International Journal of Advances in Science Engineering and Technology, ISSN(p): 2321 –8991, ISSN(e): 2321 –9009
Volume-6, Issue-2, Apr.-2018, http://iraj.in

AN AUTOMATIC ASSESSMENT OF FACIAL SYMMETRY BEFORE AND AFTER ORTHOGNATHIC SURGERY BASED ON THREE-DIMENSIONAL CONTOUR FEATURES USING DEEP LEARNING SYSTEM

[1]HSIU-HSIA LIN, [2]LUN-JOU LO, [3]WEN-CHUNG CHIANG, [4]CHIN -FA CHEN

[1]Craniofacial Research Center, Chang Gung Memorial Hospital
[2]Department of Plastic and Reconstructive Surgery, Chang Gung Memorial Hospital
[3]Department of Marketing and Distribution Management, Hsiuping University of Science and Technology [4]Department of the Graduate Institute of Sports and Health Management, National Chung Hsing University
E-mail: sharley@hust.edu.tw, lunjoulo@cgmh.org.tw, wcchiang@hust.edu.tw, fachen@nchu.edu.tw

Abstract - Improvement of the facial asymmetry has become as important as correction of the malocclusion in the evaluation and planning for orthognathic surgery. In this study, we proposed an automatic deep learning system (DLS) to extract three-dimensional (3D) contour features and assess the degree of facial symmetry in patients treated with orthognathic surgery. A total of 500 normal populations were included to construct the DLS. The ground truth was based on an average of the survey of 50 of diverse referees offering their facial symmetry ratings over a 10-point scale for 500 3D facial images via an auto-play and separate slide show. The facial region of interest (ROI) was extracted by removing the disturbed region, such as the ears, the neck and all points above the hairline. A contour map was extracted from the ROI image, and used as an input pattern for automatic DLS, which included a deep convolutional neural network (CNN) for feature extraction, and a regression network provided for prediction. The experimental results showed that our model achieved 78.85% accuracies on held-out test patterns. The facial symmetry degree assessment within 1 degree was 98.63%. In addition, our method was compared with conventional 2D approaches, which obtained better results than 2D-only features which resulted accuracy is 65% using the same sample size, and the CNN system. For clinical application, 100 patients with facial asymmetry were enrolled in evaluating facial symmetry improvement after orthognathic surgery. A paired t-test was used to compare the significance of the differences between the pre-surgery and post-surgery assessing result of facial symmetry using DLS, with $p < 0.05$ considered significant. The mean of preoperative facial symmetry degree (0.92 ± 0.17) was higher than of postoperative (0.65 ± 0.13) with a significant improvement ($p = 0.021$).

Index Terms - About four key words or phrases in alphabetical order, separated by commas.

I. INTRODUCTION

Facial appearance is a critical factor in the psychosocial development and social relationships [1], [2]. Facial asymmetry has long been used for evaluating facial attractiveness [3]–[5]. Surgical treatment is crucial because such a various deformity can translate into significant psychological burden and social problems affecting the patient's quality of life [6], [7]. Orthognathic surgery combined with orthodontic treatment could address the symmetrical skeletal midline, facial profile and dental occlusion simultaneously for the facial deformity. As such, an objective and quantitative assessment of facial asymmetry is needed to provide the guidance of effective treatment for clinicians. Recently three-dimensional (3D) imaging has become more common in quantifying facial asymmetry, such as CBCT, CT, MRI, maintain their popularity [8-11]. In the related studies, asymmetry Index have been quantitatively proposed to represent degrees of asymmetry of each facial landmark [12-15]. An auxiliary plot was proposed to visualize the quantitative measurements and help articulate severity of asymmetry of the patient. Alternatively, Visual questionnaires also were used to evaluate perceptions of plastic surgery outcomes [16], [17]. Many previous studies have employed composite faces to study the effects of symmetry and averageness of the face on attractiveness [18-20]. Machine learning methods have also been utilized to investigate whether symmetry ratings can be learned and predicted by mapping facial images to their attractiveness scales [21]. Most current work considers, however, only the 2D facial characteristics [22-24].Deep learning has been introduced as a powerful method for a wide range of computer vision image tasks to replace conventional methods using manually selected features [25-28]. Moreover, these methods have converted 2D cephalometric landmarks to a 3D cephalometric system but have not comprehensively addressed the 3D features. In this study, we propose an automatic assessment system in facial symmetry of patients treated with orthognathic surgery based on three-dimensional (3D) contour features and validate the accuracy of the method.

