Computerized Human Body Modeling and Work Motion-capturing in a 3-D Virtual Clothing Simulation System for Painting Work Clothes Development

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Abstract

By studying 3-D virtual human modeling, motion-capturing and clothing simulation for easier and safer work clothes development, this research aimed (1) to categorize heavy manufacturing work motions; (2) to generate a 3-D virtual male model and establish painting work motions within a 3-D virtual clothing simulation system through computerized body scanning and motion-capturing; and finally (3) to suggest simulated clothing images of painting work clothes developed based on virtual male avatar body measurements by implementing the work motions defined in the 3-D virtual clothing simulation system. For this, a male subject’s body was 3-D scanned and also directly measured. The procedures to edit a 3-D virtual model required the total body shape to be 3-D scanned into a digital format, which was revised using 3-D Studio MAX and Maya rendering tools. In addition, heavy industry workers’ work motions were observed and recorded by video camera at manufacturing sites and analyzed to categorize the painting work motions. This analysis resulted in 4 categories of motions: standing, bending, kneeling and walking. Besides, each work motion category was divided into more detailed motions according to sub-work posture factors: arm angle, arm direction, elbow bending angle, waist bending angle, waist bending direction and knee bending angle. Finally, the implementation of the painting work motions within the 3-D clothing simulation system presented the virtual painting work clothes images simulated in a dynamic mode.

Key words: human body modeling, painting work motion-capturing, 3-D virtual clothing simulation, painting work clothes

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I. Introduction

It is reported that there are various hazardous factors to the work environment, that consequently cause the low level of work safety in the primary manufacturing industries in South Korea such as construction and heavy industries (KOSHA, 2012). In the preliminary study (Bae, Park and Park, 2010b), the three major heavy industries in South Korea, i.e. automobile, machine, and shipbuilding were investigated, and the main manufacturing works in these industries were divided into 12 processes, each of which was classified based on the impact indexes of environmental factors and motion factors on the involved workers. The manufacturing process in automobile, machine and shipbuilding industries, which utilized steel as the primary material, included such operations as cutting, molding, assembly, welding, mounting, transferring, painting and inspection of the steel processed goods. In particular, painting was one of the most important processes that prevents the external parts from being corroded during or after the processing and that maintains the outer appearance refined (Bae, Park and Park, 2010a). Such painting work is essential in these industries in reflection of the demands in the business work processes, however most of the pigments used consist of a large amount of additives including organic compounds, and organic solvents contained in thinners for antifouling paints such as benzene, toluene, and xylene. These organic solvents stimulate the worker’s olfactory sense during the inhalation of the vapor, which may cause fatigue and dermatitis and dry skin upon pigmentation (Sim, Jeoung, Lim, Lee and Kim, 2009). In addition, long period or short period exposure to such organic compounds may cause dyspnea, headache, suffocation, coma, anxiety, insomnia, prostration, chronic skin disease, and so forth (Kim, Chung, Jeong, Sur and Moon, 1997).

Based on the results from the preliminary study (Bae et al., 2010b), it turned out that work processes in automobile, machine and shipbuilding industries involved such harm factors to the work environment as temperature, oxygen deficiency and exposure to harmful chemicals, metal particles and organic solvents. As the level of harms of each environmental factor was similarly high to each other, painting work in both machine and shipbuilding industries was classified as a similar process within these machine, automobile, and shipbuilding industries. Ashdown and Watkins (1996) and Park (2011) highlighted the importance of the consideration of the protective performance from work environmental harm factors as well as the wearer mobility (Rosenblad, 1985) regarding to work clothes development. However, there were particularly certain difficulties to control the evenness of experimental factors, for example, the iteration of work motions designed for the wearer mobility tests, the adjustment of human subject body measurements and experimental clothes sizes and most of all, unnecessary risks to expose the human subject’s body to harmful work environmental elements regarding to the wearer mobility evaluation of work clothes prototypes to be developed. To take into account all these difficulties, it seems to be in urgent requirement to conduct researches on 3-D virtual clothing simulation for easier and safer work clothes development as well as its appearance and wearer mobility tests. Therefore, this research aimed first, to categorize painting work motions by video recording painting workers motions at machine and shipbuilding manufacturing sites in South Korea. Second, to
generate a 3-D human male model by 3-D body scanning and measuring an adult male subject’s body sizes. Third, to establish painting workers work motions within a 3-D computerized virtual clothing simulation system through computerized motion-capturing. Finally, in turn to simulate painting work clothes developed based on virtual model body measurements by implementing the painting workers’ work motions to the 3-D computer virtual clothing simulation system in dynamic mode. Figure 1 shows the research objectives according to 4 phased research steps.

