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Full Length Research Paper

3D numerical definition with vectors for human smiles

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In most of the numerical methods for facial expressions in the literatures, the number of the key controls for animators or robot programmers are too complex and trivial, because what they want are less and critical controls. This study explored varied types of human smiles and extracted proper key factors affecting the smiles. These key factors then were converted into a set of control points which could serve to satisfy the needs for creation of facial expression for 3D animators and be further applied to the face simulation for robots in the future. First, hundreds of human smile pictures were collected and analyzed to identify the key factors for face expression. Then, the factors were converted into a set of control points and sizing parameters calculated proportionally. Finally, two different faces were constructed for validating the parameters via the process of simulating smiles of the same type as the original one.

Key words: 3D animation, facial expression, numerical, robot, smile, parameter.

INTRODUCTION

Those modern robots, such as machine consultants, robot officers and virtual anchors, or those future official and housing robots, have to face and interact with people (Pelachaud, 2009). Since more cold machines have been surrounding us, we will be more tired with those no-face monitor-only machines. So, servant robots having virtual facial expression will be a very important task for future artificial intelligence (AI) (Breazeal et al., 2005).

On the other hand, we meet the bottle neck of making virtual 3D face. In producing computer animation, animating facial expressions is one of the most time-consuming processes, because adjusting a 3D face model manually to create facial expressions involves a great degree of free space and most of animators are difficult to accurately grasp the facial anatomy. Therefore, in many cases, even the experienced animators usually have to spend countless hours to set vertices on the models for realistic facial animation (Shin and Lee, 2009).

For animators, they could only make lively 3D virtual character through their experiences, which means there is no way to make any 3D virtual character without trying (Tondu, 2009). Sometimes all these tries could just fail in capturing audience minds. Taking movie “Final Fantasy” as example, it cost 100 million US Dollars, and it was designed with motion capturing system to simulate the facial muscles’ vibrations (Popat et al., 2008). However, this animation has not been as lucrative as it had been expected (Elberse, 2007). Its failure and its high cost have made other film makers feel burned. We still need to put a lot of efforts into virtual facial expression producing technology (Liu, 2007).

Now, virtual world is outgrowing. In addition to 3D animation, carrying out the facial expression research into other fields such as AI, cultural and creative film and television industry is feasible and necessary. These fields need a simple set of operating rules to create artificially virtual facial expressions for cartoon roles, robot faces, synthetic anchors and receptionists with AI.

An animator creates facial expressions from scripts, and the facial expressions of a robot are translated from commands of texts. Therefore, an important issue comes about: in what specific ways can help a designer transfer these words into characters’ facial expressions to provoke consumers’ and audiences’ emotion and cognition at the same time?

This paper proposed a solution; we must first convert human facial expression into a numerical way as communication media between texts and machines. Since the

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complexity and diversity of human facial expression, and the limited duration of this study, we chose “smile”, the highest demand among all, as the subject in this research.

Therefore, the purposes of this study were to explore a numerical expression of human smiles and to transfer a specific smile data from a 3D face model to others, by which we could verify the numerical expression. The results should be able to contribute to the 3D animation produce and AI robots’ facial communications.

METHODS

For the descriptions of facial expressions, most academics and industries take an extremely open attitude to designers or animators and let them imagine. That is, experts manipulate several key points of face models via their untraceable minds and make tries over and over to reach the required facial expressions. Once they need to create the same kind of expressions in characters of different looks, experts with keen eyes can adjust with same proportion. Likewise, we assume that parameters of facial expressions can be formed as long as we define the changes of facial features with numerical way through the mathematical concept of vectors.

In this digital era, currently a lot of numerical methods have been applied in academic researches (Boumaza et al., 2009; Chen et al., 2009; Jumaat and Alam, 2010; Kalantarifard et al., 2009; Kim and Lee, 2010). However, there are fewer numerical definitions for creating virtual facial expressions in literatures. Most purposes of the related researches are developed for recognizing facial expressions, and are aimed at the need of machines’ recognition. Therefore, there are a lot of control key points defined on faces in these literatures.

Kotsia and Pitas (2007) proposed two methods to recognize facial expressions, such as, support vector machine (SVM) system and facial action units (FAUs) system, which are recognized by coordinates of grids and nodes. They showed six most representative FAUs used for facial expression recognition, including anger, disgust, fear, happiness, sadness and surprise.

