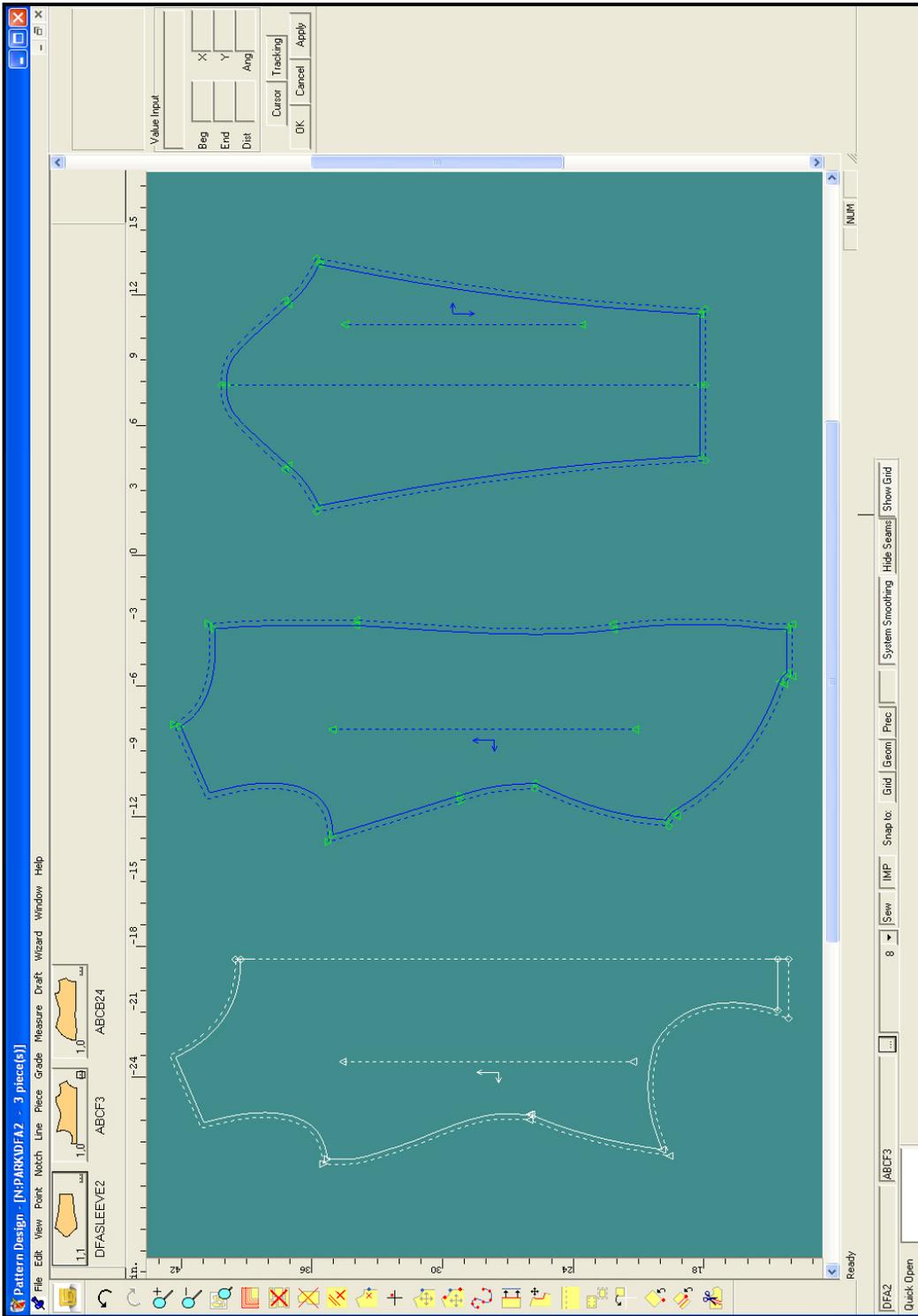


Figure 24. Gerber AccuMark CAD pattern.

3.5.7 CAM

Fabric for prototype garment was automatically cut according to the marker information using the Gerber Cutting Edge Cutter.

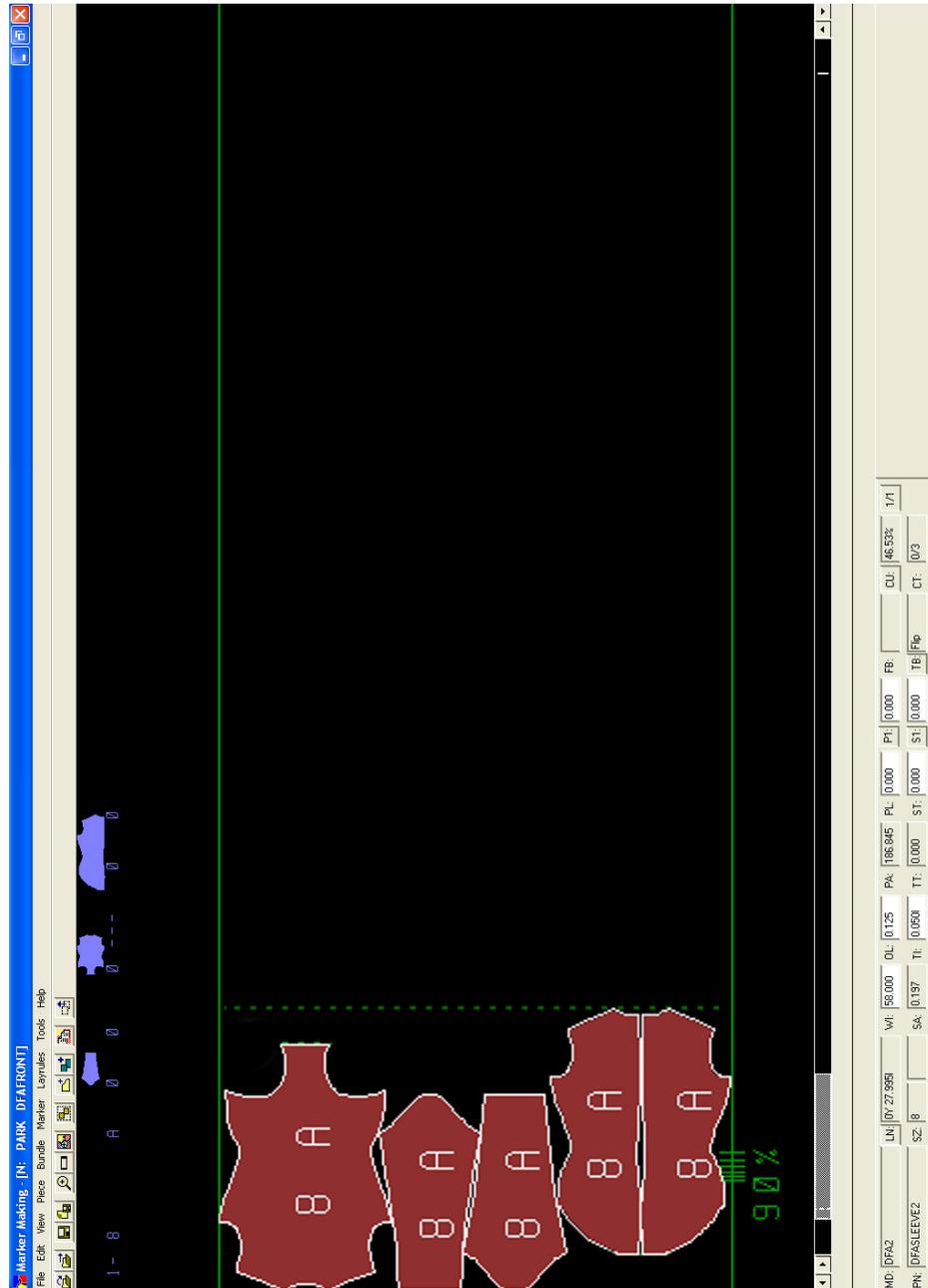


Figure 25. Gerber AccuMark maker.

3.5.8 Fixing strain gauge on the fabric

3.5.8.1 Casing

For prototype of this research, one strain gauge was fixed on the garment on the inside using fabric tape which covered the elastic strain gauge and protected it. The tape covering the gauge was fixed to the material using running stitches on both sides. Strain gauge was connected with non-stretchy tape in order to prevent the garment fabric between the both ends of the strain gauge to stretch (Figure 26).

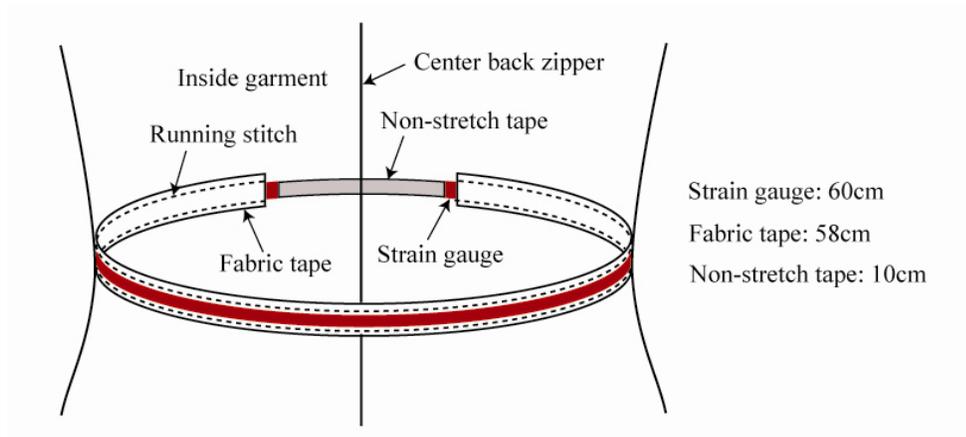


Figure 26. Casing.

3.5.8.2 Zigzag stitch

Another way to fix elastic strain gauge is sewing the strain gauge to the garment on the inside with zigzag stitches, as shown in the Figure 27. The strain gauge was positioned in the middle of zigzag stitches and the threads of stitches hold the strain gauge at the waist in the garment, but do not interfere with the stretch movement of the strain gauge.

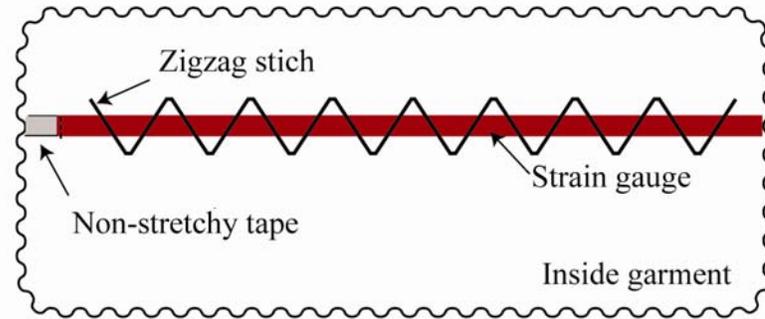


Figure 27. Zigzag stitch.

3.5.9 Dress form simulation

Five tests were conducted using single prototype of BMSA at room temperature for simulation of change of waist circumference. The elastic strain gauge of film type was inserted in a waist inside of the garment and both ends of the strain gauge were connected to the wires of a multimeter to measure electric resistance. In order to simulate increasing and decreasing of waist circumference, an air injection pack was placed on the front waist. Air was injected by pumping, until waist circumference reached to 784mm. As air was released gradually, waist circumference was decreased to 738mm. When air was released gradually, the electric resistance was measured 5 times at intervals of 2mm of waist circumference.

4 RESULTS AND DISCUSSION

In this research, we designed and developed a new smart textile product: smart apparel for the overweight, called Body-shape Monitoring Smart Apparel (BMSA), which informs users of estimated changes of waist circumference. Design considerations were proposed in aspects of apparel design. To prove the concept of BMSA, performance of BMSA were tested.

4.1 Design concept of BMSA

The design concept of BMSA is in Figure 28.

