Application of Phase Measuring Profilometry in Digital Data Acquisition for CAD/CAM of Unilateral Orbital Prostheses with Remaining Eye Open

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Abstract: Objective To investigate whether a phase measuring profilometry-based digitizer is suitable for capturing digital facial image to reconstruct a 3D digital face model for computer-aided design and manufacture of unilateral orbital prostheses when the remaining eye keeps open. **Methods** A phase measuring profilometry-based digitizer was used to acquire the primitive point data of the face profile of a patient with left orbital defect and the primitive point data was then used to construct a 3D digital facial model consequently with 3D image processing software and a reverse engineering software. With this digital model, a resin model was produced by rapid prototyping system and was used to fabricate the final prosthesis. **Results** A 3D digital face model ready for computer-aided design and manufacture of unilateral orbital prosthesis was successfully reconstructed with data acquired from the phase measuring profilometry-based digitizer and the final orbital prosthesis fabricated with the help of this digital model fitted the patient very well. **Conclusion** The phase measuring profilometry is safe and highly efficient to capture a 3D digital image of facial defects, and would be helpful to the computer-aided design and manufacture of unilateral orbital prostheses.

Key words: phase measuring profilometry; 3-D digital model; computer-aided design and manufacture; unilateral orbital prosthesis

INTRODUCTION

The orbital defect caused by surgical removal of tumor tissues or trauma is a common type of facial defects and needs prosthesis to restore normal facial appearance in most cases due to the fact that surgical reconstruction is usually unsatisfying. Orbital prostheses account for about 16% of the total facial prostheses [1]. The first and most critical step to design and manufacture a vivid unilateral orbital prosthesis is to reconstruct a face model with the information of correct height, width and inclination of the palpebral fissure, the information of the natural eyelid shape, and the information of the natural curvature of eyeball, which define the appearance of the eye. This information can only be accurately obtained when the remaining eye is open during making an impression, which is impossible with the conventional impression techniques. In addition, while the new developing CAD/CAM technology provides many advantages than conventional techniques to produce an orbital prosthesis, a faithful digital face model with the remaining eye open is the fundament of CAD/CAM-based prosthesis fabrication. Therefore, new impression techniques have been the focus of extensive researches.

Laser scanning is the most common used technique for data acquisition when making facial prostheses [2-6]. However, it usually takes 15 s to take a complete image of the face[2] and any slight movement of face during data acquisition will result in some errors in the digital images. In addition, there are potential hazards of laser light to

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the open remaining eye and the intrinsic fear of these hazards from patients make it very difficult for the patients to open their remaining eye during data acquisition. Therefore, laser scanning is not really ideal for data acquisition of unilateral orbital-defect patients. Three-dimensional computed topography (CT) data has also been used to reconstruct the digital facial model but it does not provide good information of the soft tissue and the radiation risk is also a major concern [7, 8]. The high cost of magnetic resonance imaging (MRI) precludes it to be the best choice of data acquisition. In the present study, we successfully acquired the profile data of a patient face with her remaining eye open by using a phase measuring profilometry (PMP)-based digitizer and reconstructed a digital face model which can be directly used for CAD/CAM based manufacturing of the orbital prosthesis.

MATERIALS AND METHODS

The volunteer is a female patient afflicted with left orbital defect after surgical removal of malignant tumor. The defective region has no obvious undercut and scar.

1. Optical data acquisition system

A 3-dimensional full-color digitizing system specially designed for human body surface scanning (3D CaMega, DCS-I) is commercially available from Beijing BWHX Sci-Tech Development Ltd. The chip size is 1280 × 1024 pixels with a pixel depth of 24 bit. The resolution is 0.312 mm for both the X (horizontal) and Y (vertical) dimension and 0.10 mm for Z (deep) dimension. The scanning range is 500 mm and the exposure time is less than 1 second.

2. Data acquisition and processing

The patient stands right in front of the system with a natural head position and eye looking straight forward. Once the patient's face was scanned, the acquired data was saved as an .asc file. The .asc file was first opened in CloudForm (Beijing BWHX Sci-Tech Development Ltd) and the point-cloud data was examined carefully. After deleting invalid sampled points, the data was smoothed and exported as an .obj file. The .obj file was then opened in Geomagic Studio 6.0 (Raindrop Geomagic Inc.) and the point data were transformed into a surface model by triangulation. Abnormal triangles were manually deleted and new triangles were patched to make the surface complete. The triangles were then incurved and smoothed to create a complete facial contour image. Finally, the contour surface of the healthy side was mirrored to the inflicted side with the facial median sagittal plane as the mirror to produce a digital model reflecting the presurgical anatomy of deformed region. This model, however, needed a little minor adjusting to fit the anatomy of inflicted side and the final digital model was saved as a .stl file, the standard file format for rapid prototyping systems.