Abrantes and Pereira (1999) and Sung and Kim (2008) used 2D and 3D to construct facial expressions. They defined nodes in 2D part, and then used various lines in 3D. Afterward, they used active appearance model (AAM) to show facial expressions.

Samir et al. (2006) in their paper “Three-Dimensional Face Recognition Using Shapes of Facial Curves” proposed a method to recognize facial expressions. First, they used horizontal curves called “face curves” to define facial expressions. Second, they compared the relationship between facial expressions and “face curves”.

Referring to the aforementioned literatures, we also used vectors to find a new needed numerical definition for facial expressions. First, we collected image samples of smiles to determine new key points of facial expressions with an appropriate number, and took one specific smile as an example to calculate the change of key points in vector space for generating smile parameters. Then we applied the parameters to other faces with completely different features to verify that the parameter was feasible. The details of the entire experiment are thus described.

Adjective phrases sample collection

We invited 33 freshmen of the art department as the subjects. They had been asked to recall their life experience, and to write down different adjectives that could describe different smiles, such as graceful, evil and bitter, on cards, each card for an adjective. Everyone had to write 10 cards, and we could collect 330 adjectives about smile.

After eliminating inappropriate or similar ones, there were 184 adjectives left, as Table 1 shows.

Discussed by 5 college students, 184 cards with different adjectives were classified. The smiles that cannot tell, such as “crooked smile”, “stupid smile”, “foolish smile” were all grouped into the one called “dummy smile.” Thirty two kind smiles are shown in Table 1.

Collect smile pictures

According to the 32 groups of adjectives collected in the previous step, we invited professional drama actors and actresses to perform in this experiment. Five males and five females, who had just graduated from departments of drama in colleges, were asked to perform based on our 32 kinds of smiles. When they performed, we took photos, and then chose better ones for each kind of smile. Eventually we got totally 116 smile pictures shown in Figure 1.

Set key points of facial expression

Since our purpose was to help designers create facial expressions, the way of designers’ thoughts had to be the main consideration. Therefore, we decided to ask five designers of animation to observe variables of facial features. Through focus group method, we figured out that no matter what sexes, face shapes, skin colors and hair styles of the performers are, all key factors compose of the following same items:

1. Movement of eyebrows
2. Movement of upper and lower eyelids
3. Movement of pupils
4. Upper and lower lips
5. Angle of head rotation

According to those items, the key control points of facial expressions are shown Figure 2. The key control points with a changing facial expression of same character are shown in Figure 3.

The difference of change between the two situations (that is, Figures 2 and 3) was the key to convert smile into numerical data and parameters. The principle of calculating parameter must be ratios in variations of same character. In other words, one compares with oneself. Therefore, it does not matter which performer’s face we took for this experiment. Both monster Shrek and beautiful princess were supposed to be applied the parameters well.

To compare the variation, an unchangeable datum point in common on faces was necessary. We found the two inner corners of eyes did not move in every facial expression. The midpoint of these two corners was close to the center of every face and was suitable to be a datum point for all key control points. For that reason, we defined this point as origin for numerical smile of this study and labeled it “O” point. And other key control points were also labeled as shown in Table 2 and Figure 4.

Choose photos of a neutral face and a smiling face

We chose two photos of a male performer without glasses and with clear profiles on the face. One photo was without smile and the other one was with smile. These two photos were handled with an image process program to crop into 400-pixel-square photos including each whole face from front head to chin, as shown in Figure 5.

Table 1. Thirty two group of smiles and their names.