II. METHODS

A. Patients

A total of 100 patients (56 male, 44 female) with facial asymmetry and malocclusion were who underwent orthognathic surgery, with an average age of 28.7±4.8 years (range 19 to 34 years) were enrolled in this study were recruited in this study at the Craniofacial Center, Chang Gung Memorial Hospital between August 2015 and July 2017. Exclusion criteria were cleft lip or cleft palate, a history of facial trauma, degenerative or inflammatory conditions, or inadequate imaging.

B. Image acquisition

Standardized high-resolution full-face color surface model of patient with neutral expression were acquired by using a commercial three-dimensional surface imaging system (SdMDface system, 3dMD, Atlanta, GA) based on active stereo photogrammetry (Figure 1).

Figure 1. Three-dimensional images obtained through 3dMD surface scanning.

C. Facial symmetry degree rating

All 3D facial images of 500 normal populations having a neutral expression are assessed for facial symmetry by 50 human raters on a Likert scale from 1 (least attractive) to 10. All images are presented to each rater in a random order and each image is shown on a separate page with an auto-play slide show. Each rater is ask to view the image for 5 seconds and rate the facial symmetry of each sample within a maximum of 3 seconds. The ground truth was based on an average of the survey of 50 of diverse referees offering their facial symmetry ratings over a 10-point scale for all 3D facial images.

D. The ROI and contour map extraction

Fisrt, the disturbed region on 3D facial image, such as the ears, the neck and all points above the hairline were removed to extract the facial region of interest (ROI) (Figure 2A). An object's contour lines which contains the height distribution information of the surface of a three-dimensional object [29], [30]. Then, in order to determine the degree of facial symmetry, we characterized a face by its contour lines as an input pattern extracted from the 3D facial image, where homogeneous regions were enclosed by contour lines to form iso-surfaces (Figure 2B). The contour maps have been proved that the more symmetry faces, i.e., with higher attractiveness rankings, exhibit more bluish (or near the blue end of the color spectrum) distribution than those with lower rankings. The blue contour lines correspond to smooth and distinctive facial features, while the reddish contours are normally resulted from defective or bumpy facial surfaces. Contour lines-based colorful labels can then serve to reflect local homogeneity of the facial surface [31].

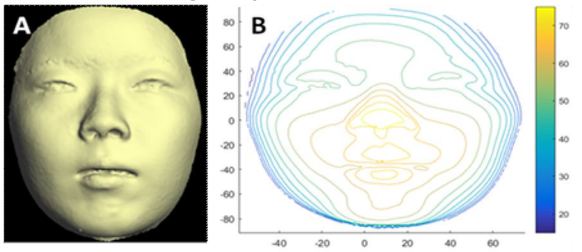

Figure 2. The ROI and contour map (3D features) extraction.

E. The deep learning system for automatic assessment of facial symmetry degree

Our deep convolutional neural network (CNN) was used for automated facial symmetry degree assessment, which consisted of a convolutional network derived from pre-trained CNN models for feature extraction, and a regression network provided for prediction (Figure 3).

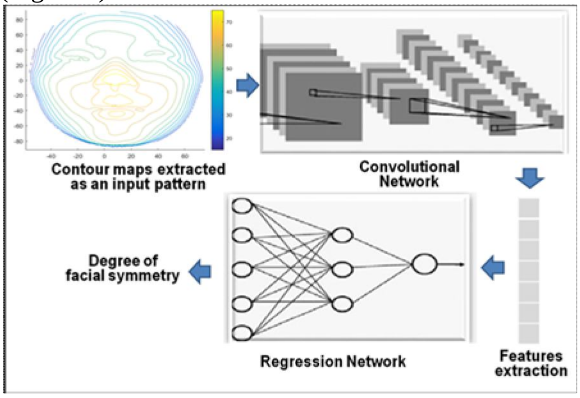

Figure 3. The deep convolutional neural network.

