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DIGITAL TWINS FOR WETSUIT DESIGN

ВИРТУАЛЬНЫЕ ЦИФРОВЫЕ ДВОЙНИКИ В ПРОЕКТИРОВАНИИ КОСТЮМОВ ДЛЯ ПОДВОДНОГО ПЛАВАНИЯ*

DIGITAL TWINS FOR WETSUIT DESIGN

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This paper presents the method of digital twins of female bodies generating and the simulation of the wetsuit with the help of virtual reality technologies. The first step includes the obtaining of a virtual clone of female bodies with 3D body scanning technology and the exploration of soft tissue deformation under an influence of diver postures and hydraulic pressure. The second step involves the use of CLO3D to conduct dynamic deformation tests on the wetsuit digital twin and the body digital twin. The experimental results show that the digital twins based on real data transformation are feasible and practical, and the process of establishing digital twins by means of 3D body scanning technology is valid and accurate.

В статье описан метод генерации цифровых двойников женских фигур и совершенствования конструкций костюмов для подводного плавания с помощью технологий виртуальной реальности. Первый этап включает получение цифрового клона женской фигуры с помощью технологии бодисканирования и исследование деформаций мягких тканей под влиянием динамических поз и водяного давления. Второй этап включает применение CLO3D для симуляции динамических деформаций виртуальных двойников костюма и фигуры. Экспериментальные результаты подтвердили реалистичность и практическую ценность цифровых двойников, полученных с помощью обра-

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ботки реальных данных, а также применимость и точность процесса получения цифровых двойников фигур с помощью технологии бодисканирования.

Keywords: wetsuit, virtual twin, 3D body scanner, digital clone, simulation.

Ключевые слова: костюм для подводного плавания, виртуальный двойник, 3D-сканер фигуры, цифровой клон, симуляция.

1. Introduction

In recent years, the application of simulation technology in clothing research and wearing performance has greatly increased [1]. On the other side, due to 3D body scanning technology has been applied in some clothing simulation researches to get accurate measurements, to generate “scanatars”, extract the cross-sections, and analyze key body parts [2]. 3D scanning technology can also be used for obtaining dynamic anthropometrical data, which is especially important for developing design of clothing with special purposes, high demands on functionality and fit [3]. The morphology and dynamic postures of the human digital twin will directly affect the virtual performance of compression clothing. For example, the digital clones are automatically created by 3D scanning in static [4], and then processed and optimized by complex calculation methods in dynamic [5], [6]. Some researchers studied the deformation of human bodies which are presented by the digital clone or avatar by analyzing some swimming and dynamic postures to improve the design of compression sportswear [7], [8].

At present, less research is about wetsuits simulation. Only a few scholars make researches related to wetsuit design, devoted to the patterns, textile material, simulation, etc. S. Kim [9] made the investigation about the relationship between the wearing condition and the size systems of different brands. M.M. Naglic et al. [10] studied wetsuit patterns obtained directly from female bodies. J.H. Choi [11], [12] made the study about patterns development, production, and consumer satisfaction of male wetsuits in their 30's. To make pattern blocks, all researches used the body measurements measured in standard standing posture, which is not related to wearing conditions.

As for the 3D simulation of wetsuit pattern design, the common way was derived from 3D surface flattening method, which involves the garment construction by drawing and creating patterns directly on a digital twin surface and separation of discrete 3D surfaces as well as transformation into 2D cutting parts [13]. M.M. Naglic [14], [15] scanned the bodies on the land in six postures, such as raising hands and squatting, and designed a virtual diving suit by means of Optitex software. T.H. Staal [16] used CLO software to test male wetsuit in terms of fitting effect and material strain, but without an optimization and comfort evaluation of the patterns.

In this study, based on 3D human body scanning technology, multiple types of digital body twins (DBT) are established in virtual reality in terms of morphological features and body deformation under dynamic compression. Then, through the analysis of body measurements and wetsuit structure, the digital wetsuits twin (DWT) were obtained to improve the wearing fit in dynamic. This process of creating a digital twin (DT) can be applied in wetsuit design and evaluation.