No.	Group	Original adjectives
01	Forced smile	Forced, disguising, pretending, fixed, weak, lopsided, awkward (7)
02	Hypocrite smile	Hypocrite , supercilious, superficial, perfunctory, flattering, fawning, ingratiating, obsequious, pleasing (9)
03	Lustful smile	Bitchy, salacious, licentious, lewd, lustful, obscene, sexual (7)
04	Disgusting smile	Disgusting, terrible, repugnant, sick, illicit (5)
05	Evil smile	Evil, cruel, frightening, scary (4)
06	sinister smile	weasel , treachery, wily, crafty, deceitful, cunning, unscrupulous, sinister, villainous, wicked (9)
07	Gloomy smile	Secret, dim, mysterious, fishy, can-not-read, incredulous (6)
08	Gruesome smile	Gruesome, ghastly (2)
09	Sheepish smile	Nervous , hesitated, humorless, mirthless, sheepish (5)
10	Bitter smile	Bitter, heart-broken, wry, strained, forced (5)
11	Confusing smile	Confusing, bewildering (2)
12	Keep straight face	Keep straight face, hiddenly (2)
13	Supercilious smile	Supercilious, mocking, enigmatic, sardonic , rude, crazy (6)
14	Rueful smile	Rueful, apologetic, sorry, regretful, weak, thin (6)
15	Cold smile	Cold, lukewarm, sneering, grim, bloody, slight, despised, scornful (8)
16	Dummy smile	Dummy, stupid, empty-minded, block-headed, slow-witted, idiotic, foolish, heartless, mindless, dull, dense, clumsy, dunce, hardheaded, mental-illness, silly, intelligence-challenged (17)
17	Knowing smile	Knowing, conspiratorial, understanding (3)
18	Surprised smile	surprised (1)
19	Victory smile	Victory, successful, achievement , winner's (4)
20	Brave smile	Brave, confident (2)
21	Wisdom smile	Wisdom, intelligent, meaningful, deep, clever, bright (6)
22	Warm smile	Warm, sunny, beatific, radiant, flowery, from-heart (6)
23	Naïve smile	Naïve, innocent, simple, natural, naked (5)
24	Excited Smile	Excited, exaggerated, crazy, overt, booming, big, booming, powerful, noisy, belly (10)
25	Harsh smile	Barking, cackling, harsh, husky, throaty (6)
26	Hearty smile	Amused, delighted, hearty, extremely, happy, joyful (6)
27	Silvery smile	Silvery, tinkling (2)
28	Satisfied smile	Satisfied, joyful, mirth, glad, grateful, happy, sweet, well-being, dreamy, slight, short, little, small, light, good, great, humor, reassuring (18)
29	With-tear smile	Moved, strong-emotion, with-tear (3)
30	Sexy smile	Sexy, charming, enchanting, lovely, attractive (5)
31	Friendly smile	Friendly , polite, gentle (3)
32	Shy smile	Shy, toothless, lopsided, pretty (4)
	Total	184

Produce 3D samples

From the neutral-face image, we produced a 3D head model with high similarity by assistance of 3D modeling programs, Face Gen Modeller 3.1 and Autodesk Maya 2008. We also made midpoint of two eyes' inner corners of the 3D model in the position (0, 0, 0) in the 3D space, as shown in Figure 6.

From the smiling-face image, we fixed the neutral-face 3D head model by adjusting change of eyebrows, eyes, lips and the angle of head rotation to high similarity with the photo and got a 3D head with a smiling face, as shown in Figure 7.

Get 3D coordinates of key points

In the 3D program, Maya, we drew NURBS curves with key control points on the neutral-face 3D head and get coordinate (X0, Y0, Z0) of each key control point as shown in Figure 8a.

In Maya, we got the angle of head rotation (Rx, Ry, Rz) from smiling-face 3D head, and then returned the head rotation to zero in 3 axes. Of course, the midpoint of two eyes' inner corners of the 3D model was still in the position (0, 0, 0) in the 3D space, because we did not move the model. It was only rotated when we transformed it from a neutral face to a smiling face. Now, we could get coordinate (X1, Y1, Z1) of each key control point from the NURBS curves on the straight angled 3D head as shown in Figure 8b.

Generate smile parameters

The coordinates of key points on face without smile were decided by the appearance of each person. In same smiles, each key

