3D Based Head Movement Tracking for Incorporation in Facial Expression System

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Summary
Head movement tracking is a necessary system in our attempt to establish the positioning of the head in an instance of the time. In computer graphics, head positioning sequence must be done in a proper manner so that the rendering will appear realistic. The head role becomes more important when a facial expression is being depicted. As a true facial expression must be accompanied with some motion of the head, rendering the facial expression without any proper description regarding head movement will make the head less realistic. This paper proposed a dual-pivot 3D-based head movement tracking system (DPHT) that enables modeler to capture the movement of the head. By having two pivots in the system, the movement of the neck can be modeled together with the yaw, roll and pitch of the head. This movement of the neck is an integral part of the facial expression depiction as can be attested by someone who 'pulls' his neck in manifestation of disgust. The results in this paper show that having a dual-pivot tracking system, head positioning can be better established hence producing more realistic head movement model.
Key words:
Face Expression Modeling, Computer Graphics, Face Tracking, Face Animation.

1. Introduction

Performance-based animation is a good starting point for evaluating movement specifically for facial expression. Using specialized markers that are being strategically placed on the face will enable assessment of facial movement. This assessment will enable the development of a better facial expression model which is reality-based as opposed to pure artistically based. Head and body movement is an integral part of facial expression. When a person produces facial expression, often time, the expression is combined with the movement of the head and body. While undeniably expression can result in bodily movement, the bodily movement can be studied independently of the facial expression. However, the same cannot be said for head movement. As face and head belongs to the same component, head movement will be as vital as the movement of the mouth during a facial expression. The popular Facial Action Coding System (FACS) as proposed by Paul Ekman [5] did outline on the description of head movement together with the other facial muscle movement. FACS can be seen in the work of [1, 7, 12, 13, 19] and [20].

While there are many methods used for head movement determination, many researches based their work on frontal view of the head. While it is undeniable that frontal view gives useful information about head movement property, the emergence of research in 3D modeling requires inspection from other angle of the head movement such as from profile view. In addition Ekman pointed out that the pulling of head movement is more visible from profile view compared to front view [5] and [6]. Researches such as [12] and [21] did propose methods that are applicable for profile view. However these researches only partly capture the head movement. One of the simple methods is by describing movement as rotation in x, y or z direction from one fixed pivot point. The method is used by Ben Yip in his paper titled "Pose Determination and Viewpoint Determination of Human Head in Video Conferencing based on Head Movement" [21]. According to Yip, turning the head to the left can be described as rotation on Y-axis. Likewise looking up can be described as rotation on X-axis. In modeling human head with expression, head pose determination based on rotation can be used to describe the way human move their head as expressions are manifested. Looking down depressively can be described by clockwise rotation on X-axis. Nodding the head signaling the act of agreement can be described as rotation on Z-axis. In short, many of the gestures can be described in terms of rotation relative to X, Y and Z-axis or combination of these axes. Yip's method assumes that rotation will be fixed on one pivot point. The following pictures illustrate some of the movement that can be described using one pivot point. Unfortunately, not all head movement can be adequately described as rotation of a single pivot. A situation may arise in which the pivot point moves forward or backward and the movement does not involve any rotation. Consider the following movement illustrated in Fig. 1:

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(a)  (b) 

Fig. 1 - Example of 'pulling' face backward. (a) Front view. (b) Profile view.

Fig. 1 shows an act of 'pulling' face backward. 'Pulling' face can be described as a movement of which a person moves his face backward in a near horizontal movement. This can be as a result of disgust or surprise situation [14]. In its pure form, the process does not involve any rotation relative to the available axes. In fact, the movement is more towards the displacement of the pivot point from one place to another. The opposite of 'pulling' face will be 'pushing' face as illustrated in Fig. 2. Similarly, the existing method by Yip [21] cannot describe the 'push' of face adequately as his method only involves rotation on one pivot point.

(a)  (b) 

Fig. 2 - Example of 'pushing' face forward. (a) Front view. (b) Profile view.

As a solution to address the situation, this paper proposes dual-pivot pose determination method to enable better pose determination. The proposed method introduces second pivot point to consider a situation in which the first pivot point is displaced by certain amount during 'pulling' or 'pushing' of face.