The convolutional network included: a pre-trained convolutional layer obtained as a grayscale version of Over Feat's first convolutional layer to adapt the first-layer kernels as they encode common application-independent low-level visual patterns, a variable number of convolutional layers were initialized randomly and trained on dataset images only, and an optional deformation layer, which learned an adaptive geometric transformation to apply to input patterns (feature maps) in order to provide invariance to affine warping. The regression network adopted a single fully connected layer (with number of neurons) followed by a linear scalar layer which outputs the estimated skeletal age for the input image.

We randomly selected 70% of the total data for use as a training datasets, 15% of the total data for use as validation datasets and 15% of the total data for use as a test dataset against independently conducted facial symmetry ratings. The prediction accuracy given the particular ground truth and stability were used to evaluate the performance of our system.

III. RESULTS

In this study, the intra-examiner reliability was qualified to avoid the human rating are subjective using Cronbach's alpha reliability coefficient with 0.967. The experimental results showed that our model achieved 78.85% accuracies on held-out test patterns. The facial symmetry degree assessment within 1 degree was 98.63%. In addition, our method was compared with conventional 2D approaches, which obtained better results than 2D-only features which resulted accuracy is 65% using the same sample size, and the CNN system. A pre-trained convolutional layer was used in our model to adapt the first-layer kernels as they encode common application-independent low-level visual patterns and avoid overfitting due to the small number of available images.

For clinical application, 100 patients with facial asymmetry were enrolled in evaluating facial symmetry improvement after orthognathic surgery. A paired t-test was used to compare the significance of the differences between the pre-surgery and post-surgery assessing result of facial symmetry using our automatic CNN model, with $p < 0.05$ considered significant. The mean of preoperative facial symmetry degree (0.92 ± 0.17) was higher than of postoperative (0.65 ± 0.13) with a significant improvement ($p = 0.021$)..

IV. DISCUSSION

3D photogrammetry is a cost-effective, nonradioactive, reliable, and reproducible method for quantitatively analyzing soft tissue analysis. Machine learning methods have been utilized to perform 3D face recognition in continuous spaces. To date, no study has investigated the predicting the facial symmetry degree, that could be the limiting factor for the utility of 3D-imaging technique and deep-learning networks. The main purpose of this study was to present an automated assessment system, a deep convolutional neural network for 3D facial symmetry.

Our study had one limitation that was included a small sample size (500 cases) for building the deep learning system and 100 patients at a single center were used for clinical application on automatic assessment of facial symmetry degree. More populations were collected in the further study.

In conclusion, our results show that 3D contour line-based features can exhibit greater correspondence with facial symmetry than 2D features, and serve as a general, useful automated and human-like efficient decision tool for objective assessment of facial symmetry pre and post orthognathic surgery for the improvement of treatment in clinical.

REFERENCES

[1] W. C. Shaw, "The influence of children's dentofacial appearance on their social attractiveness as judged by peers and lay adults," Am J Orthod., vol. 79, no. 4, pp. 399-415, Apr. 1981.

[2] A. E. Kaipainen, K. R. Sieber, R. M. Nada, T. J. Maal, C. Katsaros, and P. S. Fudalej, "Regional facial asymmetries and attractiveness of the face," Eur J Orthod., vol. 38, no. 6, pp. 602-608, Dec. 2016.

[3] L. Vingilis-Jaremko, and D. Maurer, "The influence of symmetry on children's judgments of facial attractiveness," Perception, vol. 42, no. 3, pp. 302-320, 2013.

[4] N. Pound, D. W. Lawson, A. M. Toma, S. Richmond, A. I. Zhurov, I. S. Penton-Voak, "Facial fluctuating asymmetry is not associated with childhood ill-health in a large British cohort study," Proc Biol Sci., vol. 281, pp. 1792, Aug. 2014.

[5] A. Farrera, , M. Villanueva, M. Quinto-Sanchez, and R. Gonzalez-Jose, "The relationship between facial shape asymmetry and attractiveness in Mexican students, " Am J Hum Biol., vol. 27, no. 3, pp. 387-396, May 2015.