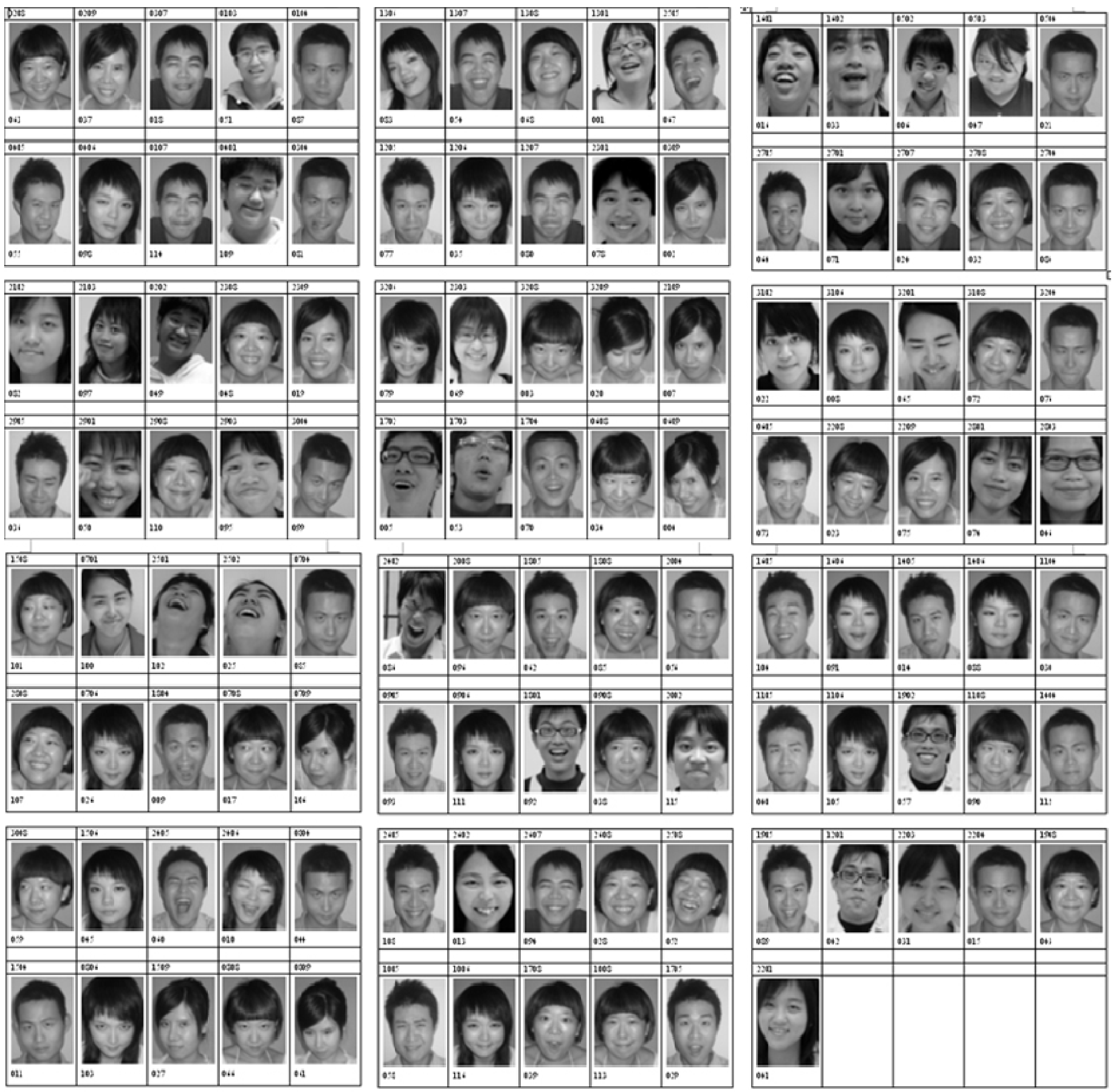

Figure 1. Collected smile pictures.

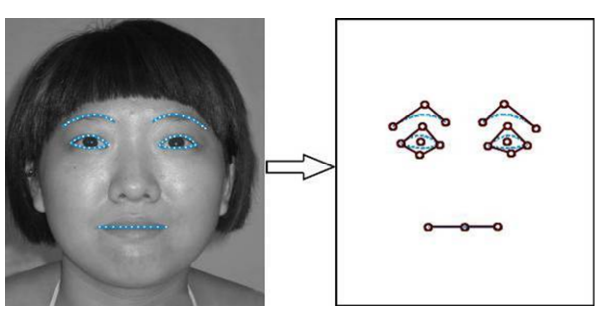

Figure 2. A face without smile.

