A-10

Variational 3D hand modeling including skin variation and joint-link structure estimation

Hokkaido University ○Yulai Xie, Satoshi Kanai, Hiroaki Date

A method for variational modeling of individual hands from a template hand model is described. The marked individual hand is reconstructed based on image-based multi-view 3D model reconstruction technique. The skin surface of the template hand model is partitioned into segments according to the hand surface anatomy by main creases on palmar side. The segments of the template hand model are scaled according to the feature dimensions of the reconstructed individual hand model. On the other hand, according to hand joint anatomical knowledge, a single axis rotation assumption is proposed for estimating the joint axes and joint centers by the positions of dot markers at the backside of the hand skin in different hand postures. Finally, the template hand model scaled in segment-wise way is registered to the reconstructed hand model using ICP algorithm. Compared with the previous measurement, the proposed hand modeling method is more subject-friendly, inexpensive and efficient.

1. Introduction

Recently, virtual ergonomic assessment of handheld products which has many advantages compared with conventional one has gotten more attention. However, the MRI-based hand modeling [1] we proposed for virtual ergonomic assessment forced subjects to take a long and difficult measurement, and it was unable to generate a lot of hand models in a short amount of time. However, human hands have a variety of sizes. Therefore, a variational hand modeling method is needed to generate different individual human hand models with size variations in a relatively simpler way than that of the previous MRI-based method.

To solve the problem, the purpose of this research is to propose an efficient variational hand modeling method where a 3D hand model with specific sizes could be efficiently generated from an existing template hand model in a simpler way, and where the size variation both of the surface skin model and the specific internal joint-link structure could be easily reconstructed.

There has been some similar work. However, [2] only dealt with the hand skin variation in a static hand posture. Therefore there was a lack in the variation for the internal joint-link structure. Also, the thickness of the hand was ignored in [3], and the estimated joint centers were not verified dynamically in different hand postures.

Different from the related work, our proposed hand modeling method utilized an image-based reconstruction, and the skin model of a partitioned template hand model was scaled and the joint-link structure model was estimated based on the photo-based 3D models of the surface skin. Finally the two models were integrated by a 3D registration process. The outline of the method is shown in **Fig.1.**

2. Image-based 3D model reconstruction

An experimental system for image-based multi-view 3D modeling reconstruction was introduced, owing to its user-friendliness and low cost. As shown in **Fig.2 (a)** and **(b)**, in an appropriate illumination condition, 6 commercial cameras were placed on a rotatable plate. During the measurement, the hand of a subject was roughly placed at the center of the rotatable plate on a stage. By rotating the plate discontinuously and shooting in every 15 degree, a series of clear and stable photographs of the hand could be taken as shown as the set of rectangles shown in **Fig.2 (c).**

When taking the hand photos, several dots were marked on the back side of the subject's hand as markers. Also, as shown in **Fig.2(d)**, the main creases on the palmar side were also painted for the partition of the model. Three hand postures including a relaxed natural posture, full flexion posture and full abduction posture were measured. For each posture, 36 digital images were taken during 30 sec to get a model in each posture with acceptable quality.

After the image capture, using a commercial multi-view 3D reconstruction software (Photoscan[4]), a 3D hand model with colored texture was reconstructed. The accuracy of the reconstruction evaluated by reconstructing a box with known dimensions was 0.65mm. The main crease meshes were then extracted from the hand model using a mesh segmentation process where only the meshes with the HSV color in a specified range, whose center was the color of the painted crease, were extracted as shown in **Fig.2(d).** According to the extracted creases, the reconstructed hand model was automatically partitioned into 15 segments of the skin surface.