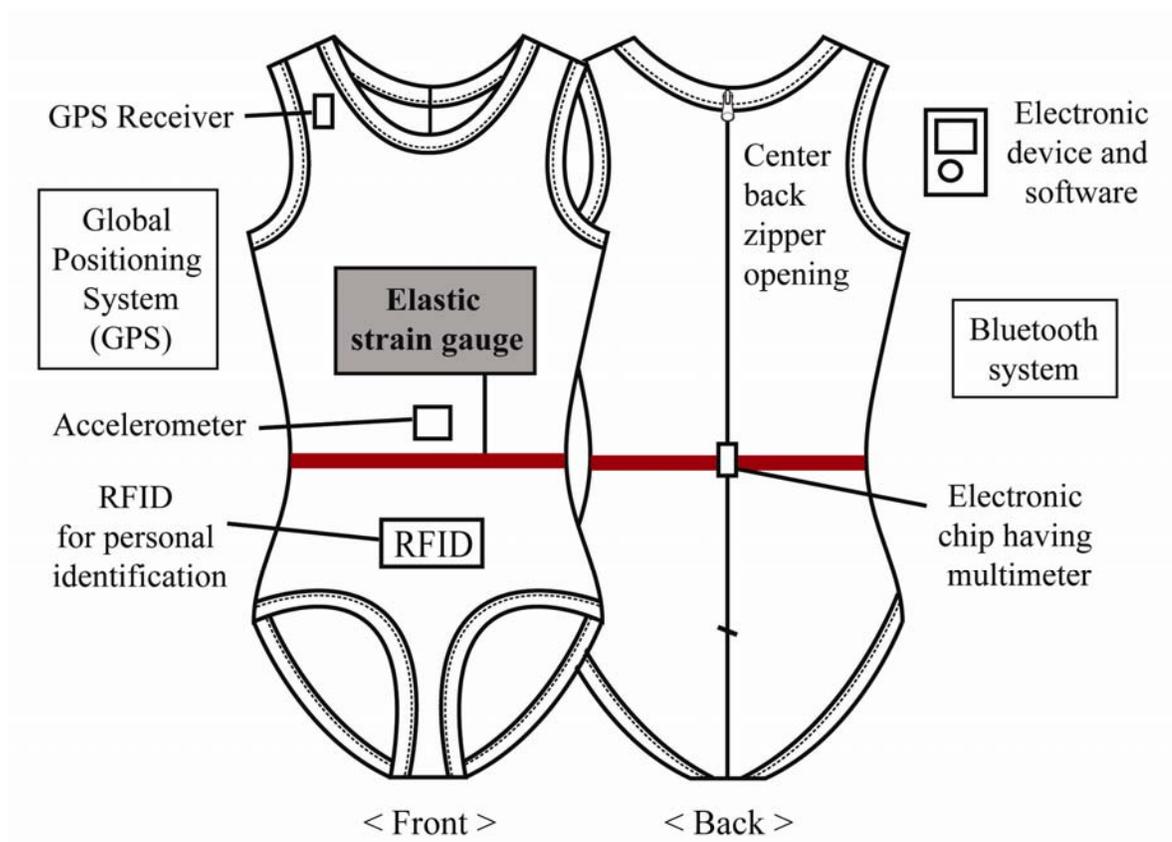


Figure 28. Design concept of BMSA.

Elastic strain gauges which are made of carbon black and polyurethane are inserted in smart apparel to measure the body circumference. The elastic strain gauge is the textile sensor having conductivity caused by carbon black and elasticity caused by polyurethane. As it is known that the electric resistance of carbon black fiber has a linear relationship with its length, the change of the length of elastic strain gauges girding the body can be estimated using the change of electric resistance of the strain gauge made of carbon black and polyurethane.

The change of electric resistance of the elastic strain gauge measured by multimeter can be sent to a cell-phone or other suitable electronic device over a Bluetooth system every day or week. An appropriate software program installed in electronic devices transform the data received to a user-friendly format, which makes sense to the users, such as amount of body circumference changed. The electronic device informs the user of estimated changes of body circumference and gives dietary suggestions and a target level of aerobic exercise. In addition, an accelerometer attached to the garment quantitatively measures the amount of exercise, and RFID has data of the user's health information such as blood type, chronic disease and recent health record. While the user exercises, A GPS can monitor the location of the users.

The users can utilize the service daily or weekly and are able to monitor their body status constantly and accurately until they meet their target weights or measurements. Use of smart apparel for the obese would help people maintain proper weights and improve their health more strategically. To enhance comfort of the product, we used cotton/spandex blended knit considering moisture management and comfort during the

users' exercise. To make the apparel product well suited to the users, the patterns of the product have been developed using a three dimensional body scanner and computer-aided design (CAD).

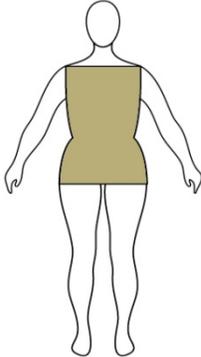
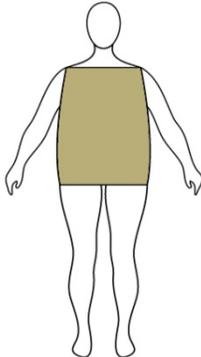
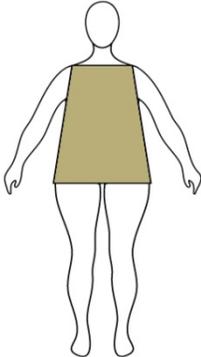
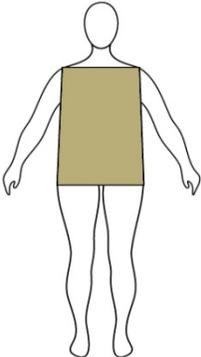
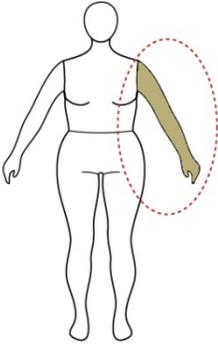
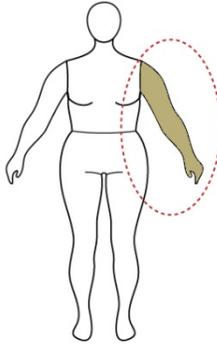
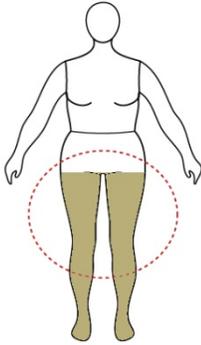
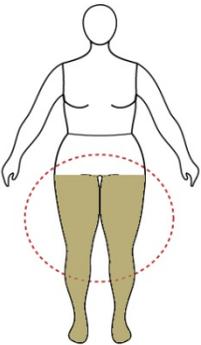
4.2 BMSA selection options

As customized patterns for individuals are to be fitted well on the body, it is imperative to measure body circumference correctly. However, current manufacturing technology to make these customized patterns has low efficiency compared to cost, and automatic computer-aided technical design technology is in development and needs to have its accuracy validated. Therefore, a way to categorize torso, arm, and leg shapes and to generate garment patterns by transformation from a basic pattern was presented as a workable solution. Named the BMSA selection options, this method not only accounts for size but also body shape and individual garment preference.

4.2.1 *Body shapes*

The torso shape of overweight women can be divided into 4 types: rectangular-8, barrel, pear, and box (Zangrillo). Even if there are two people having the same shape torso, they can have different shape arms and/or legs as shown Figure 13. Therefore, the shapes of arms and legs can be divided into 2 types: regular and thick.

Table 13. Body shapes of overweight women

	Rectangular-8	Barrel	Pear	Box
Torso shape				
	Normal type		Thick type	
Arm shape				
	Normal type		Thick type	
Leg shape				

Source: Frances Leto. Fashion Design for the Plus-Size. Zangrillo, New York: Fairchild

Publications, 1990.

4.2.2 Comparison of body measurement and adjustment for pattern design

Using ASTM standard body measurements, misses size 20 (ASTM "Standard Table of Body Measurements for Adult Female Misses Figure Type, Sizes 2-20") and women's plus size 20W (ASTM "Standard Table of Body Measurements Relating to Women's Plus Size Figure Type, Sizes 14w-32w") were compared, as shown in Table 14. The women's plus size was found to have narrower shoulder than the misses' figure and a bigger bust, waist, and hip girth. Also the plus size figure has thicker upper arms and thighs.

Table 14. Comparison of body measurement between 20 and 20W (unit: inch)

Pattern type		20 (Misses)	20W (Plus Size)
Bodice	Shoulder length	5 15/16	5 1/16
	Bust Girth	44 1/2	45 1/2
	Waist Girth	36 1/2	37 1/2
Skirt	Hip Girth	47	47 1/2
Sleeve	Upper-Arm Girth	13 3/8	14 3/8
	Elbow Girth	11 3/8	11 5/8
	Wrist Girth	6 3/4	6 7/8
Pants	Thigh Girth (Max)	28	29
	Thigh Girth (Mid)	24 1/2	25 1/2

Source: Standard Table of Body Measurements for Adult Female Misses Figure Type, Sizes 2-20. ASTM. 2001. Vol. D 5585-95., Standard Table of Body Measurements Relating to Women's Plus Size Figure Type, Sizes 14w-32w. ASTM. Vol. D 6960-04.

In order to analyze and adjust measurements for pattern development, the table of ASTM plus size measurements was used. According to the body part measured, the difference between each size is calculated, as shown in Table 15.

Table 15. Differences between sizes in ASTM standard body measurements for women’s plus size figure (unit: inch)

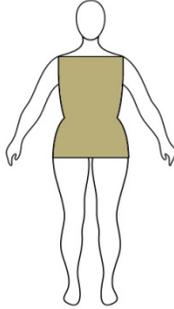
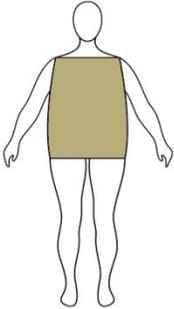
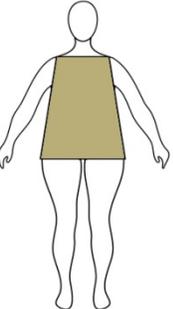
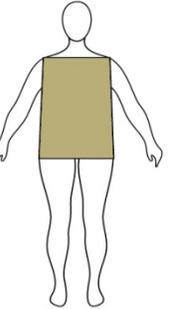
	Shoulder length	Bust girth	Waist girth	Hip girth	Upper-arm girth	Elbow girth	Wrist girth	Thigh girth (Max)	Thigh girth (Mid)
Diff.	1/16	2	2	2	5/8	3/8	1/8	1 1/4	1 1/4

Source: Standard Table of Body Measurements Relating to Women's Plus Size

Figure Type, Sizes 14w-32w. ASTM. Vol. D 6960-04.

To adjust measurements according to body type, rectangular-8 shape was used as the standard because rectangular-shape is most similar with normal body shape. Using the calculations of the differences indicated in Table 15, an attempt was made to adjust the measurements for the other body shapes. Table 16 indicates increases, decreases, or no change in measurement per shoulder, waist, and hip.

Table 16. Adjustment of body measurement

	Rectangular-8	Barrel	Pear	Box
				
Shoulder	0	0	-	0
Waist	0	++	+	+
Hip	0	+	++	0

4.2.3 *Pattern design*

Basic patterns can be developed using ASTM plus-size measurements for the rectangular-8 body shape, as shown in Table 17. Patterns for other body shapes can be created by modifying basic patterns, as shown in Table 18~ Table 20

For the barrel shape, shoulder length is kept, the waist has to be significantly increased, and the hips also have to be increased. To enlarge waist, the bodice patterns are cut and the waist parts are spread, as shown in Table 18. In the skirt patterns, the waist sections are spread, and the waist dart amount is decreased, and the hip parts are spread. Then, new darts lines are drawn.

For the pear shape, the bodice patterns are cut, the shoulder parts are overlapped, and the waist portions are spread, as shown in Table 19. In the skirt patterns, the waist and hip parts are spread.

For the box shape, the bodice patterns are cut, and waist parts are spread. In the skirt patterns, waist dart amount is decreased.

Bodice and skirt slopers are basic slopers which can be transformed into various patterns. Torso sloper can be made using bodice and skirt slopers and torso sloper can be transformed to leotard patterns.

