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Measuring System for the Facial Movements using Real-time Fringe Pattern Analysis

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ABSTRACT :

Facial movements, lips and cheeks, have great influences on the masticatory and phonetic functions. However, so far, there was few method to evaluate the facial movements. In this respect, we established a real time measuring system for the shape and the deformation of the face. This system consists of the projector for carrier fringe pattern, one CCD camera and the unit of image analysis boards. The image of the face projected with carrier fringe pattern was multiplied by three computer generated reference images grating with relative phase-shift and three phase-sifted moiré images was obtained by low-pass filtering. The phase distribution was derived from these moiré images were processed by phase-shifting electric moiré method. The intermittent phase distribution data of the pixel in the image was connected horizontally, vertically, and time-sequentially, and translate to the continuous phase data. These process was executed on the hardware with the frequency of 60Hz. Phase data was translated to actual data, by the direct linear translation method with calibrated phase data.
The accuracy of this system was evaluated with the 14 reference points placed equally on the semi-spherical test piece. Deviations of real coordinates and system data were analyzed.
Therefore, we concluded that this system was accurate and useful to analyze dynamic deformation of the face, lips and cheeks during functions.

1. INTRODUCTION

Movements of lips and cheeks have great influences on the masticatory and phonetic functions. These movements can indicate the state of harmony between a denture and the soft tissues surrounding the oral cavity, the position of the artificial teeth, the shape and length of the flange and the design of the dentures. Therefore, in the rehabilitation of edentulous patients the detailed analysis of these movements are useful for the evaluation of the rehabilitation tool, that is, dentures.
Various optical measurement technique have proven to be tools in the study of facial movement and lip functions. Motion capture system using photogrammetry was applied in this objects. These systems could trace target points and output three dimensional data time-sequentially. However in order to gain the geometric data of the surface, many points had to be placed on the target surface.
Method of pattern projection, Moiré, has been used for the deformation of the face. These image data was too large for processing and calculating three dimensional co-ordinates of the facial surface on real-time.
Therefore, we established a real-time measuring system for the shape and the deformation of the face and a method to evaluate the facial movements. The purpose of this study was to evaluate the accuracy of this system and to apply for the measurement of facial movements during oral functions.

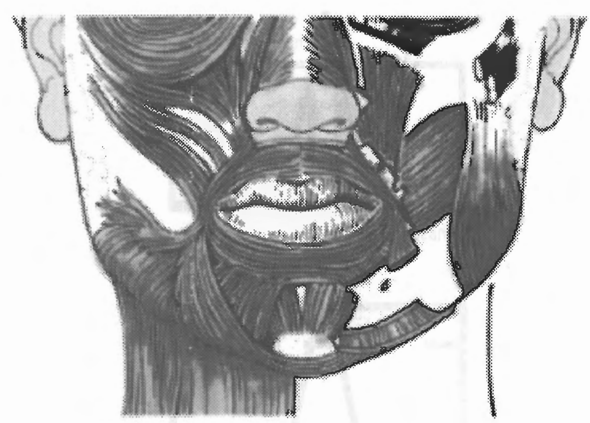

Fig.1 Facial Muscles

2. MATERIAL AND METHOD

2.1 Fringe Pattern Analysis

Various three dimensional measuring technique, three dimensional digitizing, light cutting method, pattern projection method, have been developed. However, these methods request reposing of the objects and long

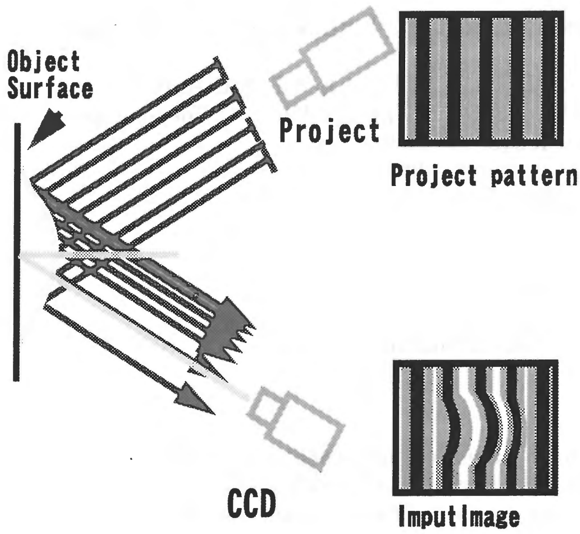

Fig. 2 Fringe Pattern Analysis

processing time. In this system, the process of fringe pattern analysis was minimized into the hardware board, and three dimensional measurement was realized in real-time rate.