[6] C. L. Maris, M. C. Endriga, M. L. Omnell, and M. L. Speltz, "Psychosocial adjustment in twin pairs with and without hemifacial microsomia," Cleft Palate Craniofac J., vol. 36, no. 1, pp. 43-50, Jan. 1999.

[7] H. Snyder and A. W. Pope, "Psychosocial adjustment in children and adolescents with a craniofacial anomaly: diagnosis-specific patterns, "Cleft Palate Craniofac J., vol. 47, , pp. 264-272, 2010.

[8] S. M. Weinberg, S. Naidoo, D. P. Govier, R. A. Martin, A. A. Kane, and M. L.Marazita, "Anthropometric precision and accuracy of digital three-dimensional photogrammetry: comparing the Genex and 3dMD imaging systems with one another and with direct anthropometry, " J Craniofac Surg., vol. 17, no. 3, pp. 477-483, May 2006.

[9] J. Y. Wong, A. K. Oh, E. Ohta, A. T. Hunt, G. F. Rogers, J. B. Mulliken, and C. K. Deutsch, "Validity and reliability of craniofacial anthropometric measurement of 3D digital photogrammetric images," Cleft Palate Craniofac J., vol. 45, no. 3, pp. 232-239, May 2008.

[10] J. M. Plooij, G. R. Swennen, F. A. Rangel, T. J. Maal, F. A. Schutyser, E. M. Bronkhorst, A. M. Kuijpers-Jagtman, and S. J. Bergé. "Evaluation of reproducibility and reliability of 3D soft tissue analysis using 3D stereophotogrammetry," Int J Oral Maxillofac Surg., vol. 38, no. 3, pp. 267-273, Mar. 2009.

[11] N. Aynechi, B. E. Larson, V. Leon-Salazar, and S. Beiraghi, "Accuracy and precision of a 3D anthropometric facial analysis with and without landmark labeling before image acquisition, " Angle Orthod., vol. 81, no. 2, pp. 245-252, Mar. 2011.

[12] C. Sforza, R. Peretta, G. Grandi, G. Ferronato, and V. F. Ferrario, "Three-dimensional facial morphometry in skeletal Class III patients. A non-invasive study of soft-tissue changes before and after orthognathic surgery," The British journal of oral & maxillofacial surgery., vol. 45 no. 2, pp. :138-144, Mar. 2007.

[13] F. A. Soto, E. A. Wasserman, "Asymmetrical interactions in the perception of face identity and emotional expression are not unique to the primate visual system," Journal of vision., vol. 22, no. 3, 2011.

[14] J. Djordjevic, P. Pirttiniemi, V. Harila, T. Heikkinen, A. M. Toma, A. I. Zhurov, and S. Richmond. "Three-dimensional longitudinal assessment of facial symmetry in adolescents," Eur J Orthod., vol. 35, no. 2, pp. 143-151, Apr. 2013.

[15] L. H. Cevidanes, L. J. Bailey, S. F. Tucker, M. A. Styner, A. Mol, C. L. Phillips, W. R. Proffit, and T. Turvey, "Three-dimensional cone-beam computed tomography for assessment of mandibular changes after orthognathic surgery," A Am J Orthod Dentofacial Orthop, vol. 131, no. 1, pp. 44-50, Jan. 2007.

[16] M. S. Lee, D. H. Chung, J. W. Lee, and K. S. Cha, "Assessing soft-tissue characteristics of facial asymmetry with photographs," Am J Orthod Dentofacial Orthop., vol. 138, no. 1, pp. 23-31, Jul. 2010.

[17] B. L. Padwa, M. O. Kaiser, and L. B. Kaban. "Occlusal cant in the frontal plane as a reflection of facial asymmetry," Journal of Oral and Maxillofacial Surgery, vol. 55, no. 8, pp. 811-816, Aug. 1997.