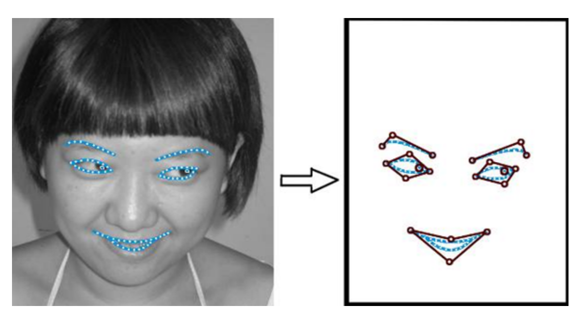

Figure 3. A face with smile.

Table 2. Codes for key points of smile.

Position of key points	Labels
Midpoint of two eyes' inner corners	O
Left eyebrow	LA, LB, LC
Right eyebrow	RA, RB, RC
Left eyelids	LD, LE, LF, LG
Right eyelids	RD, RE, RF,RG
Left pupil	LH
Right pupil	RH
Lips	LI, RI, J, K

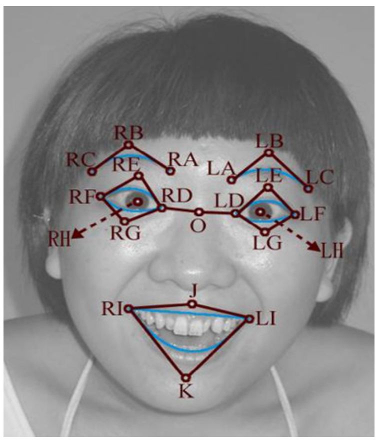

Figure 4. Positions of key points.

control point on different faces moved with same-ratio distance and same direction. For example, the distance between an eye's inner corner and Label O of monster Shrek might be longer than that of princess Fiona, but the moving distance of her eye corner was supposed to expand in same ratio with the one of his when same smile was made. Therefore, we assumed the ratios of how much key points transfer could be applied on different faces to generate same smiles. We divided the difference between a neutral face and a smiling face by the value of the neutral face of the coordinate of each key point to get a changing ratio, which was called smile parameter, as shown in Table 3.

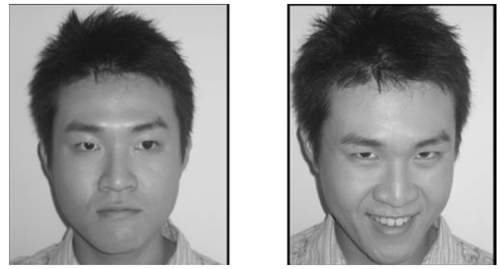

Figure 5. Choose photos before and after smile.

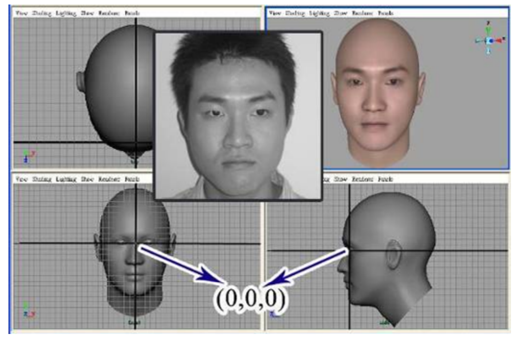

Figure 6. 3D head with a neutral face.

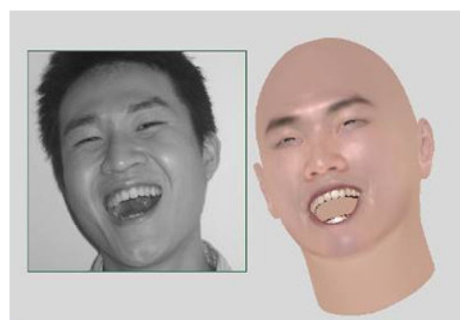

Figure 7. 3D head with a smiling face.

RESULTS

Result of the Asian male face

In 3D animation software, we got the coordinate value from the 3D models of Asian male face including the neutral face and the smile face in this experiment listed as shown in Table 4. The smile parameters of the type in this experiment are shown in Table 5.

Create same smiles with the smile parameters in an Asian female face

After getting the smile parameters, we made all key points change from an Asian female 3D head model. We found that the smile of this Asian female model looked same with the one of the Asian male model in this experiment as shown in Figure 9.