II. Methodology

1. Analysis on the Painting Work Motions

The previous study on manufacturing work processes in the automobile, machine and shipbuilding industries (Park, Park and Bae, 2012b) presented the work posture factors which were upper, lower and lateral body bending of the 12 work processes defined for these industries. Painting workers’ work motions at manufacturing sites were observed and recorded by video camera and were analyzed to categorize painting work motions in the machine
and shipbuilding industries, in terms of frequency and angle of upper, lower, side body movements.

2. Computerization of 3-D Man’s Body Modeling

To generate a 3-D virtual human male model, a human male subject was 3-D scanned and also directly measured in terms of body measurement items, that were height, bust circumference, waist circumference, hip circumference, shoulder length, neck width, back across width, arm length, waist back length, body rise, crotch height, knee height. The procedure to edit a 3-D virtual male model required the total body shape 3 dimensionally scanned in a digital format, which was revised by using 3D Studio MAX(3DS Max®, 2015) and Maya(Maya®, 2015). 3-D modeling and rendering tools.

3. Computerization of Painting Work Motion–capturing

Based on the painting work posture characteristics defined ahead, a human male subject was asked to perform 9 painting work motions following motion–capturing procedures (refer to figure 3). The painting work motion data collected were, in turn computerized to establish virtual work motions within a 3-D clothing simulation system.

4. 3-D Virtual Clothing Simulation of Painting Work Clothes

A questionnaire survey of a previous research(Park et al., 2012a) led a selection of jumper and pants type of work clothes for the painting worker. The pattern–making methods were referred to the ones derived from the relevant previous studies (Park and Lee, 2012: Park, 2013) for jumper and pants type of work clothes. Body measurements for working clothes pattern–making were taken from the 3-D virtual male avatar generated. In addition, the painting work clothes developed for a virtual male model were simulated by implementing the painting work motions within a 3-D virtual clothing simulation system (established by the use of DC Suite, 2015) to present the simulated images in a dynamic mode.

III. Results and Discussion

1. Definition of the Painting Work Motions

Park et al.(2012b) defined the work posture factors as upper, lower and lateral body bending factors throughout the analysis on the 12 manufacturing work processes in the automobile, machine and shipbuilding industries in South Korea. According to these work posture factors, the upper body posture factor was emphasized in pressing, welding, inspecting, cut–and–form processes in automobile and machine industries, grinding and painting processes in shipbuilding and the lower body posture factor was emphasized in welding of automobile and machine, painting and inspecting processes in machine industry. The painting work process also had high impact levels of the lateral body posture factor. Figure 2 is to provide the understanding of manufacturing work posture factor impact levels.

This study specifically categorized painting worker’s work motions into 4 work motion categories, that were standing, waist bending,
**Table 1.** The 4 Categories of Painting Work Motions Detailed with Arm Angles and Directions and Elbow, Waist and Knee Bending Angles

| Work motion category         | Work motion details posture factor combined                      |
|------------------------------|------------------------------------------------------------------|
| Standing motions             | Arm_side_45°~Right/Left                                           |
|                              | 1. Arm_side_90°~Right/Left                                       |
|                              | 2. Arm_side_180°~Right/Left                                      |
| Waist bending motions        | Arm_front_90°~Waist_front_90°~Right/Left                        |
|                              | 1. Arm_side_90°~Waist_front_90°~Right/Left                      |
| Kneeling motions             | 1. Kneel~Elbow_90°~Right/Left                                    |
|                              | 2. Kneel~Arm_front_90°~Waist_front_bending                      |
| Walking motions              | Knee_90°~Elbow_90°~Waist_0°                                     |
|                              | Knee_90°~Elbow_90°~Waist_45°                                    |