[18] K. M. Oh, S. K. Seo, J. E. Park, H. S. Sim, L. H. Cevidanes, Y. J. Kim, and Y. H. Park, "Post-operative soft tissue changes in patients with mandibular prognathism after bimaxillary surgery," J Craniomaxillofac Surg., vol. 41, no. 3, pp. 204-211, Apr. 2013.

[19] M. Shafi, A. Ayoub, X. Ju, and B. Khambay, "The accuracy of 3D prediction planning for the surgical correction of facial deformities using Maxilim," Int J Oral Maxillofac Surg., vol. 42, no. 7, pp. 801-816, Jul. 2013.

[20] B. R. Kim, K. M. Oh, L. H. Cevidanes, J. E. Park, H. S. Sim, S. K. Seo, M. Reyes, Y. J. Kim, and Y. H. Park, "Analysis of 3D soft tissue changes after 1- and 2-jaw orthognathic surgery in mandibular prognathism patients, " J Oral Maxillofac Surg., vol. 71, no. 1, pp. 151-161, Jan. 2013.

[21] L. K. de Paula, A. C. Ruellas, B. Paniagua, M. Styner, T. Turvey, H. Zhu, J. Wang, and L. H. Cevidanes, "One-year assessment of surgical outcomes in Class III patients using cone beam computed tomography," Int J Oral Maxillofac Surg., vol. 42, no. 6, pp. 780-789, Jun. 2013.

[22] J. W. Choi, J. Y. Lee, T. S. Oh, S. M. Kwon, S. J. Yang, and K. S.Koh, "Frontal soft tissue analysis using a 3 dimensional camera following two-jaw rotational orthognathic surgery in skeletal class III patients, " J Craniomaxillofac Surg., vol. 42, no. 3, pp. 220-226, Apr. 2014.

[23] J. San Miguel Moragas, O. Oth, M. Büttner, and M. Y. Mommaerts, "A systematic review on soft-to-hard tissue ratios in orthognathic surgery part II: Chin procedures," J Craniomaxillofac Surg., vol. 43, no. 8, pp. 1530-1540, Oct. 2015.

[24] E. Suzuki-Okamura, N. Higashihori, T. Kawamoto, and K. Moriyama, "Three-dimensional analysis of hard and soft tissue changes in patients with facial asymmetry undergoing 2-jaw surgery," Oral Surg Oral Med Oral Pathol Oral Radiol., vol. 120, no. 3, pp. 299-306, Sep. 2015.

[25] Y. LeCun, Y. Bengio, and G. Hinton, "Deep learning," Nature, vol. 521, pp. 436-444, May 2015.

[26] M. Anthimopoulos, A. Marios, C. Stergios, E. Lukas, C. Andreas, and M. Stavroula, "Lung pattern classification for interstitial lung diseases using a deep convolutional neural network," IEEE Trans Med Imaging, vol. 35, no. 5, pp. 1207-1216, Feb. 2016.

[27] P. Liskowski, L. Pawel, and K. Krzysztof, "Segmenting retinal blood vessels with deep neural networks," IEEE Trans Med Imaging, vol. 35, no. 11, pp. 2369-2380, Nov. 2016.

[28] H. Greenspan, G. Hayit, B. van Ginneken, and R. M. Summers, "Guest editorial deep learning in medical imaging: overview and future promise of an exciting new technique," IEEE Trans Med Imaging, vol. 35, no. 5, pp. 1153-1159, May 2016.

[29] D. M. Meadows, W.O. Johnson, and J. B. Allen, "Generation of Surface Contours by Moiré Patterns," Appl. Opt., vol. 9, no. 4, pp. 942-947, 1970.

[30] R.M. Costa, R.A. Braga, B.S. Oliveira, E. Silva, T. Yanagi, and J.T. Lima, "Sensitivity of the moiré technique for measuring biological surfaces," Biosys. Eng., vol. 100, no. 3, pp. 321-328, July 2008.

[31] W. C. Chiang, H. H. Lin, C. S. Huang, L. J. Lo, and S. Y. Wan, "The Cluster Assessment of Facial Attractiveness Using Fuzzy Neural Network Classifier Based on 3D Moire Features," Pattern Recognition, vol. 47, no. 3, pp. 1249-1260, 2014.

★★★