2. Body measurements

96 females (aged from 18 to 27) volunteered to participate in the body scanning test. All measurements were taken under standard ISO 7250, the total number of measurements in static and dynamic postures was 36. The heights are 147.3…173.6 cm, bust, waist, and hip girths were 74.0…94.2 cm, 56.2…90.9 cm, and 79.0…104.8 cm respectively. To show that 96 female subjects are enough for this exploration, the SPSS was used to test the normality of data. After investigation of distribution diagram of bust girth and other measurements, it was proved that measurements obey to normal distribution with the Cronbach’s α is 0.974.

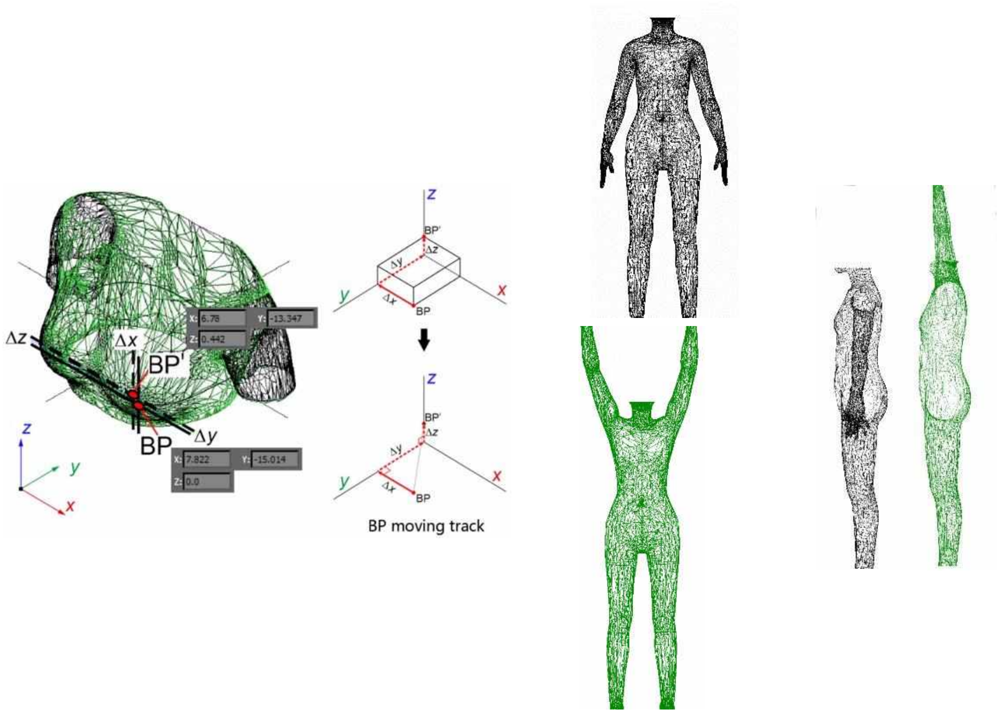
All representative measurements were obtained by means of Human Solutions Vitus smart XXL scanner and contact manual type on the floor), and the partial measurement of the model is carried out by the Anthroscan software.

The body dimensions which were changing in dynamic postures underwater were measured by hand type along the anthropometrical lines tracking on the body surface [17].

3 Digital twin of human body

The primary digital clones were obtained by direct scanning, and the digital body twins DBT were created by means of CLO and MakeHuman software. Then the primary DBT was imported to 3ds Max to further modify the soft tissue in accordance with its changes in dynamic positions, and finally, the deformed DBT with real dynamic postures was constructed.

To design the deformable digital twin of the body, two databases consisting of the same body measurements in static and dynamic positions were formed. After comparing the pair of static and dynamic measurements, the coordinates of anthropometrical points of initial and deformable clones were found to parameterize the soft tissue changing. Because the breast area is more sensitive to pressure, the deformation of the breast was simulated in 3ds Max through editing the “mesh” with coordinates. Fig. 1,a shows the scheme of bust area deformation under the influence of the dynamic posture, Fig. 1,b shows both digital clones: when the arms are down in black mesh (left) and when the arms are raised in green mesh (right).



a) b)

Fig. 1

As shown in Fig. 1-a, the coordinates of the initial bust point is (0, 0). When the arms raising, the position of BP changed in three directions *x*, *z,* and *y* and the average distances are Δx = -1.042 cm, Δy = 1.667 cm, and Δz = 0.442 cm. The parallelepiped in the red line illustrates the moving track of BP in three-dimensional space.