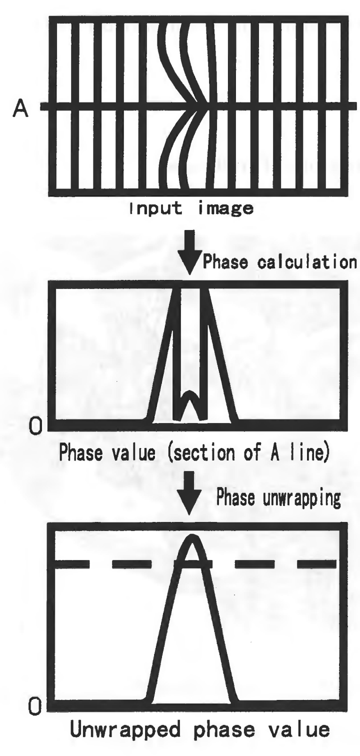

Fig.3 Process of Fringe Pattern Analysis

When the parallel grid pattern was projected on the object surface, the grid lines were deformed as contours of object surface height. The interference between the deformed and non-deformed grid lines produces moiré fringes, whose phase can be interpreted as contours of equal object surface height. Theses phase data was wrapped from 0 to 2π. This wrapped phase is normally called the object's phase map. In order to make these phase data indicate the geometry of the object, the unwrapping process was used and removed the discontinuities of the phase map.

2.2 Phase-Shifting Electronic Moiré Method

This method can deliver phase distribution directly from one fringe pattern image, which contains spatial carrier. The input fringe image was multiplied by three reference fringe patterns whose phase were shifted by $\pi/2$ before low-pass filtering, and three moiré image were produced. These image were subtracted by each other and processed by arctangent to be made sharp.

$$I=I(\theta)=a(x,y)+b(x,y)\cos(\psi(x,y)+\theta)$$

a : bias b : magnitude θ : phase

ψ : phase value indicating object's height

$$I_1=I(0)=a(x,y)+b(x,y)\cos(\psi(x,y)+\theta)$$
$$I_2=I(\pi/2)=a(x,y)+b(x,y)\cos(\psi(x,y)+\theta)$$
$$I_3=I(\pi)=a(x,y)+b(x,y)\cos(\psi(x,y)+\theta)$$

$$\psi(x,y)=Tan^{-1}\ \{(I_3-I_2)/(I_2-I_1)\}$$

These processes were introduced into a real-time fringe analyzer developed by us.