2. Literature Review

Facial Action Coding System (FACS) by Paul Ekman is being used by many researches in the field of facial expression. However, the head motion description is not being considered by many of the researches. Ekman, through his Manual of FACS defines facial expression in term of Action Unit (AU) and Action Descriptor (AD) [6]. Unfortunately, most of the research work focus on AU with minimal review on AD. As head motion is part of the AD, head motion is not given any priority in describing facial expression studies.

Pantic and Patras look at rule-based description of AU. Their first paper focuses on profile view [12] while the second paper looks at frontal view [13]. Valstar and Pantic [20] is a continuation of rule-based frontal description of AU. While there are frontal and profile elements, these works focus on fiducial points mainly for describing AU. Furthermore, no attempt is being made to implement it in 3D environment. The proposed method attempts to incorporate head motion which will be obtained from frontal and profile view in order for a 3D representation to be built. Using this approach a more encompassing movement can be visualized.

Tian, Kanade and Cohn [19] define templates to detect and track specific AU related muscle. The group's work is based on frontal view and focused on the AU. As AD description is not included, the visualization will be limited only to face. Moreover the group's work in 3D visualization will be limited due to the absence of depth information. Our proposed work on the other hand attempts to quantify movement of the head using both frontal and profile views. This enables 3D visualization as enough information is available to construct 3D coordinate.

Reisenzein, Bordgen and Holtbernd [17] attempt to investigate disassociation between emotion and facial display (surprise). However, their work only quantifies the eye area (pupil, brow) movement for sign of surprise. Incorporating description on the head movement may give more information on the surprise response.

Some other works use specialized equipment to track movement. Kapoor and Picard [9] for example work on head nod and shake detector. The group use infra-red device to detect the movement. Meanwhile, Cohn, Schmidt, Gross and Ekman [2] use EMG (Facial Electromygraphic) device to quantify selected facial muscle during expression. Usage of devices may be applicable in lab environment. Unfortunately, it is intrusive and may hinder subjects from producing good facial expression. It is the goal of this work to avoid intrusion by using image processing approach to detect feature points.

MPEG-4 specification adapted FACS into FAP [11]. However, head movement is not incorporated in the specification. This will reduce the realistic value of the FAP since some of the facial expression includes the head movement. Similarly in an attempt to describe the archetypal expression using FAP, Raouzaiou et. al. did not implement the head movement where the work is confined on facial animation only [15].

Dornaika and Ahlberg [3] include some discussion on rotational property inferring 3D situation during their attempt to infer facial expression using template. The work even discuss on the yaw motion that exist during expression. However the implementation is confined to facial component instead of a more encompassing head movement.

Fakhrul [23] expand the work of Pantic and Patras in his effort to describe the head movement. However, in [23] the focus of the work is more on establishing the head pose rather than presenting a general technique for quantifying head movement.

The detachment of head movement issue and facial expression is such that various computer animation books do not touch on head movement while discussing facial expression. Face Animation and Computer Graphic books such as [8, 10, 16] do not touch on neck motion while discussing facial expression. The neck is actually an integral part of facial expression as pointed out by Roberts in [18] where he elaborates on the head positioning during facial expression. Therefore this paper propose to explore the head and neck movement of the facial expression which has been sidelined by many researches who are more keen on analyzing only on AU-based facial expression

3. Methods

3.1 DPHT (2D Version)

A 2D version of DPHT is a good starting point in explaining the overall system. Since the neck movement view is clearer from the profile angle, tracking the neck solely from the profile view will be the most basic technique in DPHT. While the approach is mainly 2D from the angle of profile view, this method can be extended to be 3D by incorporating some extra points as will be explain at the end of this chapter. In this method two lines are used to assess the movement of the head. The two lines will connect three points as follows:

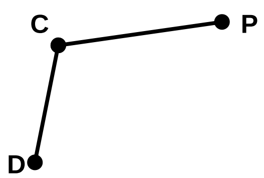

Fig. 3 – Two lines to track the head movement.

The two lines can be mapped to a head as the following Fig 4.

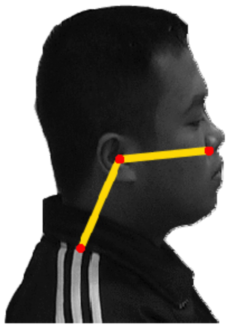

Fig. 4 - The lines imposed on a sample head.