Similar studies were done for other anthropometrical points – neck front FNP and waist front FWP, neck back BNP and waist back BWP - to determine the tilt degree. Fig. 2 shows the morphology adjustment of completed deformable clone under the soft tissue changing in dynamic.

As Fig. 2 shows, both sagittal planes of torsos - initial and deformable - are overlapped in crotch point Cr. Based on measurement data, the Δf, Δb, FNP-FWP, and BNP-BWP illustrate the upper torso tilts backward after raising arms. The length of the front line increases by 10.6%, the back line decreases by 15.5%. Therefore, the DR can be accurately controlled by adjusting the four key points and the length of measurements.

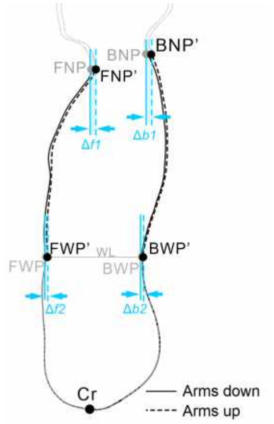


Fig. 2

4. Digital twin of female wetsuit

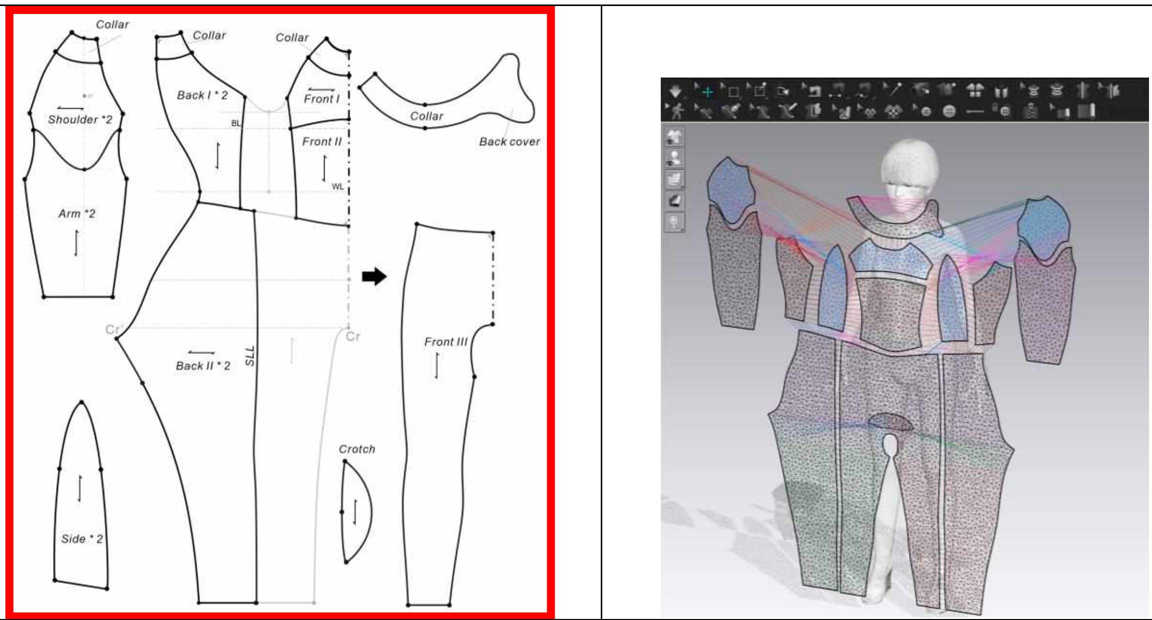
4.1. Virtual stitching and fitting

To construct a digital wetsuit twin (DWT), the patterns of wetsuit were imported into CLO. To develop a method of design, a new approach based on multi anthropometric data was proposed [18].