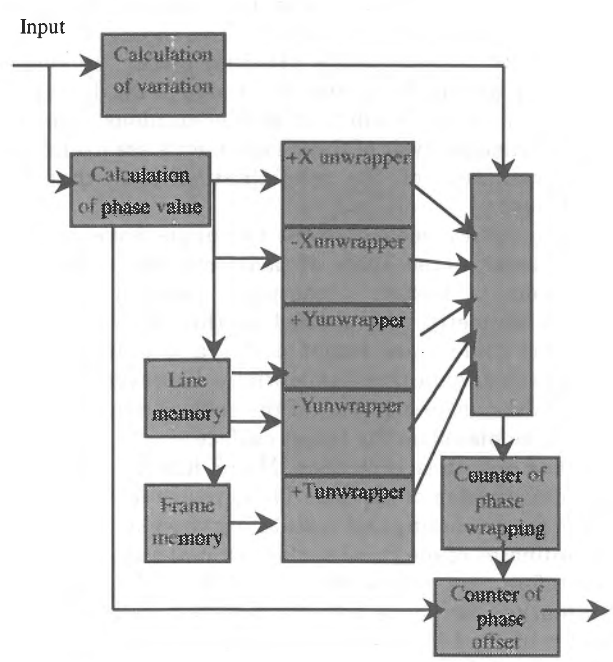

Fig.4 Data processing of 4D unwrapping

2.3 4D Unwrapping

Phase value in the object's phase image calculated by the phase-shifting method, is in the range 0 to 2π. In order to make these value indicate the height of the object, these discontinuities of the phase value are removed by the process known as phase unwrapping. In this system, the direction of phase unwrapping were not only X,Y axis but also time-axial direction. The phase jump is decided by the difference of the phase value from the neighbor pixel. If there is the defective area of the phase value in the object image, the process of the phase unwrapping can progress avoiding and going round this defective area. If the defective area fence round the normal area, the process of unwrapping is impossible. However the fence of the defective area break on one frame in the time-sequential image, the process of the unwrapping will be able to get into the fence and complete the normal area.

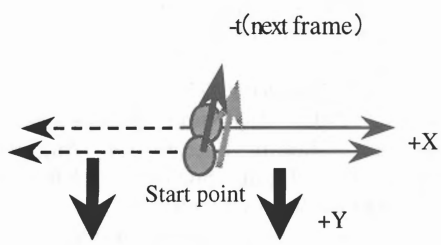

Fig. 5 Direction of 4D unwrapping

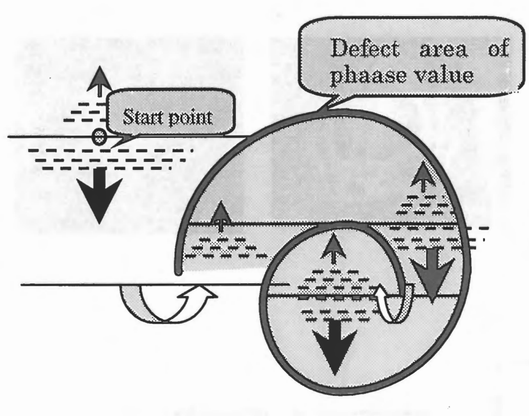

Fig.6 Roundabout way of 4D unwrapping

2.4 System

In this system, Quick Phaser (OKK INC.), the process of Phase-Shifting Electronic Moiré Method and 4D phase unwrapping was achieved on the hard ware. The block diagram of Quick Phaser and the intermediate image of each step were shown in Figure 10 and the specifications and functions are as follows:

Specifications
One pixel of the output image contains 16bit
(phase data : 9bit, phase counter : 5bit, index of the reliability : 2bit).
Output data was written directly in the memory of personal computer through PCI.
768(H)×240(V) ×60 frame/s×16bit
≒22Mbyte/s

Dimensions : 430(W)×150(H)×470(D)mm
(not including protruding parts.)
Image pick up : CCD
Image cell number : 768×240 (768×480)
Communication port : PCI bus interface

Real-time Data Imager (RDI) is a unit which can display the animation of the object's 3-D data. Using RDI we can adjust the optical situations of the system and the object's position as if we operate video camera viewing finder. RDI draws animations 256 × 256 polygon with the frequency of 30Hz.

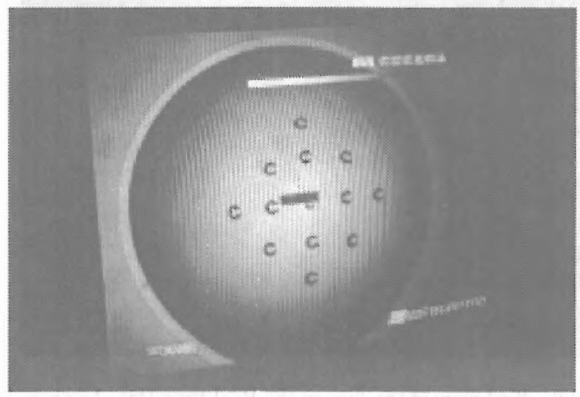

Fig.7 Control points on the spherical surface

3. CALIBRATION

Phase data of QP was transformed to real coordinates using DP/NT (DLT method including phase value).
We examined the accuracy of this system using 29 points (15 points : control point for DLT, others : objective points for verification) whose coordinates were measured by stereophotogrammetry. These points placed equally on the semi-spherical test piece were "C" shape in order to make distinguishable in phase image (Fig.8). Residuals of 14 objective points were showed in Table 1.