There are three points to be tracked. As illustrated in Fig. 4. The points are P, C and D. Point P will be at the nose region, the C will be the ear hole while the D will be at the middle lower end of the neck. These points can easily be tracked especially using template matching approach. Point P for example will have a distinct feature of the nose which enables finding it at the succeeding frames to be relatively easy. Likewise the ear hole can also be tracked easily considering its features with its distinct surrounding.

3.1.1 Tracking Point C

Ear hole (Point C) is selected to be the pivot point of the head. Based on profile view, a pitch appears to be pivoted on ear hole area. To prove our claim, a simple experiment is being conducted to investigate the change of position whenever pitch occurs.

A. Method

A male student has been asked to pitch his head up and down for ten times. The movement of three locations will be tracked namely the earhole, nose and side-burn. These locations are selected as it has distinct features and it will not change its shape like mouth or eyes. In comparing the locations, the angle of the locations on each frame with respect to a fixed origin (in this case - the pixel location (0,0)) will be calculated. A change in angle value will indicate that the location is moving in some rotational fashion.

B. Results

Based on the results in Fig. 5, 6 and 7, the movement of Point C is very minimal if compared to the movement of the nose during the pitch up and down movement. While the movement of side-burn can also be considered minimal, closer inspection shows that the variation will be more than Point C. In addition, Side-burn will be more difficult to tracked compared to ear hole because side-burn will differs from one person to another. The usage of ear hole as feature point is not new as it is also being used by Pantic and Patras who also use ear hole as their feature point to be tracked [12]. The only different is while [12] use ear hole as individual point, the proposed method use it as part of a larger interconnected system.

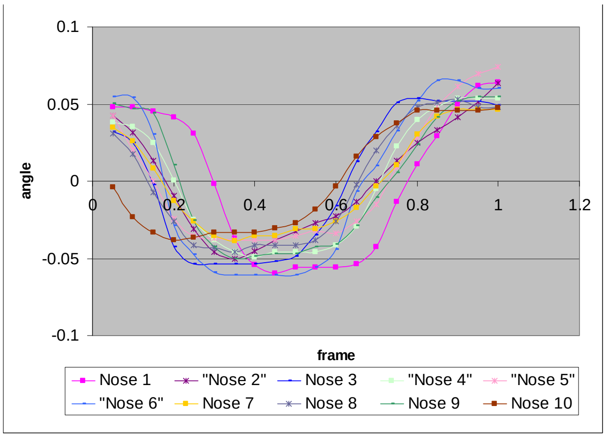

Fig. 5 - Nose (Pitch Up)

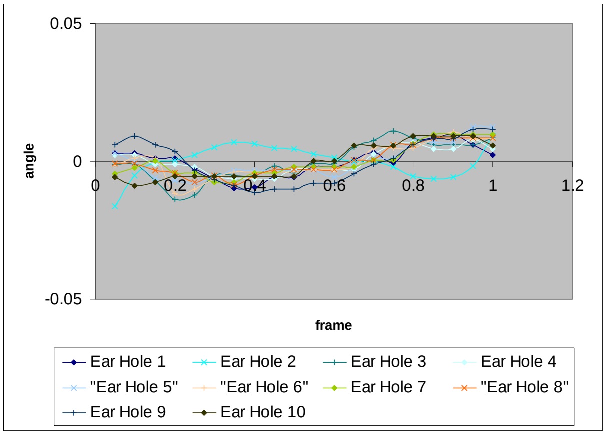

Fig. 6 - Ear Hole (Pitch Up) – Point C

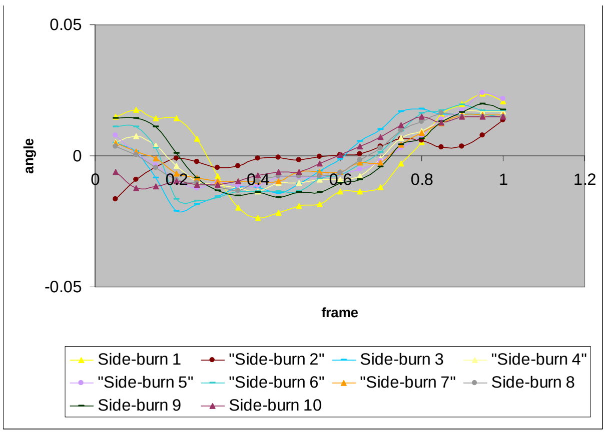

Fig. 7 - Side Burn (Pitch Up)

