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Modeling Technology on Free-form Surface of a New Military Personal Head using Quick Surface Method

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퀵서피스기법을 이용한 신장병 두상의 자유곡면 모델링 기술

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ABSTRACT

Recently, weapon system requires personal protection products due to the explosion of rapid-fire explosion, which is considered to be multi threat in modernization, complication and war against terrorism. However, the conventional Korean military bullet protection helmets are not suitable for wearing convenience and combatant interoperability in terms of ergonomic. In this paper, we propose a suitable 3D Scanning method for the head, and compare the measured 3D dimension with the existing 2D measurement value to identity the reliability. Reverse engineered soldier head using the quick surface method was realized with a perfect free-form surface and satisfactory tolerance range (±0.2 mm). Through the comparison of 3D and 2D measured head dimensions, the absolute error value was 0.73 mm on average and relative error was 0.35 %, confirming the high accuracy of the 3D scan modeling. Also, quick surface method using 3D scanner is suggested a fast and accurate skill for ergonomics in obtaining the head modeling needed for military's personal bullet protection helmet design.

Key Words : Quick Surface Method(퀵서피스기법), Three-Dimensional Scanning(3차원스캐닝), Relative Error(상대오차), Free-form Surface's Head(두상 자유곡면)

1. Introduction

Recently, many countries around the world are strengthening their national defense system by developing bullet protection helmets with improved protection against multi-threats. These helmets have durability in extreme battle environments, wearing convenience, and combatant interoperability for soldiers[1].

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The U.S. Army uses high-performance modular integrated communication helmets (MICHs). However, South Korea uses bullet protection helmets of the personal armor systems for ground troops (PASGT) type, which are lightweight helmets that have disadvantages for the interoperability of night vision devices and telecommunication equipment[2].

The bullet protection helmets of the Korean army were developed in the early 2000s. Therefore, changes in the head sizes and shapes of the new-generation soldiers need to be reconfirmed. Furthermore, better ergonomic designs than the existing bullet protection helmets that consider wearing convenience and combatant interoperability are required. Wearing convenience means that there is no sense of pressure or looseness when users wear the helmets. Combatant interoperability means that there is no interference in combat activities such as NBC (nuclear biological chemical) and shooting[1,2].

The standard head dimensions for the designs of helmets are being subdivided with technology development. For the current helmets of the Korean army, the width and length of the head are reflected in the size classification. However, bullet protection helmets cause inconveniences even with small changes in the head shape due to low material flexibility and limited shape variations. To solve this problem, head modeling was implemented using three-dimensional (3D) scanners for the quick modeling design of the ergonomic free-form surface appropriate for the head shapes of new-generation soldiers [4-7].

This study compares the absolute and relative errors for the differences of measurements in 3D head modeling with a 3D scanner and 2D head modeling, for nine measurement parts. In addition, a reliable model of the head shapes of the new-generation Korean army with standard dimensions was applied by using the quick surface method and verifying the 3D head modeling data.

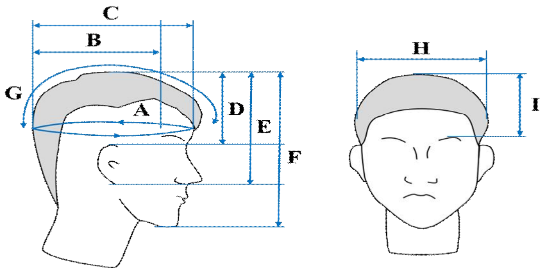

Fig. 1 Composition of measuring position for standard size of military personnel's head[3]

Table 1 2D standard size with measuring position using T-square ruler and tapeline

	Measured position	Standard size (mm)
A	Head circumference	597.9
B	Temple ~ occiput	179.1
C	Head length	199.1
D	Crown ~ earflap	122.6
E	Crown ~ earlobe	178.4
F	Crown ~ jaw tip	260.8
G	Eyebrow ~ occiput	330.9
H	Head breadth	168.2
I	Crown ~ eyebrow	99.4