Table 17. Pattern development of rectangular-8 shape

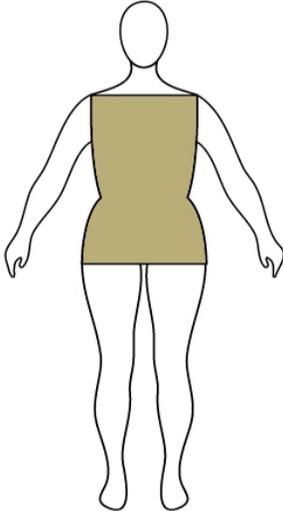
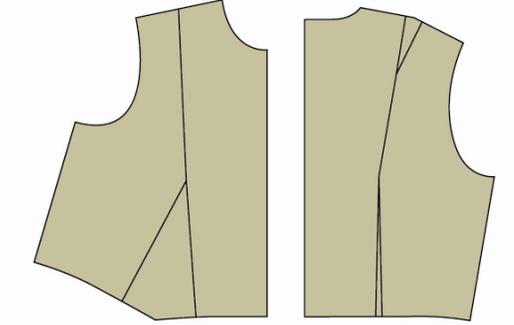
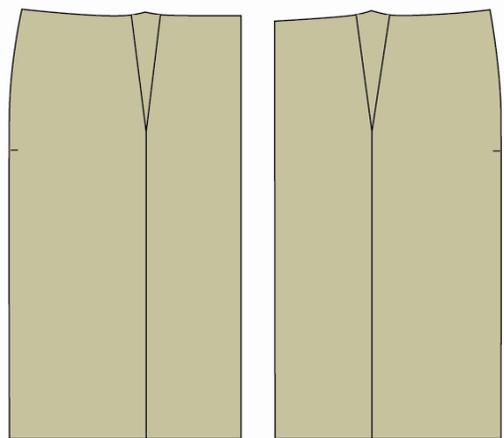
Body shape		Pattern development	
Rectangular-8 	Bodice		<ul style="list-style-type: none"> • Keep basic pattern
	Skirt		<ul style="list-style-type: none"> • Keep basic pattern
	Shoulder	0	
	Waist	0	
Hip	0		

Table 18. Pattern development of barrel shape

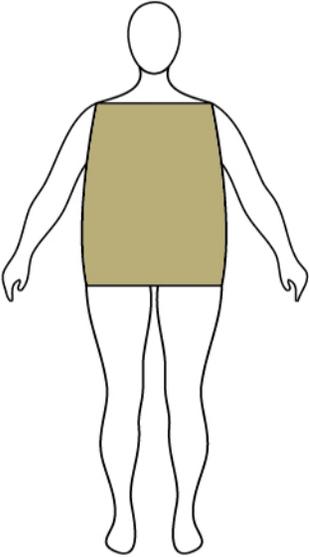
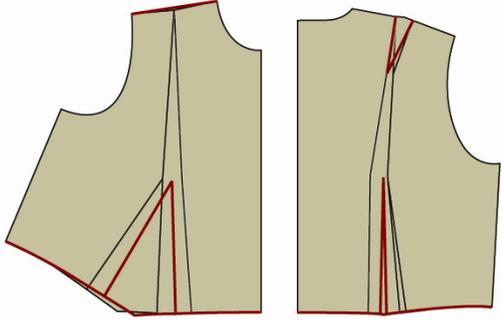
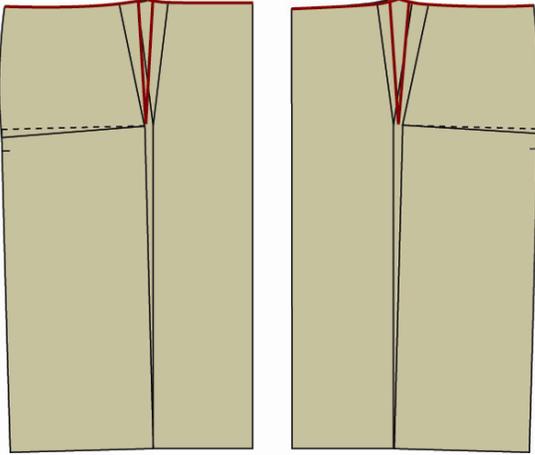
Body shape		Pattern development	
<p>Barrel</p> 	Bodice		<ul style="list-style-type: none"> • Cut dart lines • Spread waist • Apex movement • New dart lines • New shoulder lines
	Skirt		<ul style="list-style-type: none"> • Cut dart lines • Spread waist • Decrease dart amount • New dart lines • Cut dart point level horizontally • Spread hip • Blending side seam
	Shoulder	0	
Waist	++		
Hip	+		

Table 19. Pattern development of pear shape

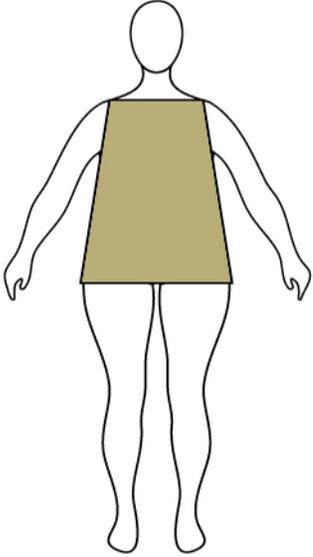
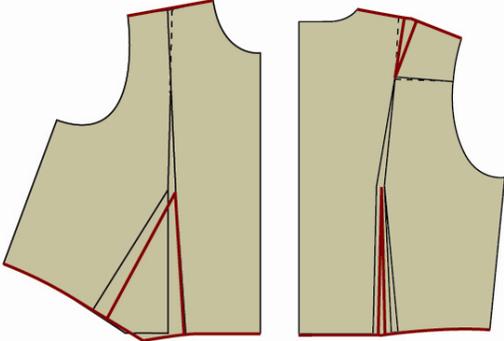
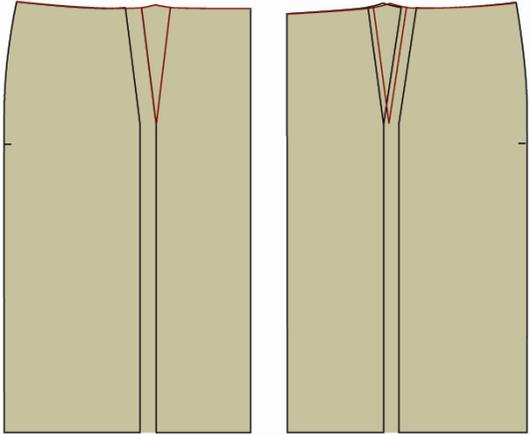
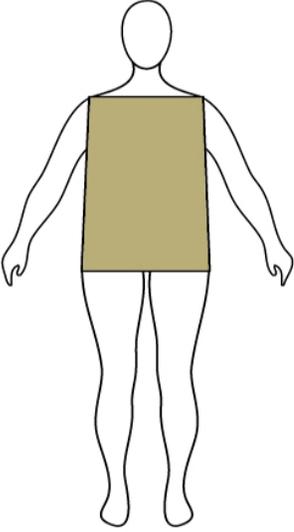
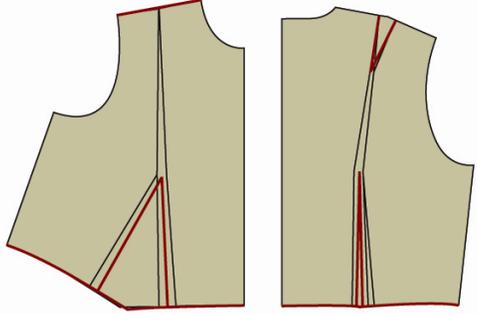
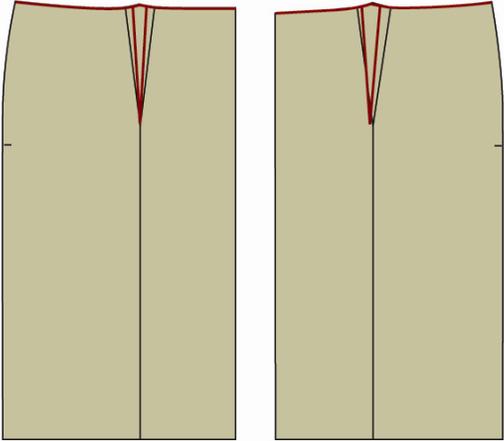
Body shape		Pattern development						
Pear 	Bodice		<ul style="list-style-type: none"> • Cut dart lines • Overlap Shoulder • Spread waist • New dart lines • New shoulder lines 					
	Skirt		<ul style="list-style-type: none"> • Cut dart lines • Spread waist and hip • New dart lines 					
	<table border="1"> <tr> <td>Shoulder</td> <td>-</td> </tr> <tr> <td>Waist</td> <td>+</td> </tr> <tr> <td>Hip</td> <td>++</td> </tr> </table>	Shoulder	-	Waist	+	Hip	++	
Shoulder	-							
Waist	+							
Hip	++							

Table 20. Pattern development of box shape

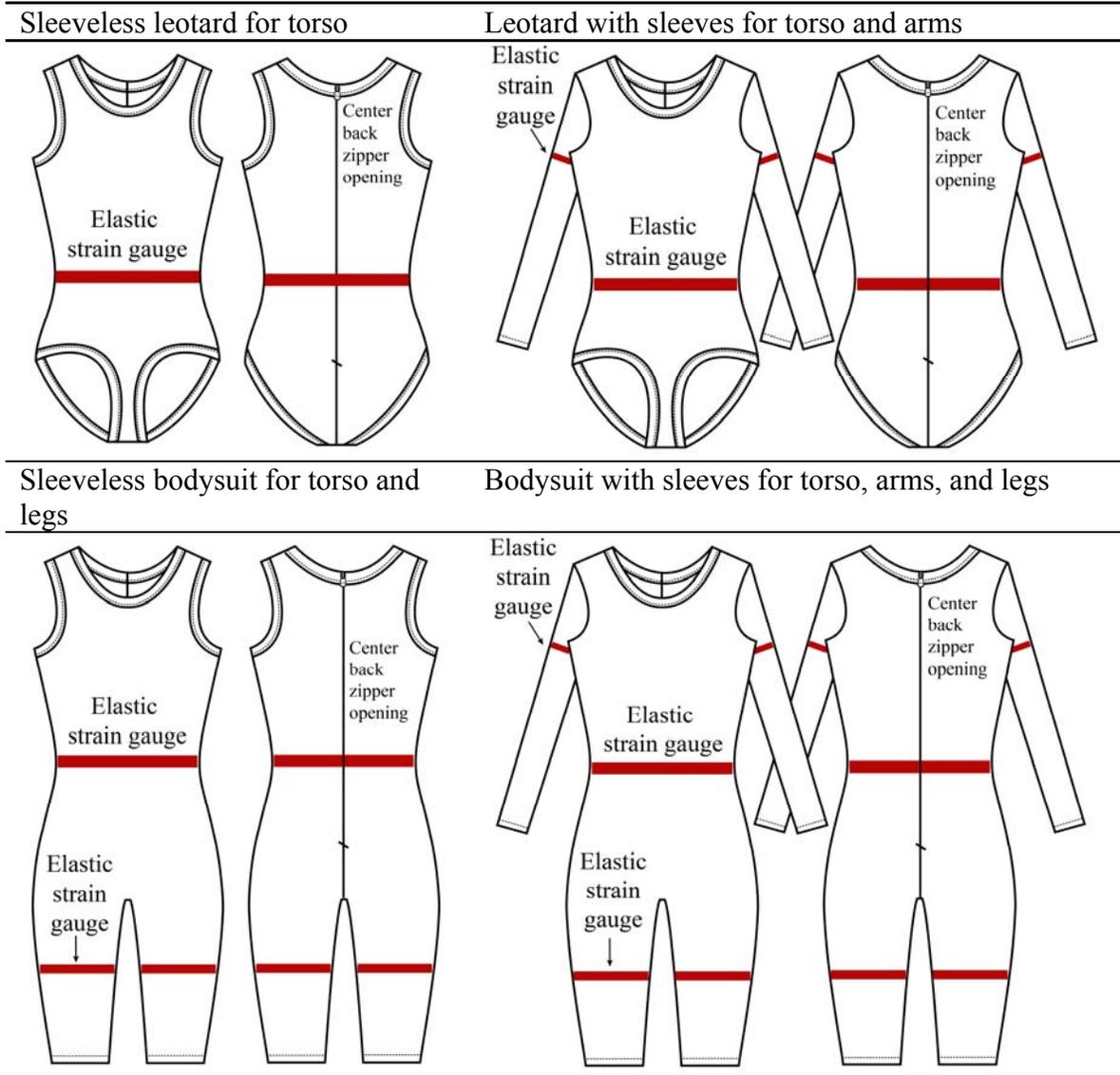
Body shape		Pattern development	
<p>Box</p> 	Bodice		<ul style="list-style-type: none"> • Cut dart lines • Overlap Shoulder • Spread waist • New dart lines • New shoulder lines
	Skirt		<ul style="list-style-type: none"> • Cut dart lines • Spread waist and hip • New dart lines
	Shoulder	0	
Waist	+		
Hip	0		

4.2.4 Garment preference

Garment design can be chosen from among 4 types according to the preference of the users - sleeveless leotard for the torso, a leotard with sleeves for torso and arms, a sleeveless bodysuit for torso and legs and a bodysuit with sleeves for torso, arms, and legs. As the strain gauge is inserted in waist, upper arm, or thigh, the garment choice of the user determines which strain gauge is used for their body monitoring (Table 21). Because elastic strain gauges need to be fitted well on the body, garments were designed to be tight fitting using knit fabric. In order to fix elastic strain gauges at the same position of the body, garments were designed as types of leotards or body suits. As top and bottom pieces are connected, the position of the waist is fixed without slipping or pulling up. A zipper opening was positioned in the center back for preventing deformation of the elastic strain gauge due to stretching and for convenience of putting on or taking off the clothing.