**Table 2.** Body Measurements of the 3-D Virtual Male Model

| Body measurement items       | Body measurement(cm) | Body measurement items | Body measurement(cm) |
|------------------------------|----------------------|------------------------|----------------------|
| Height                       | 182.0                | Back across width      | 45.0                 |
| Bust circumference           | 96.0                 | Body rise              | 25.0                 |
| Waist circumference          | 78.0                 | Waist height           | 109.0                |
| Hip circumference            | 95.0                 | Crotch height          | 84.0                 |
| Waist back length            | 48.0                 | Knee height            | 53.0                 |
| Shoulder length              | 14.5                 | Arm length             | 61.5                 |
kneeling and walking motions. Each work motion category has been detailed by considering arm/elbow angles and its moving directions and waist/knee bending angles. Table 1 shows that 4 painting work motion categories consist of 9 painting work motions in total. As to standing motion category, it is divided into 3 motions with 45°, 90° and 180° side open arms and upper body rotating from side to side. Waist bending motion category consists of 2 motions with 90° front and side open arms. 90° waist bending over and upper body rotating from side to side. Kneeling motions have 2 work motions in detail, that are one knee down with 90° bending elbows waist rotating side to side and two knees kneeling down with 90° front open arms and waist bending over. Walking motion category consists of 2 types of motions, which are 90° knees and elbows bending swinging back and forth and waist bending over 0° and 45° each.

2. Characteristics of the 3–D Virtual Male Model Avatar

Table 2 presents body measurements of the human male subject to be generated as a 3–D virtual male model avatar within the 3–D virtual clothing simulation system. The height of 182.0cm, bust/waist/hip circumferences of 96.0cm/78.0cm/ 95.0cm respectively, waist back length of 48.0cm, shoulder length of 14.5cm, waist/crotch/knee heights of 109.0/84.0/53.0cm each, back across width of 45.0cm, and body rise of 25.0cm are body measurements of the subject for the study.

To scan the whole body shape and to capture the motions of the subject in a digital format, the subject wore a fitted suit marked with sensors to perceive major body measurement points for 3–D body scanning, which is shown in Figure 3.

The scanned data of body and work motions were collected into the computer and consequently frame edited and surface rendered (refer to Figure 4) through 3D Studio Max® and Maya® software (AutoDesk Inc., 2015).

Figure 5 presents the completed male avatar’s body with the skin and hair texture in the views of front, side and back. Afterward, the 3–D clothing simulation system would apply the 9 painting work motions defined in the study to this virtual avatar model developed for the painting work clothes simulation.

3. Painting Work Motion–capturing

To motion–capture the painting work motions in a digital format, 9 painting work motions were defined for the study. Table 3 lists the 4 categories of painting work motions resulted and the motion details of each category that were based on sub motion factors, i.e. arm angle factor: 45°/90°/180° open range: arm direction factor: front/side/back directions: elbow bending angle factor: 0°/90° bending range: waist bending angle factor: 0°/45°/90° bending range: waist bending direction factor: front/side direction: knee bending angle factor: 45°/90°/180° bending range. Also, photos about motion–capturing these work motion details are shown in Table 3.

The 3–D male avatar performed these 9 painting work motions within the 3–D virtual clothing simulator, DC Suite, which are shown in Figure 6 according to each painting work motion category.
A human subject in a 3-D scanning suit

A human subject performing work motions to be scanned in a digital format

Figure 3. A human Male Subject for 3-D Body Modeling and Work Motion Capturing through the Computerized 3-D Virtual Modeling System