Create same smiles with the smile parameters in an African male face

In order to check whether the smile parameters could apply on faces of a different race, we took an African face to experiment and created an identical smile as in Figure 10. We roughly investigated the opinions about the results in this experiment. All interviewees agreed that

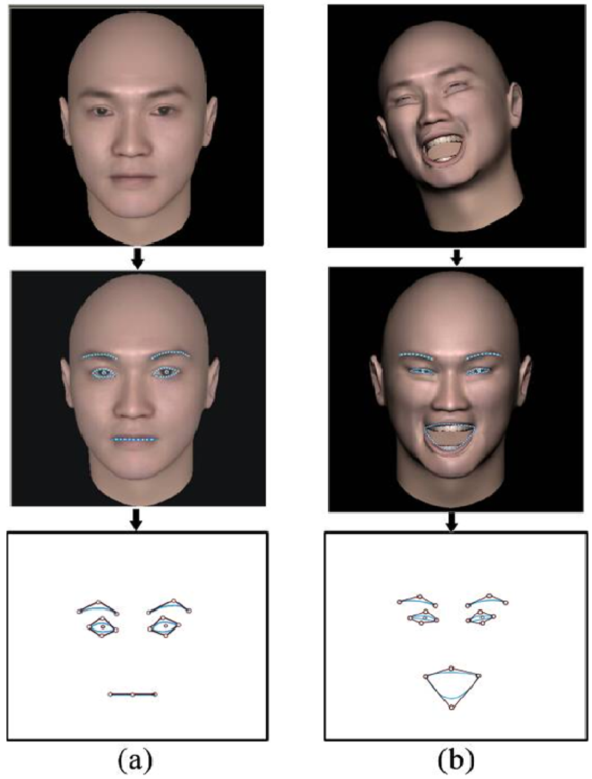

Figure 8. Get coordinate data of key points from 3D models (a) the neutral-face 3D head and (b) the smiling-face 3D head.

Table 3. Calculation of smile parameter.

Label	Coordinate or angle of plain face	Coordinate or angle of smiling face	Smile parameter
Rotate	0, 0, 0	Rx, Ry, Rz	Rx, Ry, Rz
O	0, 0, 0	0, 0, 0	
LA	X0, Y0, Z0	Xi, Yi, Zi	(Xi-X0)/X0, (Yi-Y0)/Y0, (Zi-Z0)/Z0
LB	X0, Y0, Z0	Xi, Yi, Zi	(Xi-X0)/X0, (Yi-Y0)/Y0, (Zi-Z0)/Z0
LC	X0, Y0, Z0	Xi, Yi, Zi	(Xi-X0)/X0, (Yi-Y0)/Y0, (Zi-Z0)/Z0
RA	X0, Y0, Z0	Xi, Yi, Zi	(Xi-X0)/X0, (Yi-Y0)/Y0, (Zi-Z0)/Z0
RB	X0, Y0, Z0	Xi, Yi, Zi	(Xi-X0)/X0, (Yi-Y0)/Y0, (Zi-Z0)/Z0
RC	X0, Y0, Z0	Xi, Yi, Zi	(Xi-X0)/X0, (Yi-Y0)/Y0, (Zi-Z0)/Z0
LD	X0, Y0, Z0	Xi, Yi, Zi	(Xi-X0)/X0, (Yi-Y0)/Y0, (Zi-Z0)/Z0
LE	X0, Y0, Z0	Xi, Yi, Zi	(Xi-X0)/X0, (Yi-Y0)/Y0, (Zi-Z0)/Z0
LF	X0, Y0, Z0	Xi, Yi, Zi	(Xi-X0)/X0, (Yi-Y0)/Y0, (Zi-Z0)/Z0
LG	X0, Y0, Z0	Xi, Yi, Zi	(Xi-X0)/X0, (Yi-Y0)/Y0, (Zi-Z0)/Z0
RD	X0, Y0, Z0	Xi, Yi, Zi	(Xi-X0)/X0, (Yi-Y0)/Y0, (Zi-Z0)/Z0
RE	X0, Y0, Z0	Xi, Yi, Zi	(Xi-X0)/X0, (Yi-Y0)/Y0, (Zi-Z0)/Z0
RF	X0, Y0, Z0	Xi, Yi, Zi	(Xi-X0)/X0, (Yi-Y0)/Y0, (Zi-Z0)/Z0
RG	X0, Y0, Z0	Xi, Yi, Zi	(Xi-X0)/X0, (Yi-Y0)/Y0, (Zi-Z0)/Z0
LH	X0, Y0, Z0	Xi, Yi, Zi	(Xi-X0)/X0, (Yi-Y0)/Y0, (Zi-Z0)/Z0
RH	X0, Y0, Z0	Xi, Yi, Zi	(Xi-X0)/X0, (Yi-Y0)/Y0, (Zi-Z0)/Z0
LI	X0, Y0, Z0	Xi, Yi, Zi	(Xi-X0)/X0, (Yi-Y0)/Y0, (Zi-Z0)/Z0
RI	X0, Y0, Z0	Xi, Yi, Zi	(Xi-X0)/X0, (Yi-Y0)/Y0, (Zi-Z0)/Z0
J	X0, Y0, Z0	Xi, Yi, Zi	(Xi-X0)/X0, (Yi-Y0)/Y0, (Zi-Z0)/Z0
K	X0, Y0, Z0	Xi, Yi, Zi	(Xi-X0)/X0, (Yi-Y0)/Y0, (Zi-Z0)/Z0