3. Prosthesis production

The .stl file was transferred to a CPS-600 sterolithographic rapid prototyping system developed by Xi'an Jiao Tong University to fabricate a resin model. The resin model was tried on the patient to determine the location and orientation of the eyeball. A wax replica was made by pressing the soft wax to the undersurface of resin model and carving the pore and skin texture by hand. Silicone rubber ocular prosthesis was manufactured using conventional techniques.

RESULTS

Digital point-cloud data of a patient face were successfully acquired with her remaining eye open and a 3D digital model was created. The data acquisition was complete and the digital model consisted of 302866 point with each point having its unique spatial information. There was no noise point and the surface created was smooth and clearly showed the whole face profile with good resolution (Fig 1). The details of the 3D digital model could be visualized from all perspectives and the "normal" anatomy of the orbital defect region was successfully produced by mirror projection of corresponding region in the health side in Geomagic Studio 6.0 (Fig 2). The resin model manufactured by rapid prototyping had a smooth surface and fitted the patient's face very well (Fig 3). The final silicone rubber prosthesis contacted the defect region tightly and created a symmetrical facial contour. The patient is satisfied with the prosthesis (Fig 4 and Fig 5).

DISCUSSION

To our knowledge, this study presents the first report on making a face impression, conventional or digital, with patient's remaining eye open for the fabrication of a unilateral orbital prosthesis. Phase measuring profilometry is a contact-free optical 3D sensing technology based on using a sinusoidal grating projector as the structured light pattern. When the sinusoidal grating is projected onto a 3D object, the surface height variation makes a phase modulation to the incidence light pattern to generate a deformed grating image. The shape of the 3D object can then be defined by demodulating several (n>3) frames of deformed grating images with n-phase algorithm [9]. Since it employs the ordinary illumination light rather than dangerous laser as the light source, it is absolutely safe and can be used to capture face image with the patient's remaining eye open. The resolution can reach as high as 0.05 mm, sufficient for the constructing 3D digital face model used for CAD/CAM of orbital prosthesis. In addition, the acquisition is so efficient that it can be done within 0.4 sec to acquire data of millions of point-cloud with each point-cloud having unique spatial information.

The application of PMP in data acquisition for CAD/CAM of facial prosthesis has been proposed by Dr. Runte et al [10], but the authors implied that the surface of eye did not meet the requirements of phase-measuring profilometry, i.e. the surface scanned "should show only diffuse reflection and have no major brightness contrasts" and, therefore, they acquire optical facial surface data with patient's healthy eye closed. However, a digital impression of periorbital region with healthy eye open is critical for manufacturing a vivid orbital prosthesis. We showed in the present study that this contact-free PMP technology can be used to acquire optical data of facial surface and the data acquired satisfied the needs to fabricate the unilateral orbital prosthesis.

However, information acquired with the PMP has not been taken full use of in the present study. Theoretically and in practice, PMP-based digitizer can acquire information about the color and texture of patient's skin although the resolution still needs improvement, but current available rapid prototyping systems cannot recreate any fine structures like the skin texture. Therefore, a laborious work is currently still needed to carve skin texture on the wax replica by hand. In addition, the computer shade-matching techniques to date cannot satisfy the needs to fabricate a facial prosthesis that matches patient's skin color very closely and the color selection of the prosthesis is still based on the technician's experience. Improvements on all these three systems, PMP-based digitizer, rapid prototyping and computer shade-matching, will eventually lead to the fabrication of a more vivid orbital prosthesis in a shorter time.

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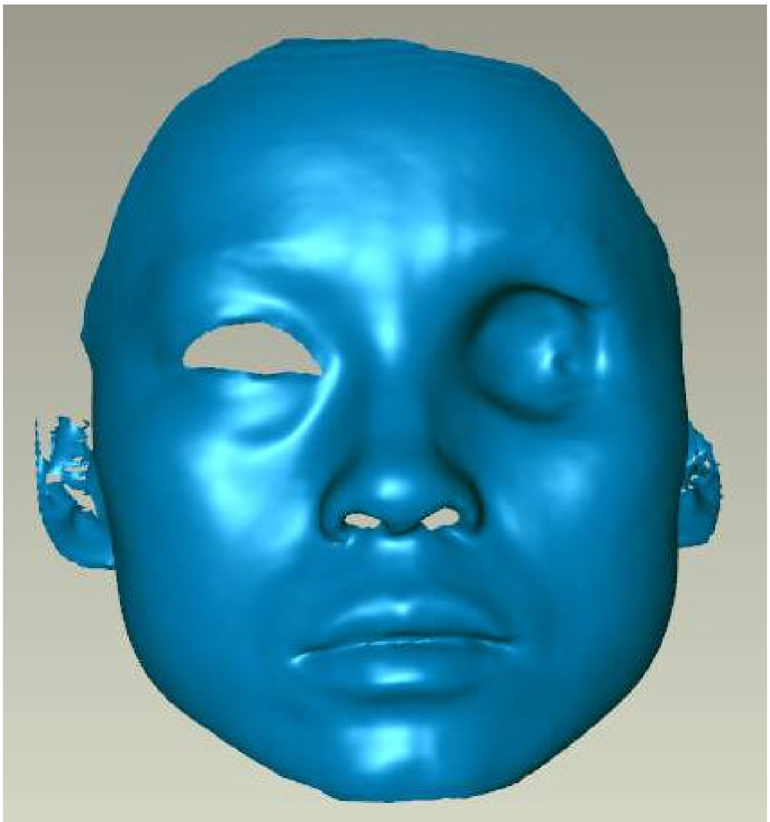

