Hand Surface Area Variation Analyzed by 3D Laser Scan Measurement

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Abstract

Gloves are designed and used to protect our hands from impairment and hurt. However, the lack of comfort and the reduction of dexterity often frustrate the use of gloves. Thus, a good design of gloves has to provide both fitness and movability. Traditionally hand dimensions had been measured by Martin-type anthropolometers and nowadays 3D laser scanning technologies to develop glove size models. Both approaches measured hand dimensions under some standard posture and failed to estimate the variation of hand surface area (HSA) as hands moving from one posture to another. Thus, suggestions for the design of glove movability are scarce. This study aimed to analyze HSA variation using 3D laser scan measurements. The raw 3D surface shape of hands was measured by a laser scan system with resolution of 1 mm × 1 mm × 1 mm and precision of ± 0.4 mm. Each hand was measured under three postures including standard, relaxed and grasp. HSA was calculated for standard and relaxed digital hands. Dorsal finger length was extracted for all three postures. The results showed that the variation of HSA for postures changed from standard to relax was about 3% reduction. And dorsal finger length increased to about 108% and 118% for postures changed from standard to relaxed and grasp, respectively. It is suggested that the palmar side of gloves remains designed by hand dimensions under standard posture while the dorsal side of gloves improves by designed for relaxed hand and providing material elasticity about 10%.

Key words: *Hand anthropometry, Hand surface area, 3D laser scan, Gloves*
JEL Classification: *L67, I19*

1. Introduction

Gloves are designed and used to protect our hands from various impairment and hurt. However, the lack of comfort and the reduction of dexterity of hands often frustrate the use of gloves. Thus, a good design of gloves has to provide both fitness and movability for hands. For fitness, traditionally hand dimensions had been measured by tapes, calipers and Martin-type anthropolometers to develop glove size models. Robinette and Annis (1986) suggested a glove size model developed by hand length, palm circumference and other twenty hand dimensions. Hidson (1991) and Tremblay et al. (1992) measured fifty and nineteen hand dimensions for the reference of glove design, respectively. The more hand dimensions measured the more adequate in the evaluation of the fitness of glove design (Jones & Rioux, 1997). Besides, Halioua et al. (1992) estimated the projected palmar and dorsal areas of hand by a dual camera system for the reference of design of gloves. The projected 2D shapes are closer to real 3D hand shapes than 1D dimensions measured by tapes, calipers and etc.

3D hand surface shape had been measured by coating methods over a century; e.g. let subjects put on thin cotton gloves on hands, pour and soak melted paraffin into the meshes of the cotton of the gloves on hands, after paraffin hardened the hand mold is made, cut the mold into small scrapes that close to a flat surface, then expose scrapes on photographic paper under sunlight, finally cut and weigh the reflections on photographic papers to calculate hand area (Du BOIS and Du BOIS, 1915). It was time-consuming and uncomfortable for subjects suffering the high melting point (52 ºC) of paraffin. Nowadays the surface shape of hands had been measured by 3D laser scanning technologies under some standard posture (Tikuisis et al., 2001; Yu et al., 2008; Yu, et al., 2013). It is faster, more comfortable for subjects, and more precise. However, most databases were measured hand dimensions by scanners with resolutions 5mm × 5mm × 2mm (Daanen & Water, 1998) ~ 2mm × 2mm × 1mm (Yu et al., 2010) under standard postures. Yu et al. (2008) had measured by a scanner with resolution 1mm × 1mm × 1mm but also only under standard postures.

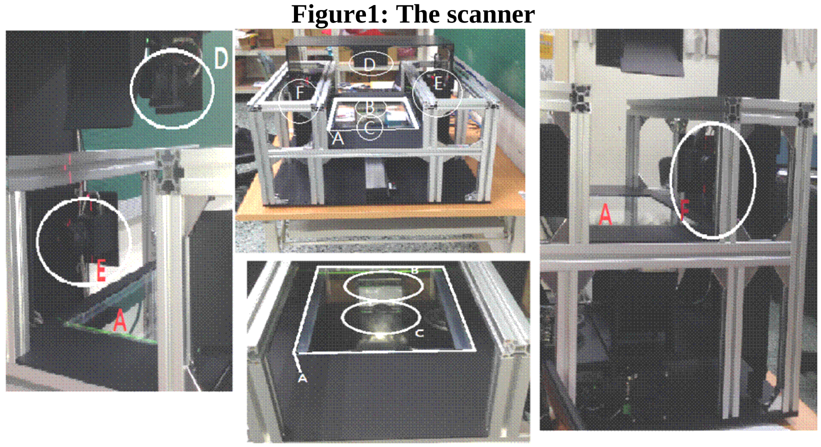
Both approaches, traditional anthropolometers and advanced 3D laser scanners, failed to estimate the variation of hand surface area (HSA) as hands moving from one posture to another. Thus, suggestions for the design of glove movability are scarce, except to use flexible materials on joint area of gloves.