If users select the garment with sleeves, elastic strain gauges can be inserted in upper arms optionally and if users select a bodysuits type, elastic strain gauges can be inserted in thighs optionally, as shown in Table 21.

Table 21. Design suggestions



4.2.5 BMSA selection options

Users can select the appropriate category in each of the 5 sections shown in Figure 29. Size, body shapes, arm shapes and leg shapes are decided by their measurements. Garment types can be chosen according to the user’s preference.

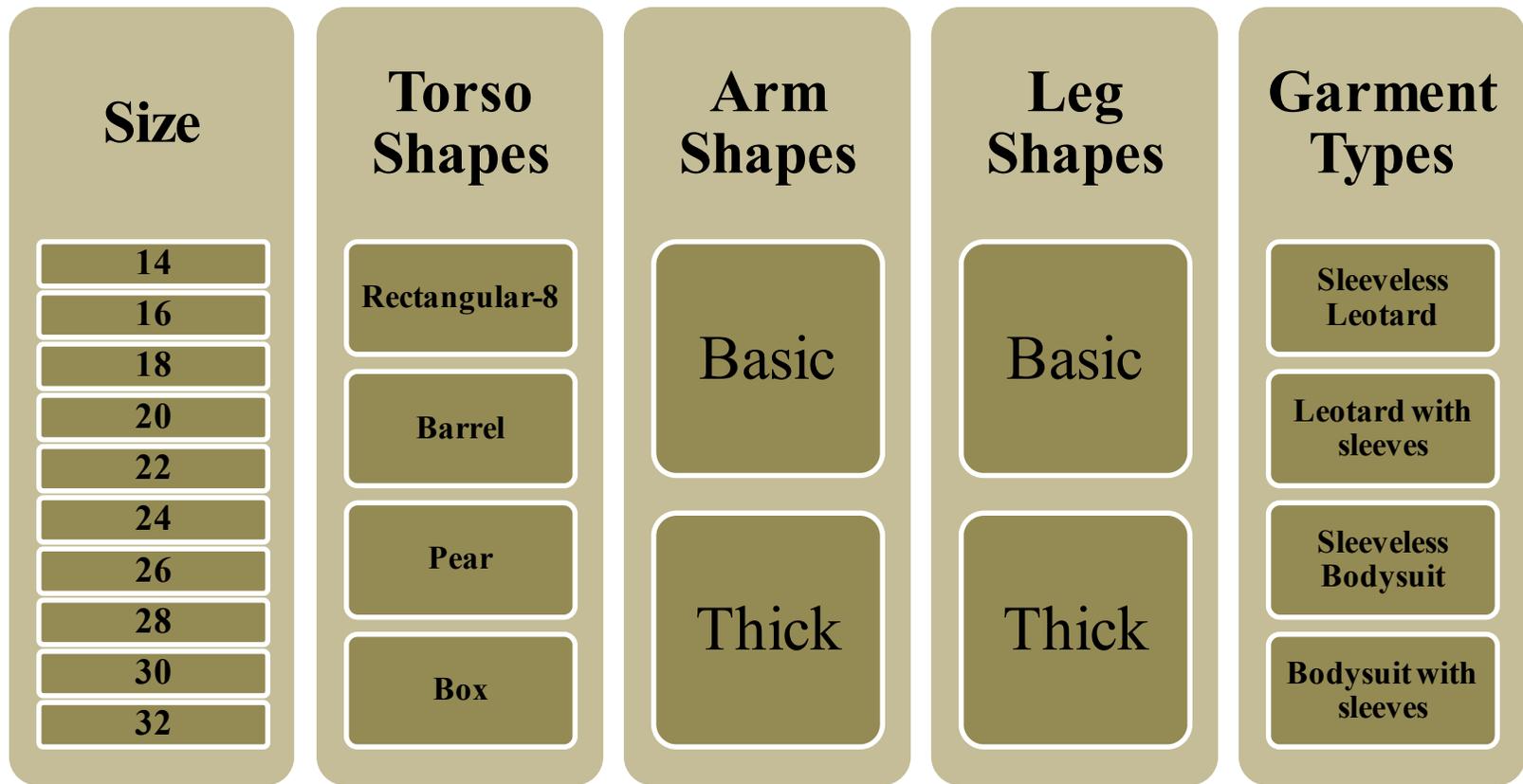


Figure 29. BMSA selection options.

4.3 Elastic strain gauge

4.3.1 Scanning Electron Microscopy (SEM)

Carbon black powder was observed by SEM as shown in Figure 30. The diameter of the carbon black particles is about 55~65nm. Typical carbon blacks consist of nearly pure carbon in colloidal entities of aciniform, meaning “clustered like grapes”, morphology (Sichel).

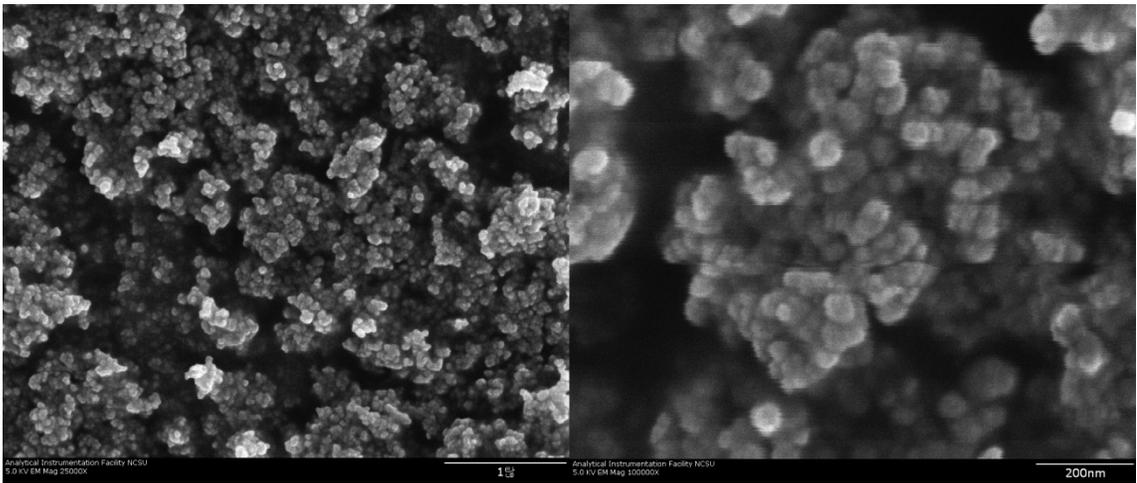


Figure 30. Particles of carbon black (magnification: 25000X, 100000X).

The elastic strain gauge produced using Hakke Minilab is fiber type as shown in Figure 31. The surface of the fiber has intermittently rough parts as shown in Figure 32. Cracks and clusters of carbon black particles are observed in 100000X magnification in Figure 32. The diameter of fiber is about 900 μ m in figure 26. Small holes in the edge are visible in fiber sections shown in Figure 33. Concentrated parts of carbon black particles and distributed parts are distinguished in Figure 33. Figure 34 is 25000X magnification of each part.



Figure 31. Fiber type elastic strain gauge.

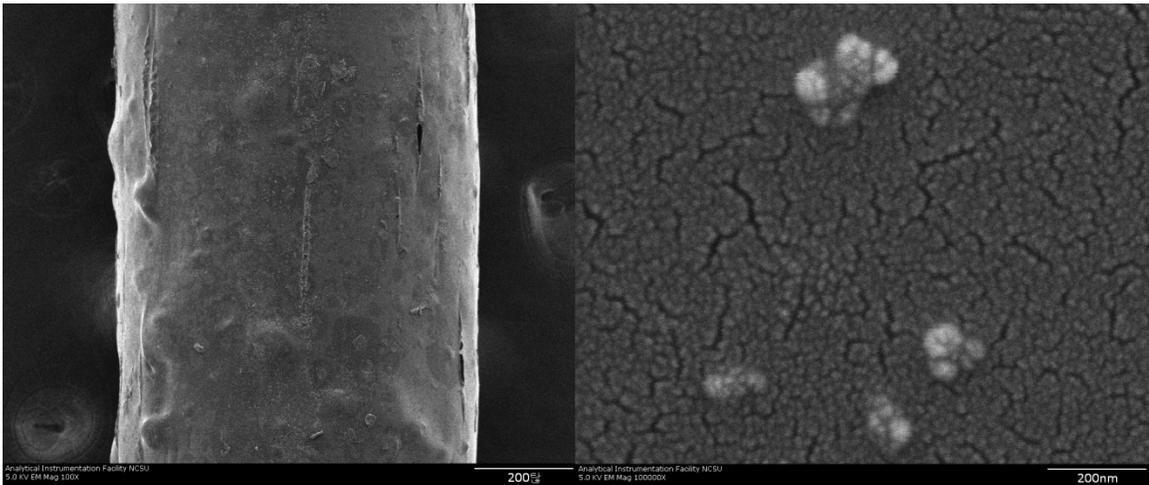


Figure 32. Surface of a strain gauge (magnification: 100X, 100000X).

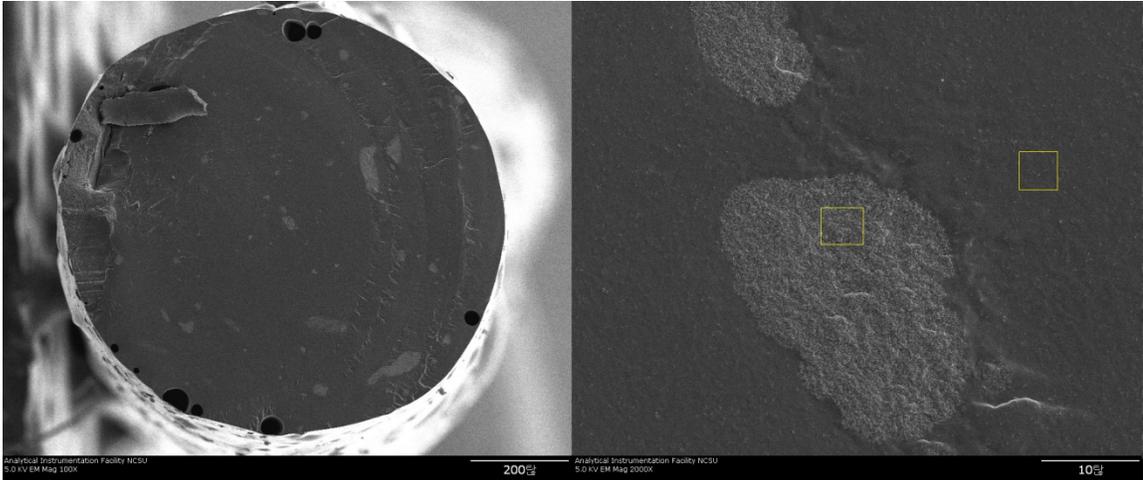


Figure 33. Fiber section of a strain gauge (magnification: 100X, 2000X).