3.1.2 Tracking Point D

Tracking Point D will be a bit of a challenge since we may not have distinct area for template matching. We propose Point D to be labeled at the midpoint of the base of the neck (refer to Fig. 4) and the whole body section will be tracked to determine its movement. The proposal is made because of two reasons which will be as follows:

1. As the method focuses on the movement of the head, this method assumes that Point D is fixed. Any movement that involves point D will be considered to be the movement of the whole body which is not the focus of this method.
2. As will be proved shortly, marking point arbitrarily near the base of the neck does not make much difference provided that the body is treated as one big point.

A. Point D as the base of the Neck

A simple experiment is conducted to show that selecting a location arbitrarily at the base of the neck will not affect the role of D as a fixed point so long that the body is treated as one big point.

B. Method

A person is asked to wear a marker at the base of his neck. He is asked to do three sequences of movements consisting of looking upwards, looking to the side and pulling the head to the back. 101 samples of these sequences are recorded from profile angle. Two markers movement are tracked. The first marker will be the marker worn by the person on the base of his neck. Another marker is a feature point that is manually selected at the base of the neck. Tracking is done using template matching technique as being described in [4]. In ensuring that the body is treated as one big point, the search region will be sub-sampled so that intra-body movement will be averaged and masked.

The displacement of the marker with respect to the first frame (neutral position) will be calculated. As both markers are assumed to be from the same region, the displacement of the two markers should be the same. A similarity analysis will be made to determine whether the markers' displacement will be the same. As the emphasis will be on similarity, comparison will be done using Angular Separation approach.

Angular Separation approach measures distance between 0 and 1 with 0 refers to rotational degree of 90^0 and 1 refers to 0^0 (i.e. objects are similar). The distance is measured as follows:

$$d(x_i, x_j) = \frac{\sum_{k=1}^{n} x_{ik} . x_{jk}}{\sqrt{\sum_{k=1}^{n} x_{ik}^{2} . \sum_{r=1}^{n} x_{jr}^{2}}} \qquad (1)$$

Where:

$d(x_i, x_j)$ = distance function between marker x_i (first) and x_j (second)

k = k th frame for each sequence

r = r th frame for each sequence

C. Results

Based on the similarity comparison, the distance recorded averaged at 0.987 for 101 samples with standard deviation (σ) of 0.012366 and median of 0.992. This indicates a high similarity between the points labeled at two different locations. As such, it can be safely said that putting the marker at any place at the base of the neck will not give a significant impact on the role of the marker (Point D) as a fixed point.

3.1.3 Movement Description

The movement pattern recorded can be described as keeping track of the angle for CP and DC given an instance:

$$CP_n = \tan^{-1}\left(\frac{P_y - C_y}{P_x - C_x}\right) \quad (2)$$

$$DC_n = \tan^{-1}\left(\frac{D_y - C_y}{D_x - C_x}\right) \quad (3)$$

3.2 3D Extension

DPHT can be extended to be 3D by including at least two more points from the frontal view. A 3D depiction of the points can be illustrated using the following Fig. 8.

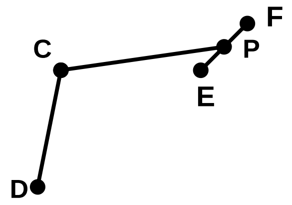

Fig. 8 – A Perspective view of 3D head tracker

Fig. 9 – A Tracker being implemented on the head

These two extra points which are joined by a line EF can be used to determine the Roll and the Yaw of the head.

3.2.1 3D coordinates of point P, C D, E and F

Based on Fig. 9, it is apparent that point P, C and D does not necessarily refer to ear hole, middle of nose and side of middle neck. However, these points (P, C, D) should be located at the middle of the head using ear hole, back of nostril and side of middle neck as guide for its y and z coordinate. The x coordinate of P will be the location of the nose tip which is defined as the middle point between E_x and F_x. The x coordinate for D can be set by tracking the neck section from frontal view with x being the middle of the neck. On the other hand, the x coordinate for C will be set to be the same as D. The proposed method is configured to detect the pulling and pushing movement where rotation on x-axis suffices.