2. Methodology

This study aimed to analyze HSA variation among different postures using 3D laser scan measurement. The raw digital hands were measured by a laser scan system. Two functional postures were compared with a standard posture. The results of difference and variation percentage of hands from standard to relaxed and grasp postures were tabulated.

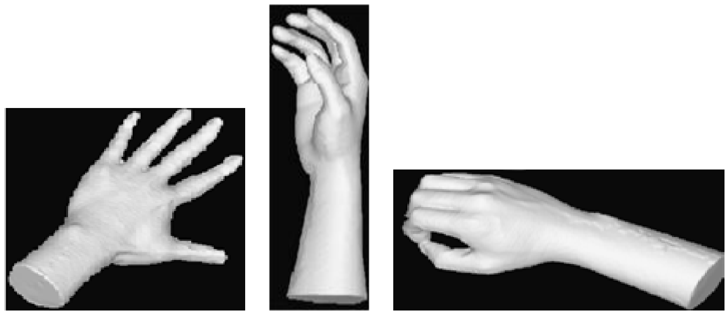
The raw 3D digital hand data used in this study were measured by a research project sponsored by the Ministry of Science and Technology, Taiwan. The scanner (shown in Figure 1) used in the project had resolution of 1 mm × 1 mm × 1 mm and precision of ± 0.4 mm, designed by Logistic Technology Corporation, Taiwan. Around the platform of transparent glass were four scanning heads, which moved simultaneously to take the pictures of target hand put on the platform. After scanning, the software Beauty3D v.3.2 integrated the data caught from all four heads; consequently about forty thousand 3D coordinates were acquired to form the surface shape of the target hand in about three seconds. Examples of scan outcome were shown in Figure 2.

Figure1: The scanner



This study is a pilot study of the project. Raw digital hands of thirty subjects measured by the project were used. Thirty subjects included fifteen males and fifteen females. Each gender comprised five slim (BMI<18.5), five medium (18.5<BMI<27) and five fat (BMI>27) subjects. Each hand was measured under six different postures, three standard and three functional postures in the project. One standard and two functional postures were chosen in this study. The standard posture was set with hands stretched straight and five fingers open to the extreme without difficulty, shown as Figure 2 (a). The relaxed posture was set with hands totally relaxed, e.g. Figure 2 (b). The grasp posture was set as the palm and fingers flexed to the extent for thumb tip and index finger tip just touched, shown as Figure 2 (c). Two hands of each thirty subjects with three postures, totally 180 raw digital hands measured by the project were used in this study. The results of validation of the measuring system of the project were 3.6% of precision and 2.2% of accuracy under the standard posture (Lin and Hung, 2014).

Figure2: The scan outcome of three hand postures



(a) (b) (c)

Take the standard digital hand as a base, relaxed and grasp digital hands were compared with by the difference and variation percentage of HSA and dorsal finger length. To calculate HSA, firstly each digital hand was cut off on the circumference at right angles to long axis of forearm at level of tip of ulna. The raw digital hand is a triangular-meshed digital model. HSA was calculated by the summation of every tiny triangular area of triangular meshes of the scanned surface. Cutting off digital hand and calculating HSA were implemented by software Anthro3D, which was also developed by Logistic Technology Corporation, Taiwan.

The HSA was calculated for standard and relaxed but not grasp posture. A hole emerged on the palm area of grasp digital hands and the HSA calculated for grasp hand would be underestimated. The hole was caused by the shadowed central region of the palm on which no laser light could reach and thus no light could be reflected into camera in the scanning heads. Although software Beauty3D v.3.2 equipped patching algorithm, it cannot be restored to the original shape of the central palm area of grasp hand.

Instead, dorsal finger length was extracted. Since the girth of fingers of each subject remained the same in the one-hour period of scanning; the dorsal surface area of the finger varied the same percentage as the dorsal finger length varied. The dorsal finger length of relaxed and grasp were compared with that of standard posture.