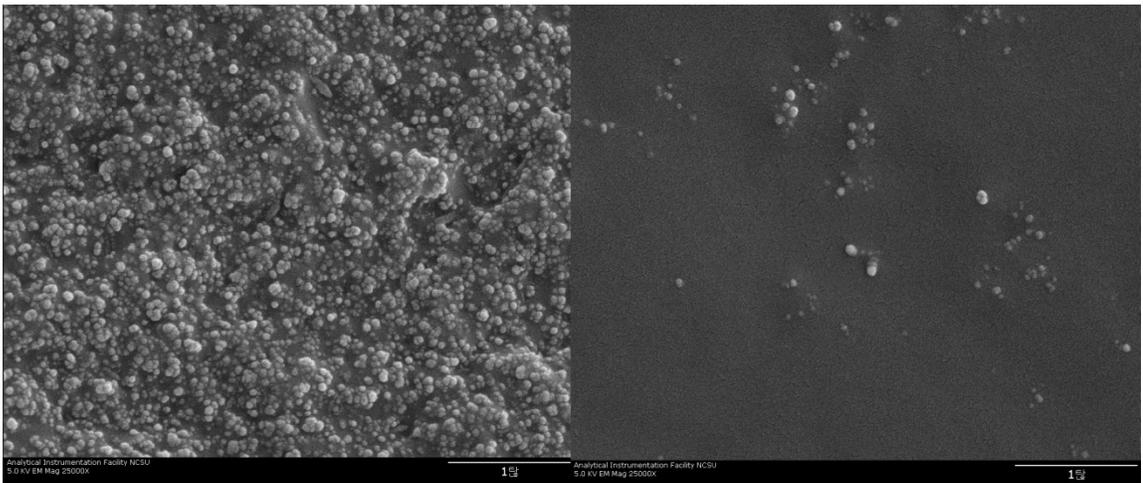


Figure 34. Concentrated parts and distributed parts of carbon black particles in a fiber section (magnification: 25000X, 25000X).

4.3.2 *Electric resistance measurement of elastic strain gauge*

Figure 35~Figure 39 show the results obtained by electric resistance measurement. Each specimen shows different range in resistance. A rise in resistance was observed when applying strain. However, a slight hysteresis of decreasing resistance despite strain

was observed in the second measurement of the 4th specimen. An almost linear resistance increase was observed for a strain range between 2.5% and 15% especially when the values of resistance and strain in each specimen were averaged. A tendency toward a small increase in the values for resistance was observed as the measurements were repeated.

Therefore, the approximate linear relation between electric resistance and length of elastic strain gauge can be used in order to estimate the change of waist circumference in BMSA.

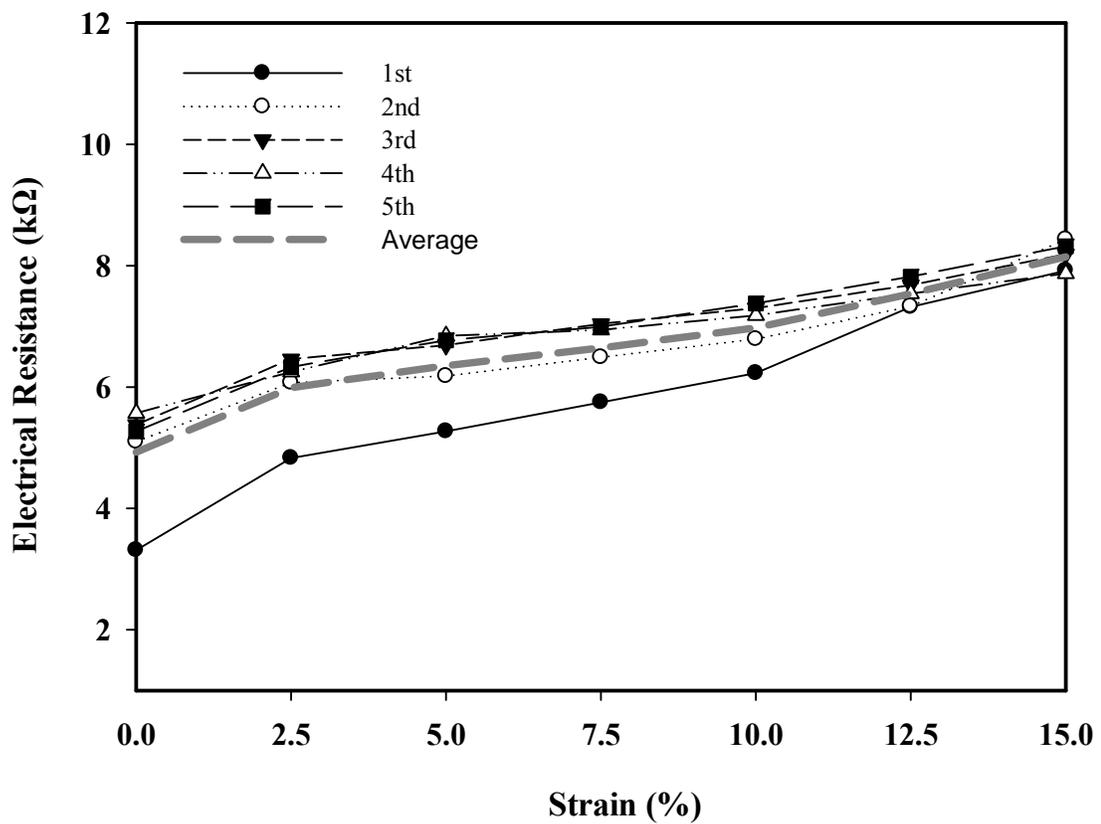


Figure 35. Relationship between strain and electric resistance of sample No.1.

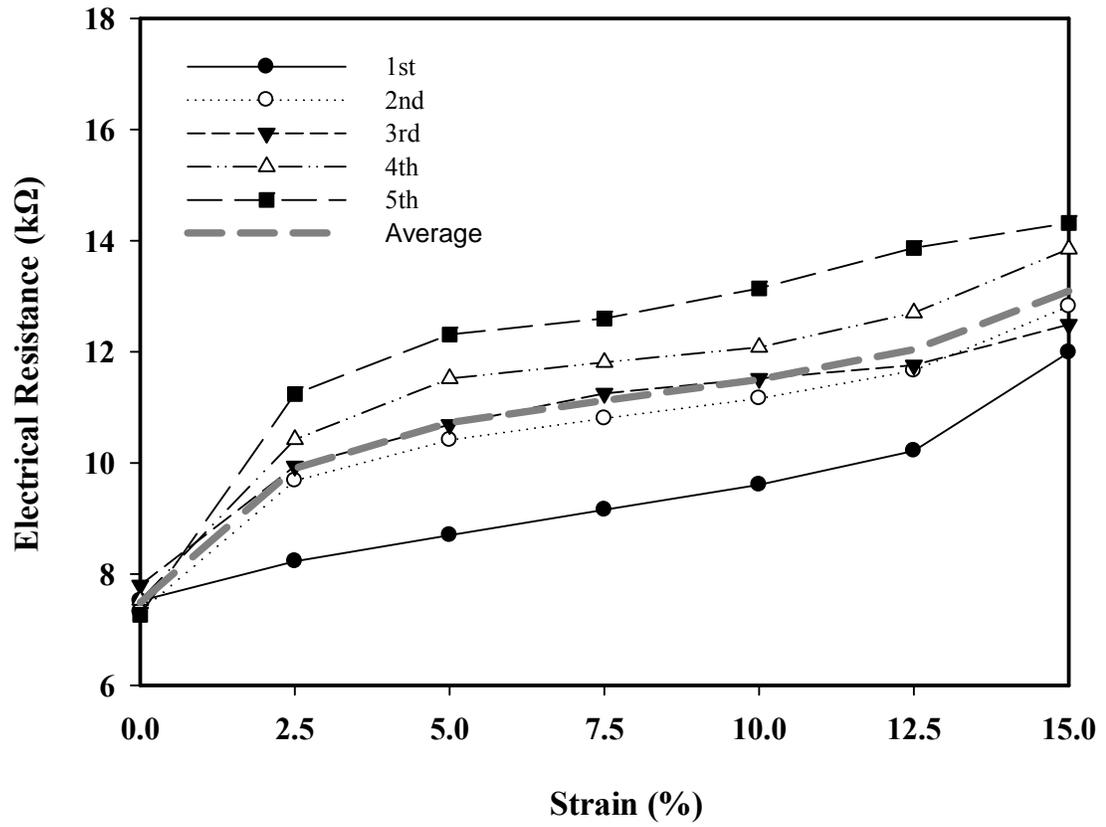


Figure 36. Relationship between strain and electric resistance of sample No.2.

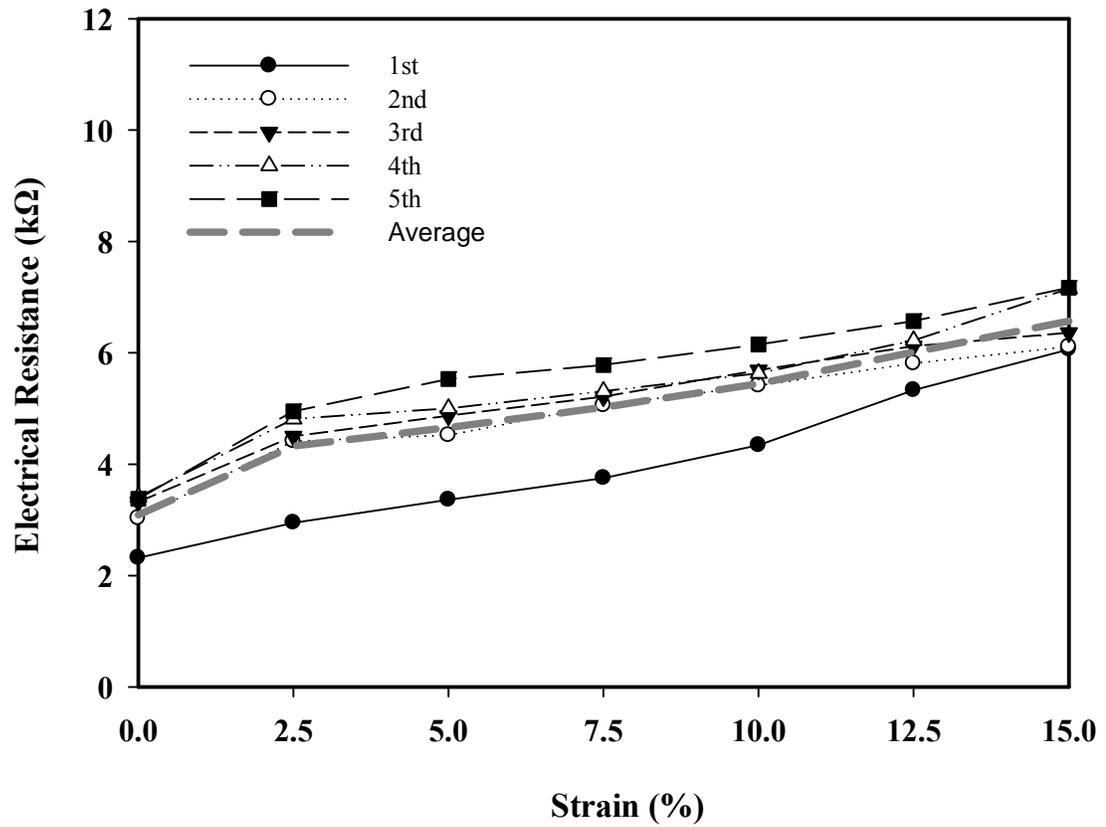


Figure 37. Relationship between strain and electric resistance of sample No.3.