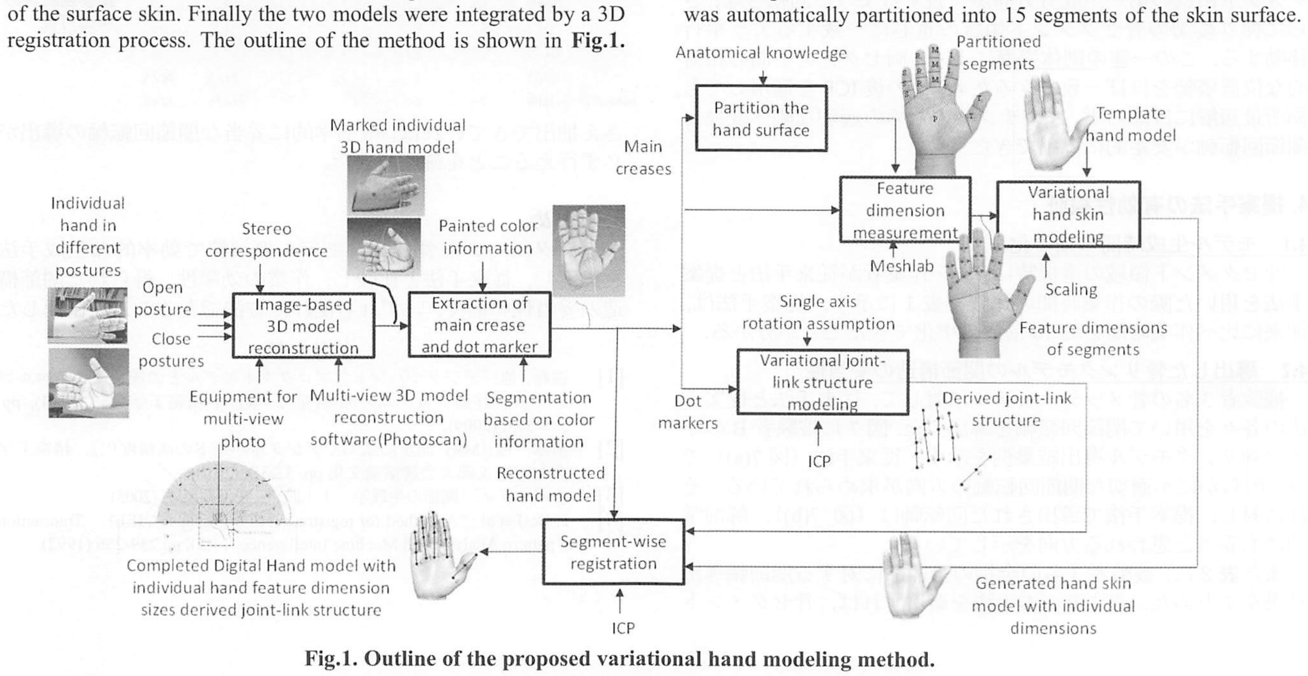

Fig.1. Outline of the proposed variational hand modeling method.

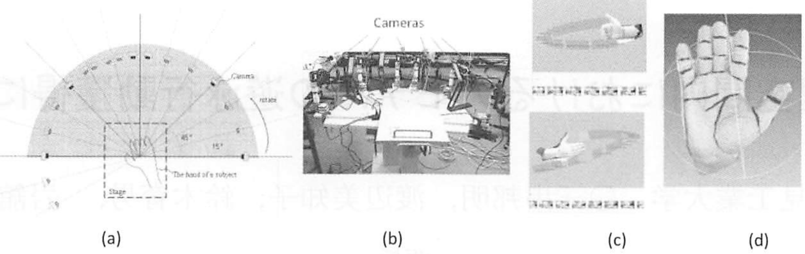

Fig. 2. Image-based 3D model reconstruction: (a) Experimental setting, (b) Experimental scene, (c)A series of photographs of the hand, (d) Extracted creases

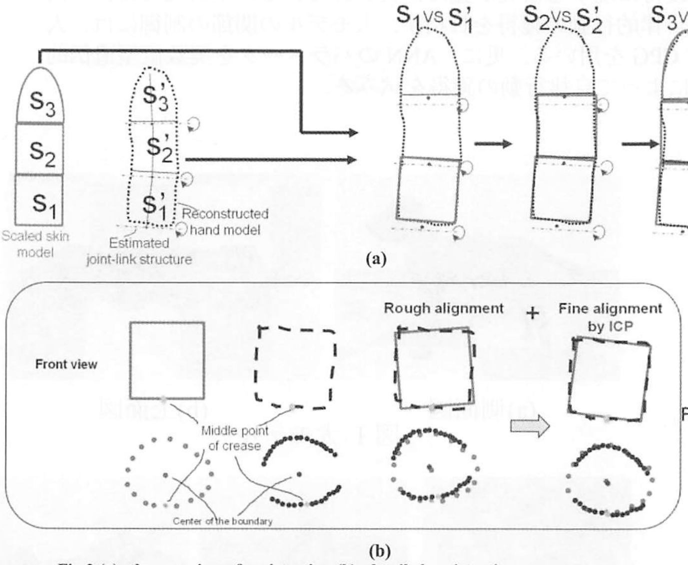

Fig.3 (a): the overview of registration (b): detailed registration process

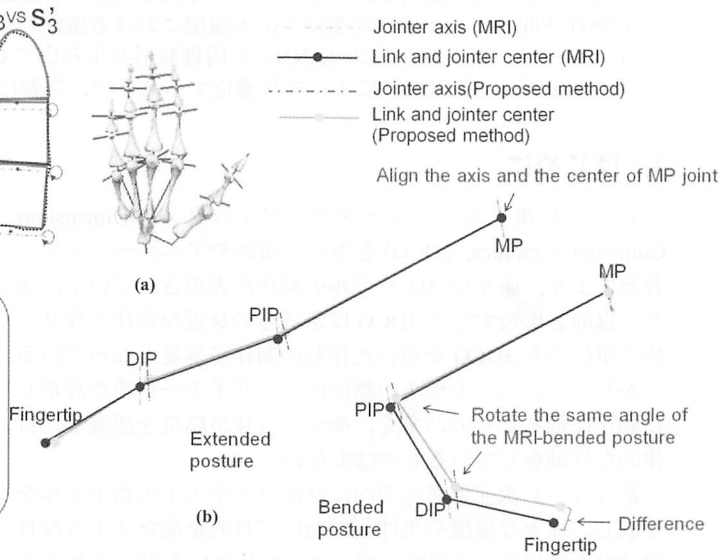

Fig.4. Verification of estimated joint-link structure: (a) Derived joint-link structure of S1's hand, (b) Verification of derived joint-link structure