The commonly used materials have been selected (the maximum elongation under 500 cN/cm is 30.2%, and the shrinkage is about 3%). Due to the particularity of wetsuit material, the properties of multi-layer material cannot be directly imported in CLO, so the default value of “elastic knitted material” is selected to conduct the simulation. The thickness is set to 3 mm. Two tools – "tack" to fix a wetsuit on DRB and "sewing" to sew wetsuit pieces - were applied to conduct try on.

Fig. 3-a shows the optimized wetsuit pattern [18]. According to the female body characteristics, a new design method of wetsuit is proposed. For example, the bust segmentation line is above BL in a certain range, and the abdominal segmentation line is below WL in a certain range in accordance with the established morhpological changes under the compressionof suit, the swimming position and the hydravlic pressure. The best segmentation and line configuration were determined through a series of tests, and the direction of material cutting is changed to improve the tight degree at the swimming position.

Fig. 3-b shows the developed patterns with negative ease, the segmentation lines exist at the bust, side, and shoulder areas.



a) b)

Fig. 3

The appearance of the virtual wetsuit has good fit performance. Besides, the objective evaluation was carried out through two measured factors - the real and virtual pressure and the material strain. The real pressure were measured above water by means of the sensor in combination with manual measurement.

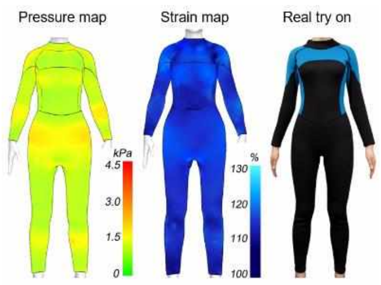
The pressure value is an important factor, will be changed during diving and should be kept in a certain range. Therefore, the fitness can be judged by calculating the value ΔP

$$\Delta P = 100\,(P_{au} - P_{ad}) / P_{ad}, \qquad (1)$$

where are ΔP is a relative difference between the virtual pressure measured in static and dynamic postures, %; P_{au} is the virtual pressure when arms up, kPa; P_{ad} is the virtual pressure value when arms down, kPa.

Besides, the virtual material strain should be checked whether it exceeds the reference value of real material mechanical elongation (KES), or the designed ease.

Figure 4 shows in virtual reality the material performance of wetsuit – pressure maps and material strain - and try on on the real body when arms down (a) and when arms up (b).



a)

b)

Fig. 4

As shown in Fig. 4, it can be seen from the pressure map that the pressure values are in a reasonable and moderate pressure range. The light green colors indicate the weaker pressure values generated by CLO, on the contrary, the yellow or orange mean that the pressure values are stronger than green. The ΔP at the critical body parts (SP, BP, and side) are -17.3%, 1.3%, and 16.2% respectively. When arms down, the average virtual pressure P_{ad} is 1.89 kPa, and the real pressure P_{ad} is 1.65 kPa; when arms up, the average virtual pressure P_{au} is 1.75 kPa, and the real pressure P_{au} is 1.60 kPa. The deviation between real and virtual is less than 0.24 kPa, which means the virtual and real compression has little difference. It can be concluded that the objective compression experience of the digital twin can be used to predict real pressure performance.

Then, through the measurement results of multiple areas, the material strain values (original is100%) change from 112.8% (wrist) to 125% (armpit). So, the pressure value and material strain are reasonable.

Moreover, the appearance fitness can be directly observed through the virtual try on in Fig. 4. The wetsuits are very tight without folds.

The simulation results show that the digital replicas of wetsuits and bodies are rational and valid, and can obtain reasonable pressure and material strain in dynamic and static, obviously improve fit performance.

CONCLUSION

Based on human body scanning data, the digital twin "wetsuit - female body" system was created by 3D software in terms of both deformation processes of bodies and textile composite materials. The digital twin was generated based on the measurements and characteristics of real human body in dynamic postures. This digital twin can adapt to the real human body shape in static and dynamic and can complete the design through virtual technology.

The wetsuit design was completed and evaluated by virtual technologies with a reasonable pressure range and good fit performance.

The virtual results will help wetsuit designers respond to rapid modification, evaluation, and omit actual repetitive manufacture works for optimizing pattern design, enhancing productivity, and further improving customer's wearing experience.

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