2. 3D Scanning Method for the Head Shapes of New Generation Soldiers

2.1 2D Measurement method for head shapes

The T-square and tapeline were used for 2D measurement, and 530 trainees were used for the master set of samples. Since the actual head shape has a free-form surface rather than a geometric shape, even fine variations in curvature can cause large differences. Therefore, additional measurement parts were defined, in addition to the three elements (circumference, width, and length) for the current bullet protection helmets. As shown in Fig. 1, there are nine measurement parts of the head shape, A to I. The critical dimensions include the head circumference A, hair length C, and hair width H.

The other six parts as measured, refer to the curvature variations of the head. The measured dimensions were classified into large, medium, and small similar to the size classifications applied to the bullet protection helmets. This study only calculated the statistics for the large size, and the standard size values are listed in Table 1.

2.2 3D scanner measurement method for head shape

The reverse engineering of the head shape using a 3D scanner was carried out in four processes, as shown in Fig. 2. In the first step, the 3D scan derived the first head shape points. In the second step, to implement the STL (Standard Triangle Language) imagery, the head dimensions measured through the optimization of polygon data interconnected among partial points, were shaped. In the third step, the surface of the head shape was created by bonding the polygons. In the final step, for solidification, the head modeling of new-generation soldiers was implemented through verification and comparison [9-11] using the solid data of the completed head shape.

To accurately measure the head shape with a 3D scanner, it is critical to capture a static moment because data errors are caused by breathing and muscle movements of the human body [4,5]. The 3D scanner used in this study is an optical device, Spider (ARTEC 3D, USA), which can scan at 16 frames per second with a 0.1 mm resolution and a 0.05 mm accuracy. In addition, the software application Geomagic Freeform (3D SYSTEMS, USA) was used for editing and verification of the acquired 3D scan data. As this application allows intuitive editing through the simultaneous control of a mouse and a haptic device, it was used for the modeling and editing of the head shape with a free-form surface.

For the acquired head shape data, standard dimensions were applied so that they can be used in the future design of bullet protection helmets. The quick surface method was applied to convert the surface-based mesh data to NURBS-based data for solidification and to implement the same dimensions as the head shape standard dimensions. Furthermore, the modeling after the reverse engineering was verified through a quality inspection of the tolerance range.

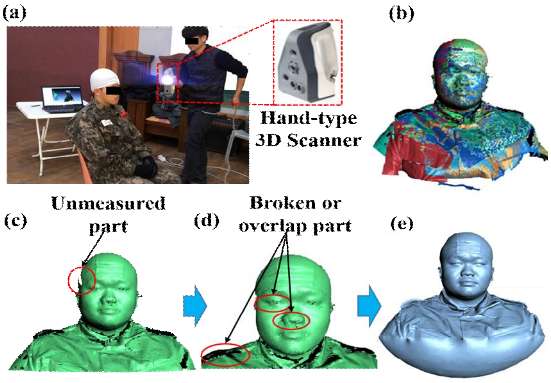

Fig. 2 Process from 3D measurement using hand-type 3D scanner to surface data acquisition: (a) photographing 3D measurements, (b) primary acquired 3D point cloud data, (c) aligned 3D point cloud data, (d) best-fitted 3D polygon data and (e) fusion merged 3D surface data

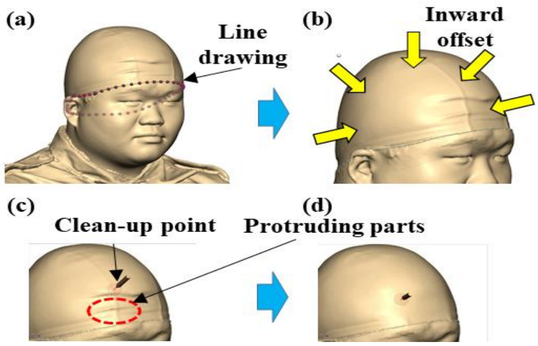

Fig. 3 Process of getting a clean headpiece: (a) removing thickness of swim wool using line drawing and (b) removal of protruding part using clean-up function