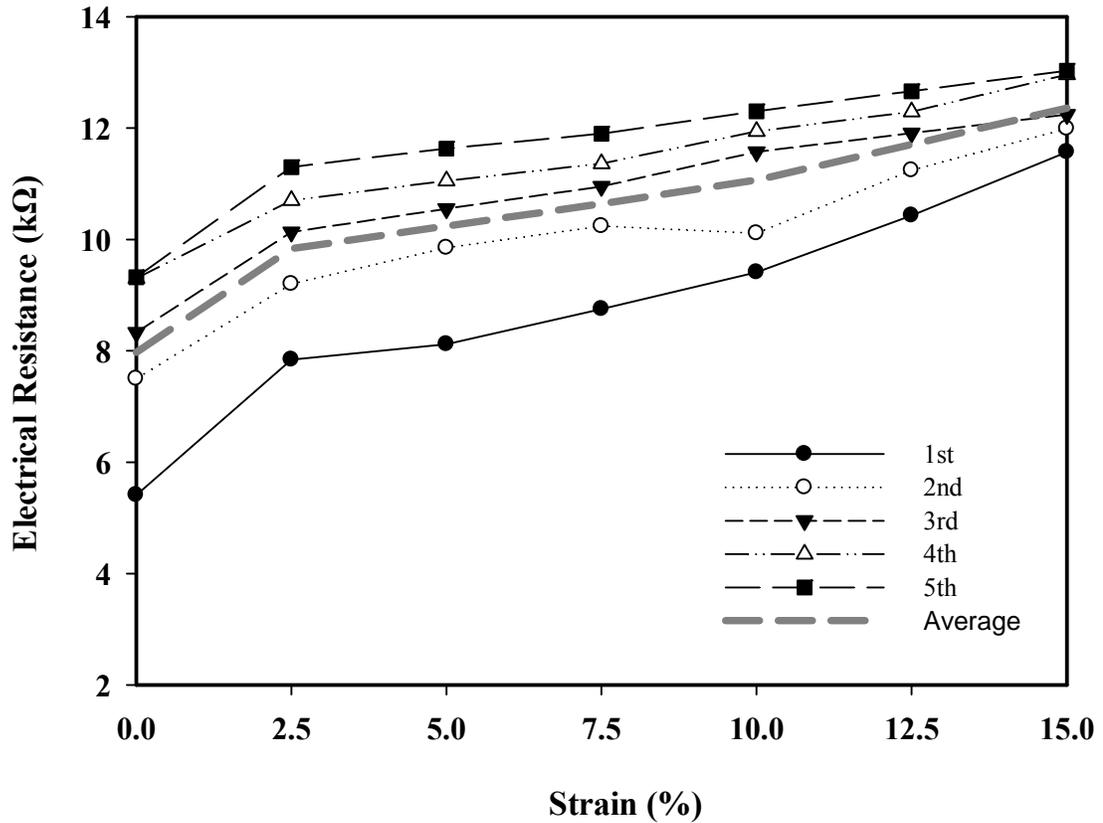


Figure 38. Relationship between strain and electric resistance of sample No.4.

4.3.3 Washing test

After 20 times washing the strain gauge samples, a rise in electric resistance was observed when applying strain (Figure 39 ~ Figure 42). The electric resistance value increased after washing and the range of electric resistance was wider than before washing. The slope of change of electric resistance was increased. Slight hysteresis of decreasing electric resistance despite strain was observed in the second and third measurements of the 1st sample. A rapid increase of electric resistance at 10% strain was

observed in the 3rd sample. Compared to the first three, fluctuating electric resistance for repetitive measurements was observed in the 4th sample.

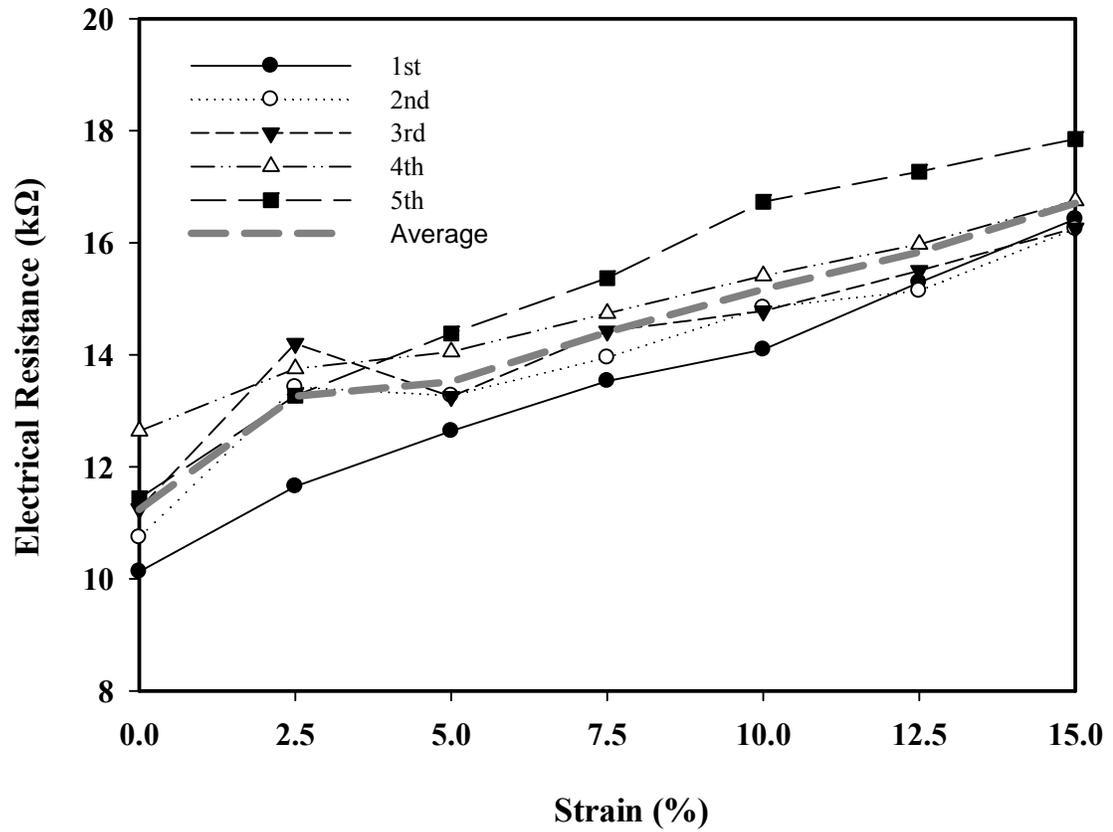


Figure 39. After 20 washings the relationship between strain and electric resistance of sample No.1.

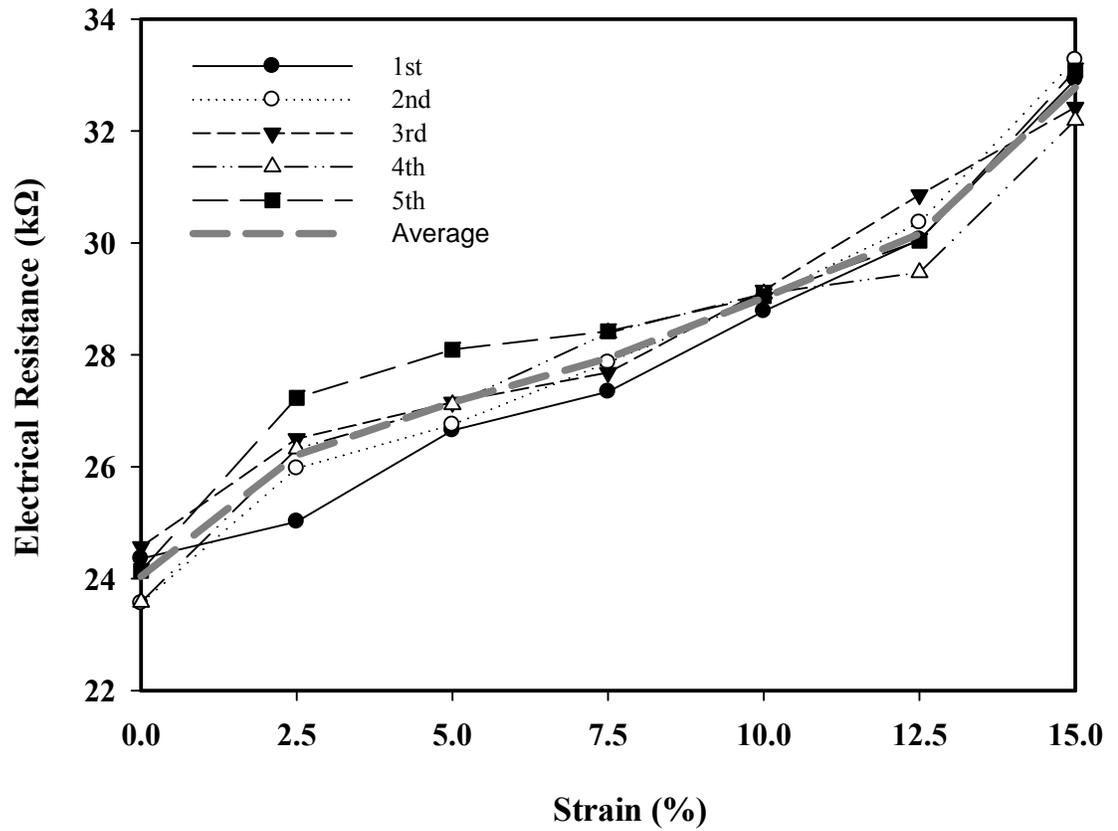


Figure 40. After 20 washings the relationship between strain and electric resistance of sample No.2.

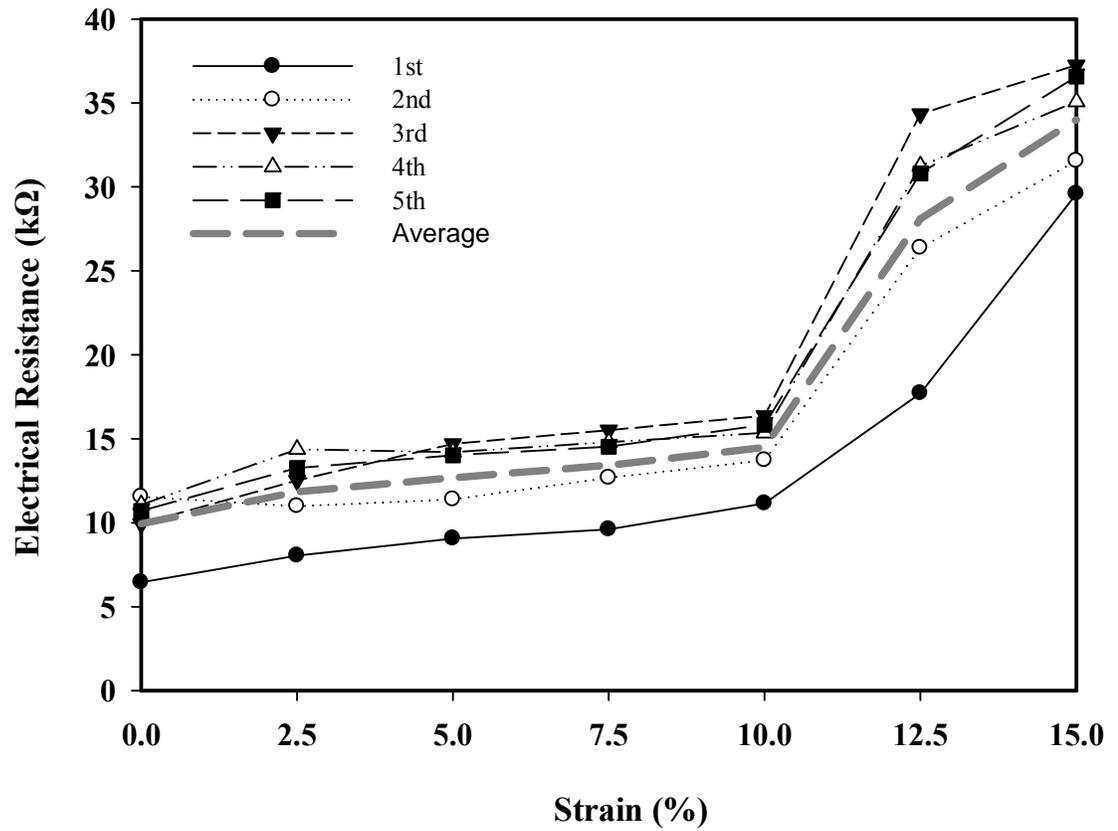


Figure 41. After 20 washings the relationship between strain and electric resistance of sample No.3.

