SUBJECT-SPECIFIC FINGER MODEL FROM GEOMETRIC DATABASE

[1]Kanako Kimura, [2]Mitsunori Tada, [1]Kenji Terabayashi and [1]Kazunori Umeda
[1]School of Science and Engineering, Chuo University, Japan,
[2] Digital Human Research Center, National Institute of Advanced Industrial Science and Technology, Japan

SUMMARY

In this paper we propose a method for synthesizing subject-specific 3-dimensional model of index fingers from their representative dimensions that can be measured by a caliper. Geometric database of adult finger is constructed for this purpose by computing the individual difference between two subjects from their MRI images, and analyzing the difference statistically to obtain the principal features of the geometry. We can synthesize possible variation of index fingers by computing weighted summation of these features. In order to synthesize subject-specific geometry, an optimization method was introduced for minimizing the errors in the representative dimensions such as joint length, width and thickness between the synthesized model and the target subject. We also show that this method can be extended to the synthesis of child fingers having different size and proportion from that of adult's by introducing scaling factor. The results of the experiment demonstrate that the average geometric error was at most 1.5mm even in the bone geometry. Though the child finger has thicker proportion than adult, such a geometric feature can also be synthesized by emphasizing corresponding principal feature.

INTRODUCTION

Subject-specific models are fundamental for validating the biomechanical simulation results. Automating segmentation process by a thresholding is one of the straightforward solutions for creating such models from medical images. However this method usually requires heuristic parameter tuning and manual intervention to obtain acceptable results. Another possible solution is a template-based method [1] where template geometry is transformed to obtain that of the other subjects. This method still requires us to obtain medical images of the target subject, although the manual segmentation is no longer necessary. Statistical approach [2] is more attractive since it is able to synthesize possible variations by blending geometric features. This method is extended to the synthesis of subject-specific model where the weight for each feature is computed by numerical optimization so that the geometric error between the synthesized model and the target subject is minimized.

In this paper we propose a method for synthesizing subject-specific 3-dimensional model of index fingers from their representative dimensions that can be measured by a caliper. Geometric database of adult finger is constructed for this purpose from their MRI images. We also show that this method can be extended to the synthesis of child fingers having different size and proportion from that of adult's by introducing the scaling factor.

METHODS

We constructed a geometric database of index fingers from MRI images. Non-rigid volumetric registration technique [3] was employed in order to measure individual difference of geometry between two subjects. In this registration, displacement vector was computed for all the control points distributed over the entire volume uniformly. The resulting total displacement vector represents the individual difference in geometry including surface and internal structures.

We computed the individual difference between the reference and the other subjects. The computed total displacement vectors along with zero-vector representing the individual difference for the reference subject were analyzed by principal component analysis (PCA) to obtain the principal features of the geometry. We can synthesize possible variation of index fingers by transforming an average geometry according to a total displacement vector computed by weighted summation of these principal features.

In order to synthesize subject-specific geometry, a numerical optimization method was introduced for minimizing the errors in the representative dimensions such as joint length, width and thickness between the synthesized model and the target subject. As given in equation (1), the objective function for this purpose is composed of two terms,

$$e(\mathbf{w}) = \sum_{i=1}^{m} \left(L_i - l_i(\mathbf{w})\right)^2 + \sum_{j=1}^{n} c_j \left(\frac{w_j}{2\sigma_j}\right)^2 . \tag{1}$$

The first term is the summation of the squared error, while the second term is the summation of the penalties to regulate the range of the weights. In this equation, L_i and $l_i(\mathbf{w})$ in the first term represents the i^{th} representative dimension of the target subject and the synthesized model, while w_j, σ_j and c_j in the second term represents weight, standard deviation of the principal component score, and contribution of the penalty for the j^{th} feature. $\mathbf{w} = (w_1, w_2, \ldots, w_n)$ is the weight vector to be optimized. If the geometry follows normal distribution, 95% of the population will fall within the two standard deviations. The second term prevents the weights from being optimized into excessive value since such a subject scarcely exists.

We introduced additional scaling factor for synthesizing a geometric model of a child finger since it is saliently smaller than that of adult's. In this case, representative dimensions of child finger was first scaled up to the typical adult finger dimension and then the synthesized model was scaled down to the original size by multiplying the inverse of the scaling factor used for the scale up.

RESULTS AND DISCUSSION

We imaged index fingers of 50 male subjects aging from 21 to 39 by a 4.7T MRI scanner (Varian UNITY INOVA: Varian Technologies Japan Ltd.). These images have volume size of $128 \times 128 \times 256$ with the field of view of $30 \times 30 \times 60$mm. The control point for the registration distributes every 16 voxels over the entire volume. We thus have 4131 degrees of freedom in total. We then computed the individual difference between the reference and the other subjects by using the volumetric registration. The computed total displacement vectors along with the zero-vector were analyzed by PCA. Figure 1 shows the average geometry transformed by the 6th principal component corresponding to the finger pad thickness.