3. Free-form Surface Modeling of Head Shapes Using 3D Scanner

3.1 Measuring and editing 3D scan data

The 3D measurements and the first point areas are shown in Fig. 2(a) and Fig. 2(b). The conversion from the point data to mesh-based 3D modeling is shown in Figs. 2(c) to 2(e). The acquired point data were aligned based on the central axis and the zero point as shown in Fig. 2(c). In the best fit process, the aligned data for all frames were aggregated into absolute coordinates and represented as polygon data, as shown in Fig. 2(d). Finally, the point data (aligned to one coordinate system) were converted to mesh data through a fusion merge. This fusion merge matches suitable multiple frames to one polygon's data to create surface data. As shown in Fig. 2(e), approximately 42,000 curved surfaces were obtained by converting fusion merged head-shape polygon data to surface-based mesh data.

The white swimming cap that covered the heads of soldiers to supplement the shortcomings of the optical scanner was removed by the clean-up function in the software application. As shown in Fig. 3, the starting point of the swimming cap was set by a line drawing. The clean-up was performed for 3 mm inward, considering the thickness of the swimming cap (3 mm). Furthermore, to remove the wrinkles of the swimming cap, the projected parts of the swimming cap were removed using a haptic device, as shown in Fig. 3(b).

3.2 Reviewing the accuracy of 3D scan data

To review the accuracy of the 3D scan data for measuring the head shape with a free-form surface, the 3D data were compared with the 2D measurement data. Among the 530 subjects, a soldier who has the closest head shape to the large

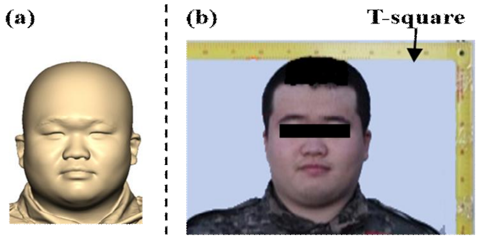

Fig. 4 Photographs of different ways to measure the size of headpiece: (a) 3D measurement using 3D scanner and (b) 2D measurement using T-square ruler and tapeline

Table 2 Analysis of the errors according to measurement method for the nine measuring position [mm]

	3D data (α)	2D data (β)	Absolute error ($\lvert\alpha-\beta\rvert$)	Relative error ($\left\lvert 1-\frac{\beta}{\alpha}\right\rvert \times 100$) %
A	605.9	605.0	0.9	0.14
B	173.9	175.8	1.9	1.09
C	196.0	195.9	0.1	0.05
D	130.4	130.0	0.4	0.30
E	180.6	180.0	0.6	0.33
F	269.3	270.0	0.7	0.25
G	323.8	323.0	0.8	0.24
H	179.3	180.3	1.0	0.55
I	105.2	105.0	0.2	0.19
Average			0.73	0.35

size was selected and a 3D scan was performed. Then, the results were compared with the 2D measurement data of the soldier. Fig. 4(a) shows the curved surface data of the 3D scan data, and Fig. 4(b) shows the 2D measurement image using T-square. Table 2 lists the nine measurement parts derived through 3D measurements and shows the different ratios for the 2D and 3D measurement data. The calculated absolute error was found to be less than 2.0 mm. For the head length, it was 0.1 mm, which is the minimum difference. Furthermore, the maximum difference with the 3D measurement data was 1.09 mm. The overall relative error (comparing the 3D and 2D measurement data), was less than 0.35 % on average, indicating a very high accuracy.

4. 3D Head Modeling and Verification Using Quick Surface Method

4.1 Change of the 3D modeling dimensions

The head shapes for designing the bullet protection helmets must be those of the Korean army, for which the standard dimensions are applied. In this study, the quick surface method was used to apply the large size standard dimensions. The quick surface method increases or decreases the dimensional changes by setting the reference planes to the curved surface data obtained from the 3D scan data, as shown in Fig. 5[6]. The locations of the reference planes were set at the eyebrows, the projected back of the head, and the center of the head shape. In addition, the shoulder part, which is unrelated to the head shape, was removed. The NURBS-based standardized head shape result is shown in Fig. 5(b).