Table 4. The coordinate data in 3D space.

Label	Neutral face			Smiling face		
	X0	Y0	Z0	X1	Y1	Z1
Rotate	0.00	0.00	0.00	-20.42	-10.82	15.21
LA	6.87	7.22	6.30	6.54	8.37	5.58
LB	15.61	11.99	6.86	15.17	12.21	7.37
LC	23.34	8.14	-2.91	23.51	7.65	-2.94
RA	-6.87	7.22	6.30	-6.54	8.37	5.58
RB	-15.61	11.99	6.86	-15.17	12.21	7.37
RC	-23.34	8.14	-2.91	-23.51	7.65	-2.94
LD	8.09	-0.04	-0.62	7.88	-0.05	-0.78
LE	14.55	5.24	3.77	13.10	3.98	4.63
LF	18.62	1.51	-2.32	18.54	1.36	-1.56
LG	14.55	-2.93	1.91	13.10	1.01	4.63
RD	-8.40	-0.20	-0.60	-8.27	-0.03	-0.77
RE	-13.66	4.93	4.43	-12.51	3.21	5.04
RF	-18.37	1.05	-1.99	-18.54	1.36	-1.56
RG	-13.66	-3.33	1.87	-12.51	0.82	5.04
LH	13.79	1.79	1.35	13.70	1.98	1.74
RH	13.68	1.52	1.54	13.79	1.83	1.74
LI	19.28	-30.17	-5.24	11.43	-27.38	-5.69
RI	-19.28	-30.17	-5.24	-11.63	-27.80	-5.19
J	0.00	-29.34	4.09	-0.01	-24.59	9.81
K	0.00	-29.53	3.66	-0.01	-50.46	1.93

Table 5. Smile parameters of this experiment.

Label	X axis	Y axis	Z axis
Rotate	-20.417	-10.819	15.209
LA	-0.05	0.16	-0.11
LB	-0.03	0.02	0.08
LC	0.01	-0.06	0.01
RA	-0.05	0.16	-0.11
RB	-0.03	0.02	0.08
RC	0.01	-0.06	0.01
LD	-0.03	5.64	0.25
LE	-0.10	-0.24	0.23
LF	0.00	0.00	-0.18
LG	-0.10	-1.34	1.42
RD	-0.02	-0.83	0.28
RE	-0.08	-0.35	0.14
RF	0.01	0.29	-0.22
RG	-0.08	-1.25	1.70
LH	-0.01	0.11	0.29
RH	0.01	0.20	0.13
LI	0.19	-0.09	4.07
RI	0.21	-0.08	4.58
J	-5.15	-0.15	0.10
K	-5.15	0.75	-0.78

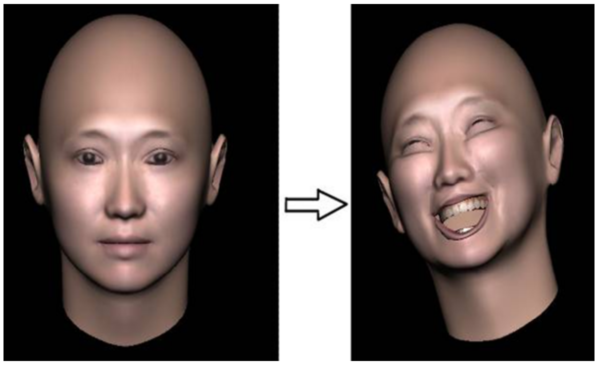

Figure 9. Smile of a Asian female head model.