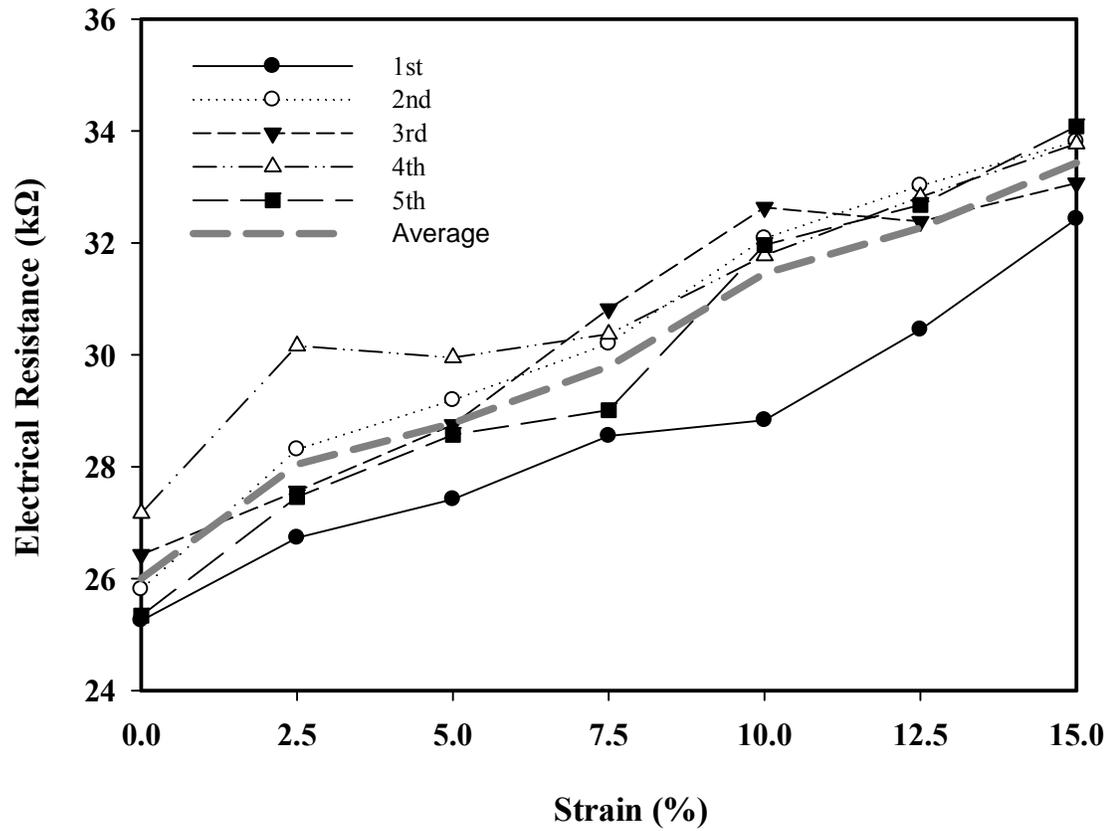


Figure 42. After 20 washings the relationship between strain and electric resistance of sample No.4.

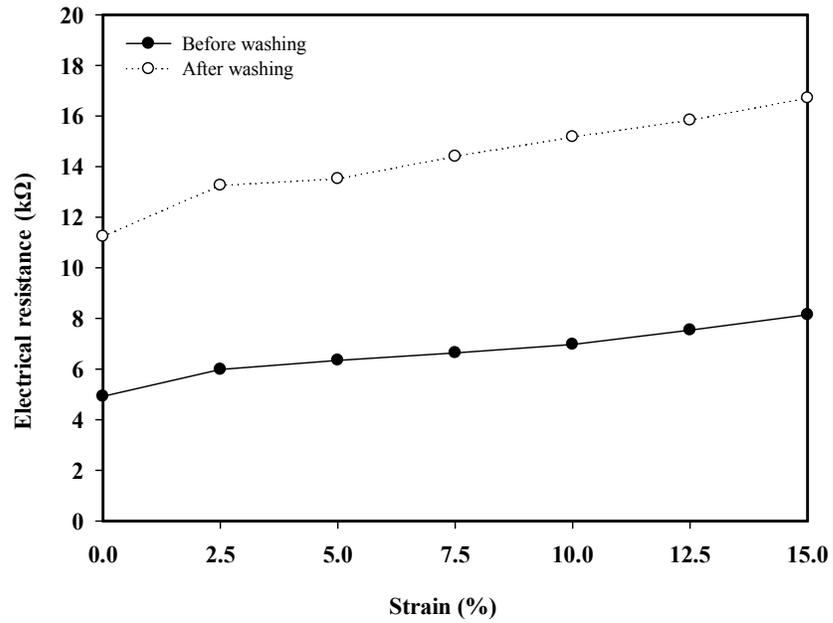


Figure 43. Average electric resistance of sample No.1 before and after 20 washings.

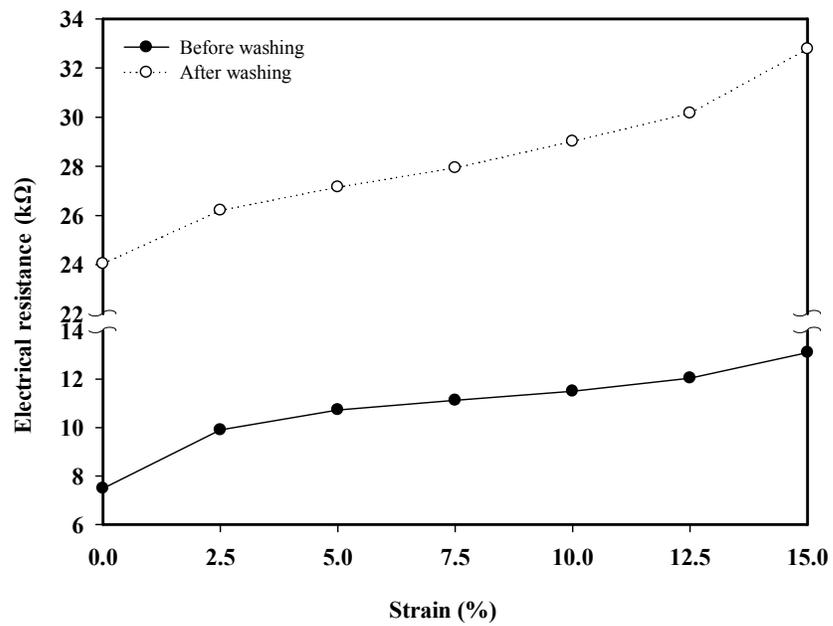


Figure 44. Average electric resistance of sample No.2 before and after 20 washings.

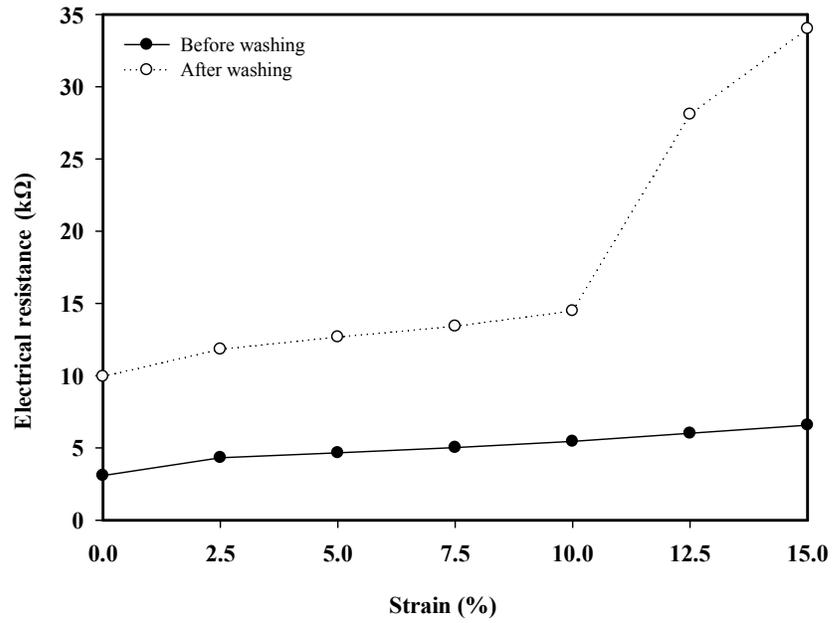


Figure 45. Average electric resistance of sample No.3 before and after 20 washings.

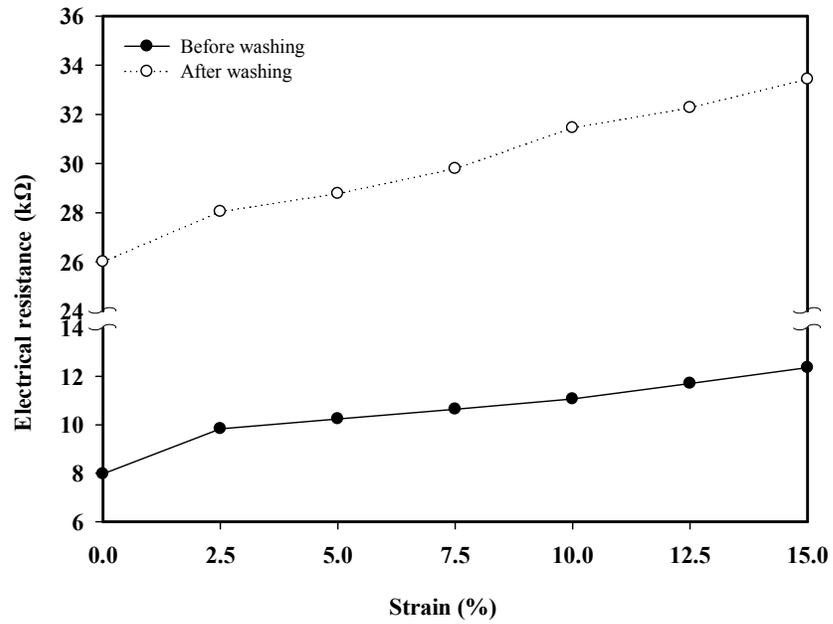


Figure 46. Average electric resistance of sample No.4 before and after 20 washings.

4.4 Electric resistance measurement of elastic strain gauge

Air was injected by pumping, until waist circumference reached to 784mm. As air was released gradually, waist circumference was decreased to 738mm. As waist circumference decreased, electric resistance of the strain gauge decreased from 535k Ω to 337k Ω . The change due to repeat measurements was about 30k Ω . Slight hysteresis of increasing electric resistance despite decreasing a waist circumference was observed at some points, as shown in Figure 47. The relationship between electric resistance and waist circumference was almost linear, as shown in figure 32. However, the slope suddenly increased at the point of 750mm of waist circumference.

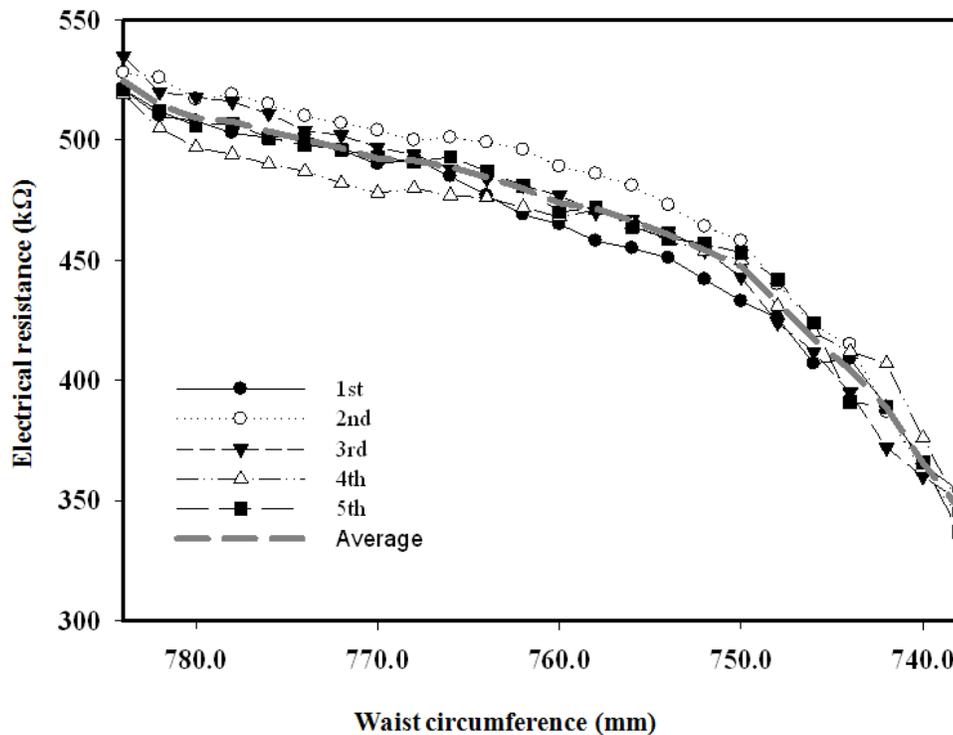
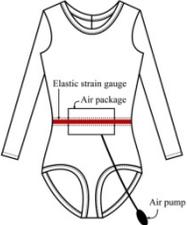
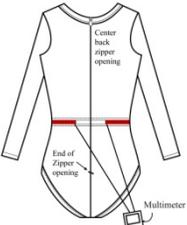


Figure 47. Electric resistance of strain gauge regarding change of waist circumference.