3. Variational hand skin modeling

Based on the partition, hand surface feature dimensions of an individual were measured directly on the 3D reconstructed hand model using a mesh modeler (Meshlab [7]). Then, a hand model with size variation was constructed by scaling the segments of a template hand model to those with the feature dimensions of the reconstructed model. The more detail could be found in our previous work [5].

4. Variational joint-link structure modeling

Based on a single axis rotation assumption based on anatomical knowledge[6], joint parameters (joint center and its axis direction) were derived by comparing 3D positions and orientations of two corresponding markers taken from a segment of the reconstructed hand mesh model at two different grasp postures. First, the marker positions at the reference posture (natural extended posture) and the ones at a bended posture either of a full flexion posture or a full abduction posture were extracted using a mesh modeler [7]. Then the position and orientation of these two sets of markers were matched using ICP the algorithm. The more detail of the matching could be found in our previous work [1].

5. Segment-wise registration between joint link structure and hand skin model

The difference in the positions and orientations between the segments of the template hand model and the corresponding ones of the reconstructed model is inevitable. Therefore, a registration process including a rough alignment and a fine alignment was developed for registering the segments of the template hand model to corresponding ones of the reconstructed hand model.

The registration process is illustrated in **Fig.3.** In the rough alignment, by aligning the centers of vertices on the segment boundary and the middle point of the crease on palmar side, a scaled segment of the template hand model was roughly aligned to its corresponding segment of the reconstructed hand model. While, in the fine alignment, ICP algorithm was used to register all of vertices of the roughly aligned segment to those of the corresponding segment of reconstructed hand model. After the fine alignment, the scaled segments of template Digital Hand model were incorporated with the derived joint-link structure.

6. Result and verification

The results and their verification of variational skin modeling could be found in [4]. Moreover, the joint-link structure of the hand of a subject was estimated as shown in **Fig.4 (a)**. For verifying variational joint-link modeling, the derived joint-link structure was compared with the one of the same subject by the previous MRI-based hand modeling method [1]. As shown in **Fig.4 (b)**, the axis and its center of MP joint of the index finger of two joint-link structures were aligned in the fully extended reference posture for evaluating the position and angle differences in PIP, DIP and fingertip. Moreover, the joints derived the proposed method were rotated by the same joint angles from the virtual reference where the angle between two links takes zero degree to the limit bended one of MRI-based joint-link structure, also for evaluating the position and angle differences of the axis joint PIP, DIP and the position difference in fingertip. The results were listed in **Table** 1.

The accuracy could satisfy the virtual ergonomic assessments of handheld products in case of a power grasp. For the case of a pinch operation or a human interface operation using a fingertip, the accuracy of the proposed method needs to be evaluated further.

Table 1. Average position and orientation errors of four fingers at fully extended posture and limit bended posture.

	Full flexion posture			Full abduction posture
Difference	PIP	DIP	Fingertip	PIP
Natural extended posture [mm]	1.5	1.9	2.9	1.5
Limit bended posture [mm]	1.5	2.7	4	1.7
Joint axis angle deviation [deg]	3.2°	3.9°	-	3.1°

References:

[1] Shimizu, Y., Kawaguchi, K., Kanai, S., 2010. Constructing MRI-based 3D Precise Human Hand Models for Product Ergonomic Assessments, Proceedings of 2010 Asian Conference on Design and Digital Engineering, Jeju, Korea, pp. 837-844.

[2] Kouchi, M., Miyata, N., Mochimaru, M., 2005. An Analysis of Hand Measurements for Obtaining Representative Japanese Hand Models. SAE Technical Paper 2005-01-2734.

[3] Rhee, T., Neumann, U., Lewis, J.P., 2006. Human hand modeling from surface anatomy, Proceedings of the 2006 symposium on Interactive 3D graphics and games. ACM, Redwood City, California, pp. 27-34.

[4] PhotoScan. http://www.agisoft.ru/products/photoscan.

[5] Xie, Y., Kanai, S., Date, H., 2013, Anatomy-based variational modeling of Digital Hand and its verification, Proceedings of JSPE 2013 spring conference, Tokyo, pp.831-832

[6] Kapandji, A.I., The Physiology of the Joint: The Upper Limb. 2005, Churchill Livingstone.

[7] Meshlab. http://meshlab.sourceforge.net/.