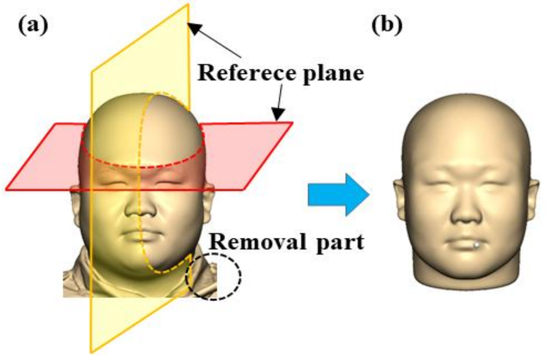

Fig. 5 Modification of head size using quick surface method: (a) method of changing head size by creating reference planes and (b) standard sized head obtained using quick surface method

4.2 Verification of the reverse engineering of 3D head modeling

A tolerance analysis was performed for the NURBS-based standardization head modeling. This head modeling was converted through the quick surface method in the CAD-based software, which has a high precision for dimensions. In the quick surface process, as shown in Fig. 6(a), the basic meshes were implemented through the auto surface. The centerline for left and right symmetry was created, and the precise mesh data were created through the cloud function. Finally, to verify the 3D head modeling, a deviation analysis was carried out for the precision mesh data created with quick surface and the data that were not completed as NURBS-based data. The result showed a deviation of less than ±0.2 mm[5], as shown in Fig. 6(d). This satisfies the tolerance range of ±0.2 mm determined through the tolerance function with a scan precision of 0.05 mm.

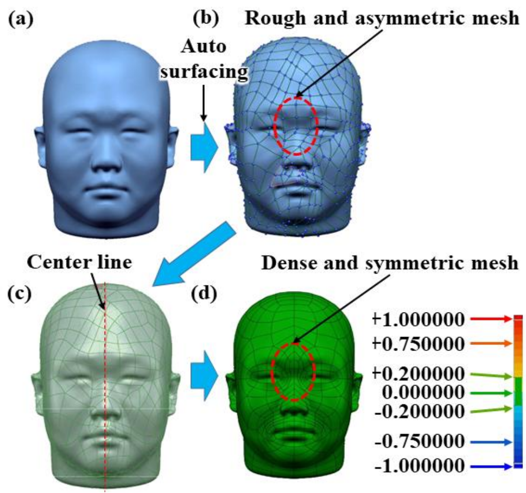

Fig. 6 Result of generation and verification of nurbs data: (a) existing 3D modeling data, (b) composed basic mesh by auto surface method, (c) inserted center line for symmetry and (d) precision mesh generation and analysis of deviation from existing 3D modeling

5. Conclusions

This study used the quick surface method to perform head modeling with a 3D scanner and analyzed the differences between the 3D and 2D measurement data. Furthermore, NURBS-based data conversion and deviation analysis were performed, and the following results were obtained. A comparison of the nine parts for the head shape measurement data obtained with the 3D scanner and the 2D measurement data found a relative error of 0.35%, which confirmed the high accuracy of the 3D scan data. The 3D head shape data of the quick surface method satisfied the tolerance range through the deviation analysis. The reverse engineering of the complex free-form surface shape of the head could be presented quickly and accurately.

In the future, this method can obtain the head modeling data for the design of personal bullet protection helmets for the South Korean army. Reverse engineering with a 3D scanner is expected to be highly useful for designing new ergonomic bullet protection helmets. These helmets have advantages in terms of personal protection, improved wearing convenience and interoperability. Furthermore, the results of this study are expected to improve the morale and combat power of soldiers through an effective shape design of “bullet protection helmets with improved bullet protection performance”.

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