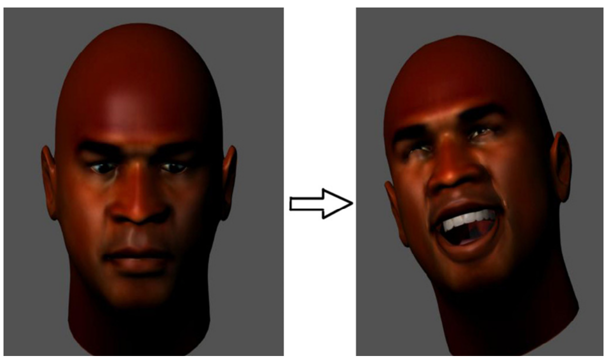

Figure 10. Smile of an African head model.

these three smiles of pictures belong to same type of smile. We believed that the smile parameter worked.

DISCUSSION

In most of the numerical methods for facial expressions in the literatures (Abrantes and Pereira, 1999; Kotsia and Pitas, 2007; Samir et al., 2006; Sung and Kim, 2008), we think that the number of the key controls for the computers is indeed in an acceptable range. The more detectable points, the more accurate facial expression recognition is, and it does not affect computation a lot. For example, there were 70 points defined on a face in the study (Sung and Kim, 2008).

Nonetheless, for the animators or the robots at current stage, those controls are too complex and trivial, because more controls mean more troubles (Shin and Lee, 2009). What they want are less and critical controls. To satisfy the needs of animators or robot programmers, we wanted to find a more appropriate method of numerical definition for facial expressions.

We had focus group observe the collected smile pictures. Because these images contained a huge number and variety of smiles from performances of 10 professional theatric actors/actresses, we believed that they covered adequate representations of all human smiles. After observing these pictures, the defined key points of facial expressions were much less than before. In other words, those were moderate in quantity and met the needs of this study.

On the other hand, in order to verify, smile could be defined by the method of vectors, we chose a specific smile to calculate the vector parameters according to the positions of these key points, and did successfully create a same facial expression in other different face models.

However, only the calculation method of numerical smiles is not enough in practice. There are so many types of smiles, and this study only chose one in the experiment. All kinds of smiles can be named, and the numerical method of this research can be used to calculate the parameters of all smiles and even all facial expressions for users to refer to.

Moreover, we could further integrate the parameters of this study with a friendly user interface to generate virtual facial expressions that 3D animators and robots need.

Conclusion

In this study, the collected smile pictures contained a huge number and variety of smiles from performances of 10 professional theatric actors/actresses, so we believed that they covered adequate representations of all human smiles. After observing these pictures from the experts of adjusting facial expressions, the defined key points of facial expressions were moderate in quantity and met the needs of need of practice. Then, we calculated the parameters of vectors based on the less and critical facial features and their positions in 3D coordinate. We successfully got the results of same type smile in face models of different races or sexes.

For research and development engineers of commercial robots to give the robot facial expressions, the first issue to be faced is how to show proper smiles in different situations to face consumers, even how to achieve effective and interactive mood. Robot engineers need the result of this study to set transformations of robots' faces in different conditions.

For professional animators, if they can get the numerical information of key control points on a face, they can easily create smiles of humans or anthropomorphic characters, and do not have to try positions of the key points on faces again and again (Shin and Lee, 2009) to meet the need of plots.

For theater performers, if a beginner feels difficult in a moment to grasp the performance of different smiles, such as a crafty smile and a proud smile, he or she may also refer to the results of this study which is helpful to quickly grasp the keys of performance.

For most people, in daily life, the lines on the faces often send the wrong messages in the interpersonal absence of oral communication, resulting in cognitive suspicion or misunderstanding unconsciously. This research provides general public to consult and to possibly fix the lines on faces, helping to improve interpersonal relations.

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