Fig. 1 Digital model produced with the primitive point data shows a whole face profile with smooth surface.

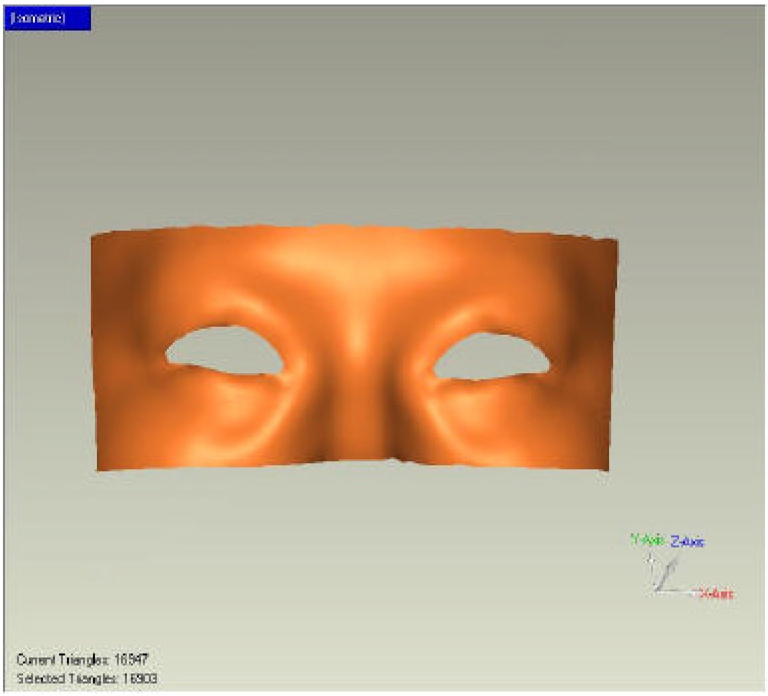

Fig. 2 The "normal" anatomy of the orbital defect region can be recreated by mirror projection of corresponding region in the health side. This also provides a means of communication with the patient to show the predicted treatment outcomes.

Fig. 3 The resin model manufactured by the rapid prototyping has a smooth surface and fits the patient face very well.

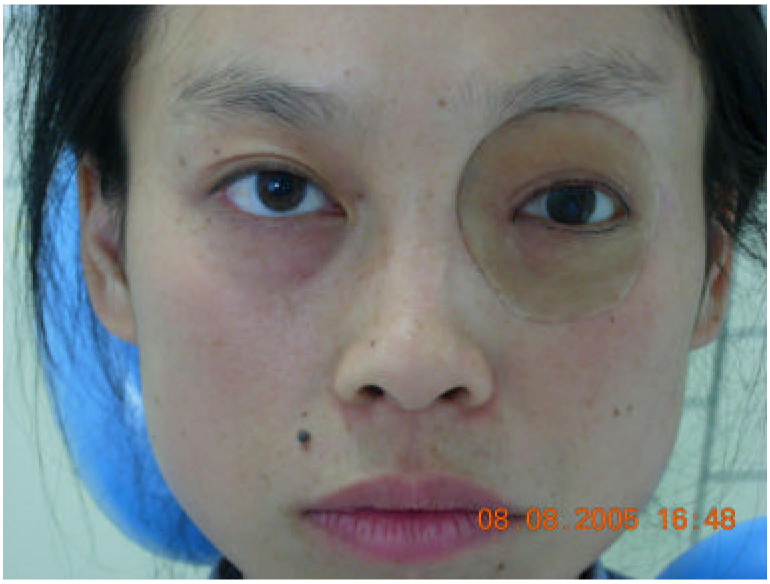

Fig. 4 The front view of the prosthesis to show the good shape and marginal fit of the prosthesis.

Fig. 5 The lateral view of the prosthesis to show the good shape and marginal fit of the prosthesis.