3. Results

The mean (standard deviation) of HSA of standard and relaxed posture in cm^2 were shown in Table 1. The mean HSA of standard and relaxed posture of thirty subjects' both hands (totally sixty hands) was 367.61 (55.15) cm^2 and 356.99 (53.61) cm^2, respectively. The data showed that the HSA of standard posture was bigger than that of relaxed posture. The mean (standard deviation) difference of standard HSA minus relaxed HSA was shown in the row of "S－R" in Table 1. The smallest difference was 8.12 (4.75) cm^2 of female medium group and the biggest difference was 14.02 (4.69) cm^2 of male medium group. And the mean difference was 12.21 (6.01), 8.96 (4.38), 10.62 (5.47) cm^2 for male group, female group, and all subjects, respectively. The mean reduction percentage of HSA from standard to relaxed posture was 3.0% (1.4%), 2.8% (1.4%) and 2.9% (1.4%) for male group, female group and all subjects, respectively.

Table1: The HSAs of standard and relaxed posture of hands [cm^2]

Mean(s.d.)		Slim(BMI<18.5)	Medium(18.5<BMI<27)	Fat(BMI>27)	Mean
Male	Standard	379.74 (53.16)	386.44 (12.87)	447.27 (44.12)	404.48 (49.87)
	Relaxed	373.23 (50.72)	375.42 (15.65)	435.73 (43.03)	394.79 (48.13)
	S－R	9.28 (5.23)	14.02 (4.69)	12.99 (7.35)	12.21 (6.01)
Female	Standard	310.12 (15.73)	335.47 (18.84)	326.94 (16.16)	324.17 (19.56)
	Relaxed	301.63 (12.78)	327.35 (20.74)	323.33 (17.83)	317.44 (20.36)
	S－R	10.65 (2.18)	8.12 (4.75)	8.24 (5.65)	8.96 (4.38)
All subjects		Standard: 367.61 (55.15)、Relaxed: 356.99 (53.61)、S－R: 10.62 (5.47)			

The mean dorsal finger length (variation percentage) of standard, relaxed and grasp posture were shown in Table 2. The data showed that the longest was middle finger, the shortest was thumb. And grasp finger length was the longest, relaxed the next, and standard was the shortest. When fingers flexed from standard to relaxed and grasp, the dorsal finger length stretched 107.9% and 118.3% averaged by five fingers of both hands of all thirty subjects. For group means of relaxed posture, 109.9% of male thumb group was the biggest, and 106.4% of female ring finger group was the smallest. On the other hand, 126.9% of male little finger group was the biggest, and 115.4% of female thumb and index finger group was the smallest in grasp posture.

4. Discussions and Conclusions

Hand surface area is hard to measure. The measurement used in this study integrated 3D laser scan technologies and software algorithms. The data in this study possessed the level of precision and accuracy that technologies can achieve so far. And the area variation was measured directly from different hand postures of subjects. The results shown above could suggest the extent of movability that a glove should provide.

Table2: The dorsal finger length of standard relaxed and grasp hands [cm (%)]

Mean Length(Variation)		Thumb	Index	Middle	Ring	Little	All fin -gers
Male	Standard	5.67	8.82	9.85	9.12	6.80	
	Relaxed	6.22(109.9)	9.46(107.3)	10.58(107.6)	9.89(108.7)	7.44(109.8)	(108.6)
	Grasp	6.98(123.7)	10.24(116.3)	11.36(115.5)	10.69(117.6)	8.59(126.9)	(120.0)
Female	Standard	5.48	7.95	8.82	8.14	6.00	
	Relaxed	5.84(106.7)	8.56(107.9)	9.44(107.3)	8.65(106.4)	6.44(107.5)	(107.2)
	Grasp	6.31(115.4)	9.15(115.4)	10.18(115.8)	9.39(115.7)	7.20(120.7)	(116.6)
All subjects	Standard	5.57	8.38	9.34	8.63	6.40	
	Relaxed	6.03(108.3)	9.01(107.6)	10.01(107.4)	9.27(107.5)	6.94(108.7)	(107.9)
	Grasp	6.65(119.6)	9.69(115.9)	10.77(115.7)	10.04(116.7)	7.90(123.8)	(118.3)

3D laser scanning system has its own limits. Holes emerge on the acquired raw digital data if some region of the target objects is shadowed. And it is difficult to restore the exact original 3D surface shape when the hole is big. The error of the extracted 2D (e.g. area) and 3D (e.g. volume) dimensions from the digital data with holes increase. Thus the development of technologies of good patching algorithm is expected. In the project three functional postures were measured, i.e. relaxed, grasp and fist postures, in which grasp and fist could not be scanned into intact digital hand. The central region of palm shadowed. And the spaces between fingers were too narrow for the scanner to resolve into in grasp and fist postures. Thus holes emerged and fingers stuck shut. Only some 1D dimension was extractable. Therefore HSAs were only calculated for standard and relaxed hands. For grasp posture, dorsal finger lengths were extracted instead.