We synthesized index finger models of adults and children from this database. In both cases, we measured 8 representative dimensions as shown in Figure 2. First 10 principal components were used for the geometry synthesis. In the objective function, σ_j was computed from the database, while c_j was set to 0.5 for all the principal components. We used downhill-simplex method in order to find the weight vector $\mathbf{w}$ that minimizes e. The initial simplex was composed of the origin and 10 random vertices in the 10-dimensional space. The j^{th} component of each random vertex was within the range of two standard deviations. The optimization terminates when the maximum ratio of the objective function value in each vertex get smaller than 1.0e-5. It took about 5 to 10 minutes for this optimization with 2.4GHz Intel Core2Duo processor and 4GB memory.

As for adult finger, we choose one target subject from the 50 subjects except the reference, and reconfigured the database without this subject in order to eliminate relevant information on this subject from the database. We then synthesized a geometric model from his representative dimensions, and compared the synthesized model with the geometry including skin and bones created from his MRI images. Since there are 49 potential target subjects, we have 49 validation data for adult fingers. As for child fingers, we synthesized geometric model of 26 subjects aging from 2 to 14 from their representative dimensions by introducing the scaling factor, and compared the synthesized model with the skin geometry created from their plaster model.

Figure 3 shows the result of the experiment. These results demonstrate that the average geometric error was at most 1.5mm even in the bone geometry that was not explicitly included in the objective function. In addition, though the child finger has thicker proportion than that of adult's, such a geometric feature can also be synthesized by emphasizing corresponding principal feature. These are one of the remarkable advantages of our method that can synthesize geometries by blending different geometric features including the skin and the internal structures.

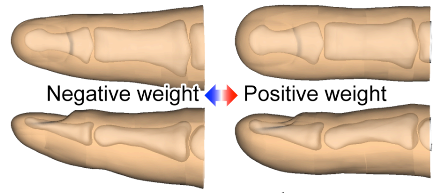

Figure 1: Geometric feature of the 6th principal component.

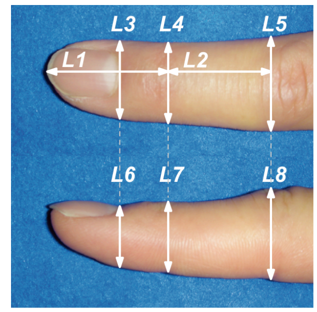

Figure 2: Eight representative dimensions for optimization.

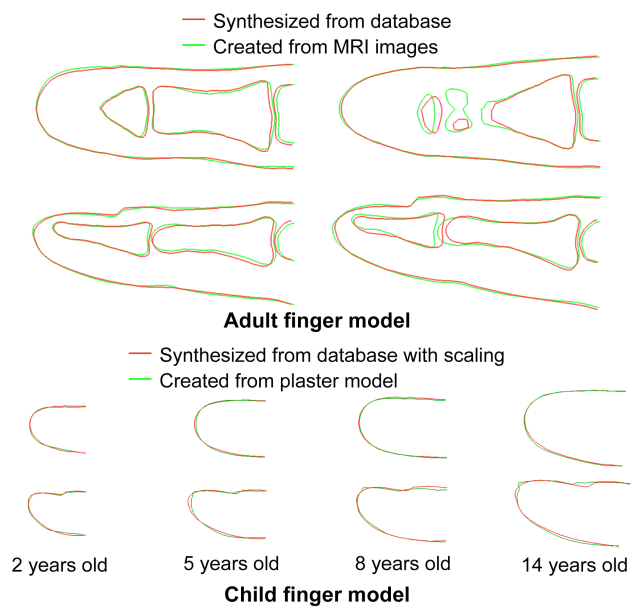

Figure 3: Results of the geometry synthesis.

CONCLUSIONS

We presented a method for synthesizing subject-specific 3-dimensional model of index fingers from their representative dimensions. By using our method, we can synthesize the bone geometry from the external representative dimensions. Also, we can synthesize the child finger though it has different size and proportion from that of adult's.

REFERENCES

1. Couteau B, et al. *Journal of Biomechanics*. **33**(8): 1005-1009, 2000.
2. Mochimaru M and Kouchi M. Proceedings of SAE Digital Human Modeling, 2000-01-2149, 2000.
3. Tada M, et al. Proceedings of Eurohaptics, 99-104, 2006.