Given that the profile and frontal image are orthogonal and assuming the face to be symmetrical for simplicity, the 3D coordinate of P, C, D, E and F can be recovered as follows:

$$P_x = \frac{E_{x:Frontal} + F_{x:Frontal}}{2} \quad (1)$$

$$P_y = P_{y:Profile} \quad (2)$$

$$P_z = P_{z:Profile} \quad (3)$$

$$D_x = D_{xFrontal} \quad (4)$$

$$D_y = D_{y:Profile} \quad (5)$$

$$D_z = D_{z:Profile} \quad (6)$$

$$C_x = D_x \quad (7)$$

$$C_y = C_{y:Profile} \quad (8)$$

$$C_z = C_{z:Profile} \quad (9)$$

$$E_x = E_{x:Frontal} \quad (10)$$

$$E_y = E_{y:Frontal} \quad (11)$$

$$E_z = P_z \quad (12)$$

$$F_x = F_{x:Frontal} \quad (13)$$

$$F_y = F_{y:Frontal} \quad (14)$$

$$F_z = P_z \quad (15)$$

By using these points, all the head movement namely yaw, pitch and roll can be described. And most importantly, by having these points, two new head movement can also be described namely the pullback and push forward. It is important to note that the initialization of all this values should be obtain when the head is at neutral position so that the value of P_x, C_x and D_x will coincide. As the head move around after initialization, Point D only will be moved with the movement of the body, Point C only moved along z -axis and Point P as well as E and F will move freely according to the movement of the head.

3.2.2 3D Movement Description

The lines presented in this paper (DC,PC and EF – Fig. 8) are meant for quantifying the head movement with the assumption that the head movement can be generalized using these lines with DC indicating the general movement of the neck with PC and EF for head movement. As such the rotation for the head will be centered at CV1 of the cervical vertebrae using amount obtained from PC and EF. Whereas the movement of the neck is centered at CV7 using data obtained from DC. CV7 will be the base of the neck. The usage of CV1 and CV7 are consistent with the fact that CV1 is the uppermost component of cervical vertebrae and CV7 is the bottom most section [22].

A. Determining Roll

Roll of the head can be determined by measuring the tilt angle of EF:

$$\angle \text{EF} = \tan^{-1}\left(\frac{F_y - E_y}{F_x - F_x}\right) \quad (16)$$

B. Determining Pitch

Pitch of the head can be determined by measuring the tilt angle of PC :

$$\angle \text{PC}_{\text{Pitch}} = \tan^{-1}\left(\frac{P_y - C_y}{P_z - C_z}\right) \quad (17)$$

C. Determining Yaw

Yaw of the head can be determined by measuring the angle of PC that rotates about y -axis:

$$\angle \text{PC}_{\text{Yaw}} = \tan^{-1}\left(\frac{P_z - C_z}{P_x - C_x}\right) \quad (18)$$

D. Determining Pulling and Pushing

Pulling back of the head or pushing forward can be determined by measuring the angle of DC that rotate about x -axis:

$$\angle \text{DC}_{\text{PullingPushing}} = \tan^{-1}\left(\frac{D_y - C_y}{D_x - C_x}\right) \quad (19)$$

4. Experiment

To demonstrate the applicability of this approach, a person's various movements are tracked using DPHT. The person is asked to look down and produced a disgust expression. As the focus of this experiment is to demonstrate the usability of DPHT to track general head movement, no specific facial expression requirements are set up. However, the student is requested to do the disgust expression for three times before the actual sampling is done. Two video cameras are being used to capture the expression. One camera is positioned at the front and another one at the profile view of the subject. The two cameras that are orthogonally arranged enable the recovering of 3D coordinate with the assumption that the human face is symmetrical. As the focus is the general movement of the head, high precision of the exact location will not be the priority.

The movements are tracked for two seconds. Upon recording, the video clip will be split into still image and DPHT will be applied to the subject head to track the movement. The movement use simple normalized cross correlation based (NCC) template matching [4] to track the fiducial points. For situations where occlusion cannot be avoided, a marker is put on subject to enable tracking.

A 3D head are developed using OpenGL using a wireframe model obtained from Poser version 4.0. The head is animated using the movement from the control points (Point P, C, D, E and F). As a comparison, another head is build using only feature points as used in Pantic and Patras [12]. A visual inspection is made to ascertain the quality of the displayed animation.