Besides, the extracting of all kinds of 1D ~ 3D dimension from raw digital data has to be performed by experienced researchers. Except to be familiar with the basic operation of the software, the recognition of anatomic points is more difficult on scanned digital data than on real skin surface of human body. The researchers need to be trained and tested for the operating precision before performing the project task formally.

Despite the limits of 3D laser scan technologies, the results of analysis by the 3D laser scan measurements of the project could be good references for glove design. It was suggested that the variation of HSA for postures changed from standard to relax was about 3% reduction. And about 120% of elasticity for the dorsal area of fingers of gloves was suggested.

Most researches about fitness of gloves measured the dimensions of hands under a standard posture which was similar to the one shown in Figure 2 (a) to make suggestions about glove size model (Robinette and Annis, 1986; Hidson, 1991; Tremblay et al., 1992; Halioua et al., 1992) or to evaluate the approaches to glove fitness (Jones & Rioux, 1997; Yu, et al., 2013). This study analyzed hand dimensions under standard, relaxed and grasp postures. The results showed that HSA reduced and dorsal finger length increased for postures changed from standard to relax. It suggests that a glove designed by dimensions of hands under standard posture seems proper for palmar side but not dorsal side of hands. The dorsal side of hands could stretch to about 108% and 118% in skin area for postures changed from standard to relaxed and grasp, respectively. It is suggested that the palmar side of gloves remains designed by hand dimensions under standard posture while the dorsal side of gloves improves by designed for relaxed hand and providing elasticity about 10%.

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References

Daanen, Hein A.M. and van de Water, G. Jeroen (1998) "Whole Body Scanners", *Displays*, 19, 111–120

Du Bois, D., and Du Bois, E.F. (1915) "The measurement of the surface area of man", *Arch.Intern. Med.*, 15, pp.868-881

Halioua, M., Liu, H.C., Bowins, T.S., and Shih, J.K. (1992) "Automated topography of human forms by phase-measuring profilometry", In: A. Alberti, B. Drerup and E. Hierholzer, Editors, Surface Topography and Spinal Deformity: Proc. 6th Int. Symp. Estoril, Fischer, Stuttgart, pp. 6-61.

Hidson, D. (1991) "Development of a standard anthropometric dimension set for use in computer-aided glove design", In: Technical Report DREO-TN-9122, National Technical Information Service, U.S Dept. of Commerce.

Jones, P.R.M., Rioux, M. (1997) "Three-dimensional surface anthropometry: Applications to the human body", *Optics and Lasers in Engineering*, 28(2), pp. 89-117.

Lin, Ching-Hua and Hung, Kuo-Chiang (2014) "The Validation of Hand Anthropometry Using 3D Laser Scan", *Applied Mechanics and Materials*, Vols. 543-547, pp 1167-1170.

Robinette, K.M., Annis, J.F. (1986) "Nine-size system for chemical defense gloves", In: Report AAMRL-TR-86-029, National Technical Information Service, U.S Dept. of Commerce.

Tremblay, J.F., Crown, E.M., Rigakis, K.B. (1992) "Anthropometric analysis of fit problems in chemical protective gloves", In: Performance of Protective Clothing J.P. McBriarty and N.W. Henry, Editors, ASTM Special Technical Publication, No. 1133, Vol. 4, American Society for Testing and Materials, Philadelphia, PA, pp. 634-650.

Tikuisis, P., Meunier, P., and Jubenville, C.E. (2001) "Human body surface area: measurement and prediction using three dimensional body scans", *European Journal of Applied Physiology*, 85(3-4), pp.264-71.

Yu, A., Yick, K.L., Ng, S.P., Yip, J. (2013) "2D and 3D anatomical analyses of hand dimensions for custom-made gloves", *Applied Ergonomics*, 44, 381-392.

Yu, C.Y., Hsu, Y.W., Chen, C.Y. (2008) "Determination of Hand Surface Area as A Percentage of Body Surface Area by 3D Anthropometry", *Burns*, 34(8), pp. 1183-1189.

Yu, C.Y., Lin, C.H., and Yang, Y.H. (2010) "Human Body Surface Area Database and Estimation Formula", *Burn*, 36(5), pp. 616-629.