Table 22. Front, side and back view of BMSA prototype

	Air injected	Air released
<p data-bbox="297 233 375 264">Front</p>  <p data-bbox="358 464 472 485">Elastic strain gauge</p> <p data-bbox="375 485 456 506">Air package</p> <p data-bbox="448 579 492 600">Air pump</p>		
<p data-bbox="297 730 358 762">Side</p>		
<p data-bbox="297 1228 370 1260">Back</p>  <p data-bbox="391 1402 435 1451">Center back zipper opening</p> <p data-bbox="342 1493 435 1514">End of Zipper opening</p> <p data-bbox="440 1577 492 1598">Multimeter</p>		

4.5 Summary of results

First, the design concept of BMSA was proposed with consideration for components such as technical devices and garment design.

Second, BMSA selection options considering size, body shapes, and garment preference were proposed.

Third, performance and durability of the elastic strain gauge which was developed were tested by measuring the electric resistance and laundering tests.

Finally, the decreasing waist circumference of the BMSA prototype containing the elastic strain gauge was simulated and the electric resistance of the elastic strain gauge was measured in a garment on the dress form (Figure 48).

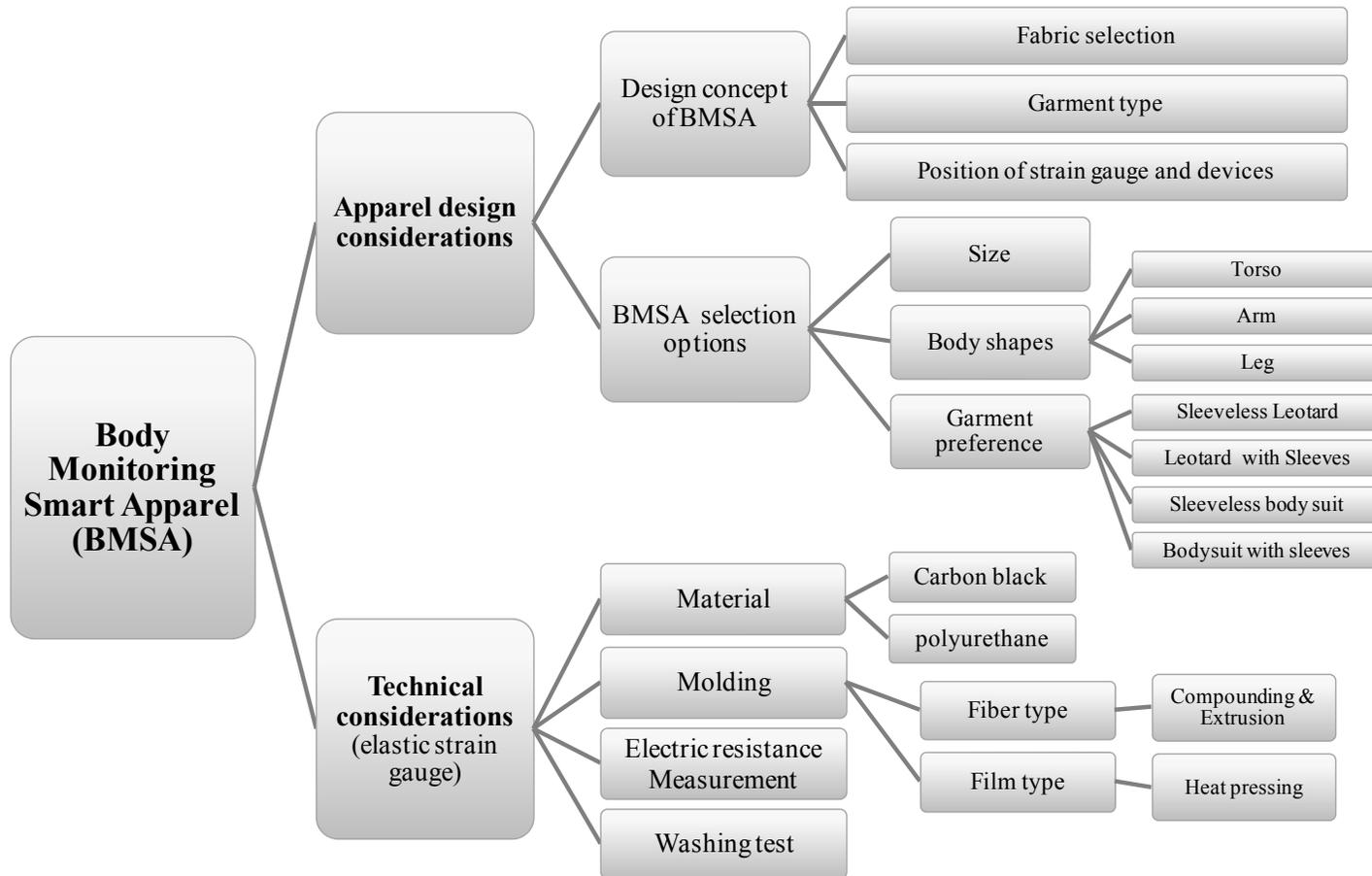


Figure 48. Conceptual framework of BMSA.

5 CONCLUSION

This research proposed the concept of BMSA which has the function of measuring and monitoring body circumference. A prototype of BMSA was developed and tested. As waist circumference is a useful indicator of obesity status and obesity-related health risks, the BMSA was designed to take this measurement.

BMSA has been developed by considering apparel design and developing conductive strain gauge. The concept of BMSA which is equipped with elastic strain gauges, an electronic chip having a multimeter, an accelerometer, Radio Frequency Identification (RFID) and Global Positioning System (GPS) receiver and batteries was proposed in this research. However, this research only dealt with the technical considerations of the elastic strain gauge, and apparel design considerations of BMSA.

A textile sensor in the form of an elastic strain gauge made of carbon black and polyurethane is inserted in the garment in order to measure the waist circumference. Changes in the waist circumference can be estimated using the linear relationship between electric resistance of the strain gauge and waist circumference. As carbon black provides conductivity for estimating waist circumference and polyurethane provides elasticity to cover changes of waist circumference without breakage, the mixing of these materials was appropriate for strain gauge development. A conductive strain gauge providing good performance has been developed in this research. Electric resistance of the elastic strain gauge was measured by stretching of the gauge in order to find the relationship between electric resistance and length. This relation was found to be approximately linear. Therefore, a linear relationship can be used to estimate the change

of waist circumference in the BMSA. In order to test the durability of the elastic strain gauge, laundering tests were conducted. After washing, it was observed that the linear relationship remains but the slope and value of electric resistance increase. This shows that it is necessary to enhance the durability of the strain gauge.

Because elastic strain gauges need to be fitted well on the body, tight fitting garments such as a leotard or a bodysuit made of cotton/spandex knit fabric were designed. In order to place the strain gauges accurately on the body without slipping or pulling up, the garments were designed such that the top and bottom clothes connected. Thus, the designed garment was appropriate to be used as a BMSA.

In order to make BSMA fit well on the body, customized patterns are appropriate. However, current computer-aided technical design technology which can be used for automatic customized pattern making is in development and needs to be verified for accuracy. In addition, current manufacturing of customized patterns for each individual has low efficiency compared to cost. Therefore, BMSA selection options considering body shapes, size and garment preference was proposed (as shown in Figure 48). As numerous selection options considering different body shapes were provided, it is predicted that this would prevent errors in BMSA because of fit problems. The pattern development proposed in this research can be applied to not only BMSA but also to other garments. However, if the automatic computer-aided technical design is more advanced and generalized, 3D body scanning, Computer-Aided Design (CAD), and Computer-Aided Manufacturing (CAM) can be used to create well-fitting BMSA.

A combination of apparel design, material science, and technology made the prototype of BMSA available. A BSMA prototype was created using a 3D body scanner and the CAD system and the strain gauge was inserted in the waist of the prototype. Waist circumference change was simulated by air injection, and electric resistance of the elastic strain gauge was measured according to decreasing waist circumference. A decreasing tendency in electric resistance of the elastic strain gauges was observed as the waist circumference lessens. This research aimed to propose the concept of BMSA and to prove the concept by developing a BMSA prototype. The approximate linear relationship between electric resistance of elastic strain gauge and waist circumference successfully proved the BMSA concept. The prototype development provides basis for development of an advanced BMSA. If this BMSA concept is developed further, it can be a useful tool for monitoring change of waist circumference.

6 LIMITATIONS AND FUTURE WORK

6.1 Limitations

This research does not show which variables affect performance of the apparel on the human body because a dress form was used for the testing of the BMSA prototype. Also, a size 10 dress form is used instead of plus size dress form for BMSA prototype manufacturing, and only a single garment is tested. As air package was inserted in the front waist for simulation of decreasing waist circumference, the body shape was not natural. Only a leotard type garment having the elastic strain gauge in the waist was tested for one body shape. Future research can deal with testing of BMSA for various garment designs and different body shapes.

6.2 Future work

Development of a strain gauge showing stable results for measurements of repetitive electric resistance is required for successful application to BMSA. A durable strain gauge resistant to washing is needed in order to get constant results. The linear relationship between the length of strain gauge and electric resistance must be automatically calibrated.

To miniaturize the current multi-meter is required in order to attach it to the smart apparel without causing discomfort and inconvenience. A data transfer system similar to the bluetooth system from multimeter to electronic devices such as cell-phones and computers is required. Development of software to suggest proper weight management plans to each user is required.

For accurate and rapid production of garments, an automatic pattern developing method from 3D body surface to 2D garment patterns will be useful. Application of this technology to various garments to satisfy consumers' needs should be considered.

Elastic strain gauge can be applied to athletic wear such as jogging suit or swimsuit to compare the body circumference before and after exercise. Smart fabric such as Coolmax® is suggested to be used for BMSA.

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APPENDICES

Appendix A : Differences in ASTM standard body measurements for women's plus size figure (unit: inch)

	14W	16W	18W	20W	22W	24W	26W	28W	30W	32W	Diff.
Shoulder length	4 7/8	4 5/16	5	5 1/16	5 1/8	5 3/16	5 1/4	5 5/16	5 3/8	5 7/16	1/16
Bust girth	39 1/2	41 1/2	43 1/2	45 1/2	47 1/2	49 1/2	51 1/2	53 1/2	55 1/2	57 1/2	2
Waist girth	31 1/2	33 1/2	35 1/2	37 1/2	39 1/2	41 1/2	43 1/2	45 1/2	47 1/2	49 1/2	2
Hip girth	41 1/2	43 1/2	45 1/2	47 1/2	49 1/2	51 1/2	53 1/2	55 1/2	57 1/2	59 1/2	2
Upper-Arm girth	12 1/2	13 1/8	13 3/4	14 3/8	15	15 5/8	16 1/4	16 7/8	17 1/2	18 1/8	5/8
Elbow girth	10 1/2	10 7/8	11 1/4	11 5/8	12	12 3/8	12 3/4	13 1/8	13 1/2	13 7/8	3/8
Wrist girth	6 1/2	6 5/8	6 3/4	6 7/8	7	7 1/8	7 1/4	7 3/8	7 1/2	7 5/8	1/8
Thigh (Max) girth	25 1/4	26 1/2	27 3/4	29	30 1/4	31 1/2	32 3/4	34	35 1/4	36 1/2	1 1/4
Thigh (Mid) girth	21 3/4	23	24 1/4	25 1/2	26 3/4	28	29 1/4	30 1/2	31 3/4	33	1 1/4

Source: Standard Table of Body Measurements Relating to Women's Plus Size Figure Type, Sizes 14w-32w. ASTM. Vol. D 6960-04.