5. Results and Discussion

Based on our experiments, it can be shown that neck movement is important in complementing facial expression.

Fig. 10 - No Neck Movement (using feature points as in Pantic and Patras [12])

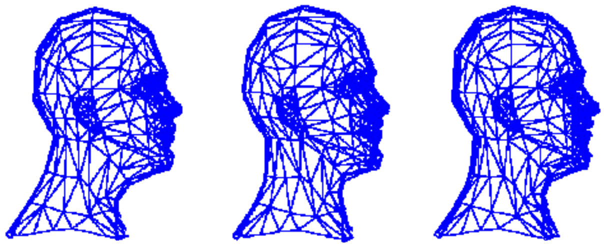

Fig. 11- With Neck Movement (using DPHT)

Both Fig. 10 and Fig 11 illustrate a person who is expressing disgust upon viewing a picture of human waste. Without the neck movement, the interpretation of the expression requires the examination of the face movement which can be quite hard in this situation. With the head movement, we can see that the person is pulling his head away, one of the traits being associated with disgust. The shape of the neck itself will deform accordingly making the visualization to be more realistic. Moreover, the facial expression without the specification of the head movement is indeed awkward and seems to be out-of-place as illustrated in Fig. 12.

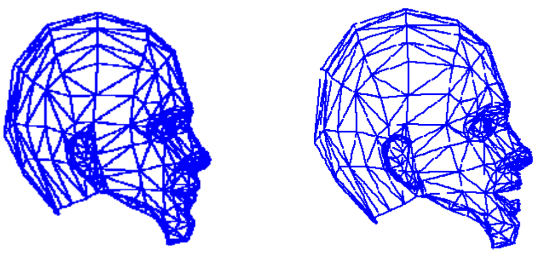

Fig. 12 - Expression without neck (using feature points as in Pantic and Patras [12]).

Based on Fig. 13, the person's posture can be identified by using the DPHT approach. The availability of point D that is connected with Point C enables the estimation of neck slanting as shown in Fig. 13.

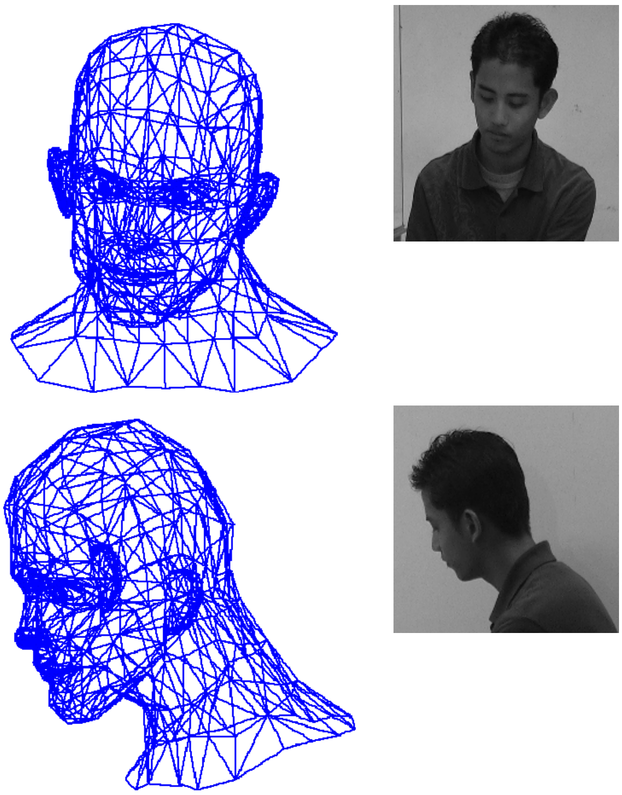

Fig. 13 - Usage of DPHT Approach enable the establishment of head position

It is obvious from the simple experiment that DPHT can be used to quantify the head movement inclusive of the neck. The inclusion is vital in order for the facial expression to be more realistic, believable and certainly better quantified.

6. Conclusion

As a conclusion, it is obvious that the positioning of the head and the neck do play some role in the believability factor for facial expression. Without these movements, movement of the mouth or blinking of the eyes will not be perfect in visualizing facial expression. Therefore, DPHT can be used to quantify these movements. The information obtained can be used with existing information of mouth or eye movement to form a better manifestation of facial expression.

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