Table 1

⊿X	⊿Y	⊿Z
0.28±0.45	0.18±0.73	-0.06±0.50 (mm)

We concluded that this system was accurate and useful to analyze the dynamic deformation of the face, lips and cheeks during functions.

Fig.8 Phase image of control points

Fig.9 Bird view of the face in the Real-time Data Imager

4. FACIAL MOVEMENTS

The subject with normal occlusion was settled in the distance of 500mm from camera, and projected with a fringe pattern. The data of phase image during functional movements, tapping and mastication, was calibrated to the geometric data of the facial deformation. Geometric data was analyzed by 3-D image analyzer (3D-Rugle, Medic Engineering Co. LTD). Figure 9 shows subject's RDI image during functions.

5. CONCLUSION

The accuracy of this system meets the requirements for measurement of facial movements. On the other hand, there are some problems of recognition of the specific points on the face. To cope with this problem we would integrate the data of the motion capture system.

ACKNOWLEDGMENT

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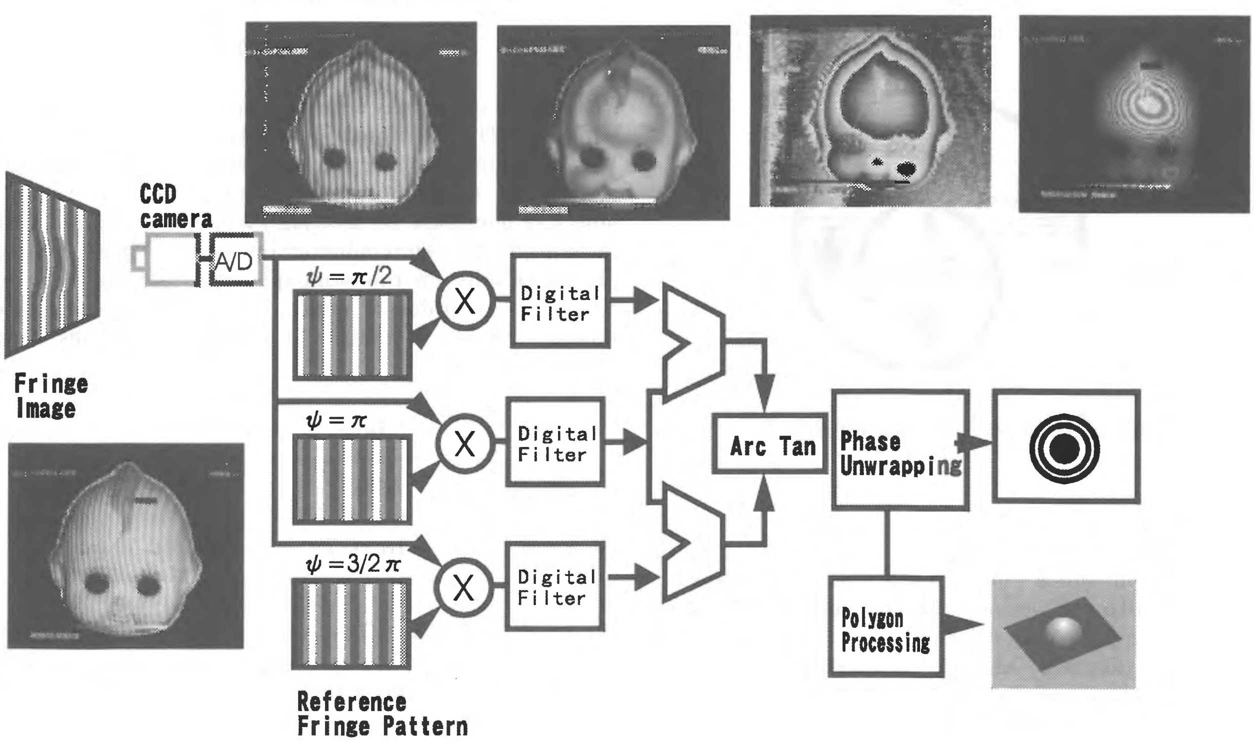

Fig.10 Block of Quick Phaser