A male model’s body shape symmetrically edited

A male model’s body surface smoothly rendered

Figure 4. A Male Model’s Body 3-D Virtually Edited and Generated Using 3-D Virtual Modeling Software
### Table 3. Painting Work Motions Defined for Motion-Capturing

| Work motion category | Work posture factor combined | Work motion-capturing images |
|----------------------|-----------------------------|------------------------------|
| Standing motions     |                             |                              |
|                      | Arm_side_45°–Right/Left     | ![Image](image1.png)         |
|                      | Arm_side_90°–Right/Left     | ![Image](image2.png)         |
|                      | Arm_side_180°–Right/Left    | ![Image](image3.png)         |
| Waist bending motions|                             |                              |
|                      | Arm_front_90°–Waist_front_90°–Right/Left | ![Image](image4.png)         |
|                      | Arm_side_90°–Waist_front_90°–Right/Left | ![Image](image5.png)         |
| Kneeling motions     | 1_Kneel–Elbow_90°–Right/Left | ![Image](image6.png)         |
|                      | 2_Kneel–Arm_front_90°–Waist_front_bending | ![Image](image7.png)         |
| Walking motions      | Knee_90°–Elbow_90°–Waist_0° | ![Image](image8.png)         |
|                      | Knee_90°–Elbow_90°–Waist_45° | ![Image](image9.png)         |
Figure 5. The Body Images Complete with the Skin and Hair Texture of the 3-D Virtual Male Avatar Generated in a 3-D Clothing Simulation System

- Standing motion 1: 
  Arm_side_45°—
  Right/Left

- Standing motion 2: 
  Arm_side_90°—
  Right/Left

- Standing motion 3: 
  Arm_side_180°—
  Right/Left
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**Bending motions**

- Waist bending motion 1:
  - Arm_front_90°
  - Waist_front_90°
  - Right/Left

- Waist bending motion 2:
  - Arm_side_90°
  - Waist_front_90°
  - Right/Left

**Kneeling motions**

- Kneeling motion 1:
  - 1_Kneel:
    - Elbow_90°
    - Right/Left

- Kneeling motion 2:
  - 2_Kneel:
    - Arm_front_90°
    - Waist_front_bending

**Walking motions**

- Walking motion 1:
  - Knee_90°
  - Elbow_90°
  - Waist_0°

- Walking motion 2:
  - Knee_90°
  - Elbow_90°
  - Waist_45°

**Figure 6.** The Painting Work Motions Performed by the 3-D Virtual Male Model Avatar
The jumper and pants type of painting work clothes patterns were drafted based on the men’s work jumper and pants block pattern-making methods (Park and Lee, 2012; Park, 2013). Figure 7 shows the work clothes patterns worn by the male avatar within the 3–D clothing simulation system.

In conclusion, the 3–D painting work jumper and pants clothing simulation finally produced the virtual images worn by the virtual male avatar while performing given work motions in a dynamic simulation mode (refer to Figure 8). Which means the usage of the virtual clothing simulator can be extended from dealing with the fashionable items in the context of the appearance evaluation to the industrial clothes and equipments for the investigation of the wearer’s iterative movement without fatigue and excluding the harmful environmental factors.

IV. Conclusion and Suggestion

The results derived from the research highlighted that the work motions observed at
manufacturing sites were varied in multiple categories and wide posture factor ranges. Concerning the research aims, the research has been successful to define the painting work motions and consequently to implement the digital format data of a human male subject’s body features and painting work motions captured to the 3-D clothing simulation system for the study. It also effectively suggested the virtual images of the painting work clothes 3-D simulated by a virtual male avatar’s wearing and performing the work motions designated.

In particular, the 3-D painting work clothes simulated images were caught in various aspects including cross-sectional views of the clothes, that would evaluate its appearance effect and the wearer mobility by analyzing percentage of voids between body and clothes at the level of selection (refer to Figure 9).

![Figure 9. 3-D Clothing Simulation Cross-sectional Images for the Percentage of Void Analysis of the Painting Work Pants Developed](image-url)
Figure 10 and Figure 11 also suggest the examples of the simulated work clothes images with seam line indication and also with textile mesh effect, that would facilitate the investigation on the clothing construction effect of patterns developed.

Considering all these results, the research provides with the high possibility to utilize the 3-D clothing simulator for the purpose of investigating the protective or functional clothes performance with effect. Besides, the research may emphasize the necessity of more studies on work motions in different industries and consequent functional clothes of requirement.
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