Three-Dimensional Face Caricaturing by Anthropometric Distortions

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***Abstract*—Caricatures are models of persons or things in which certain striking characteristics are exaggerated in order to create a comic or grotesque effect. This paper is concerned with a strategy for automatically generating caricatures of three-dimensional models based on anthropometric measures and geometric manipulations by influence zones. In the proposed strategy, measures from a reference model serve as means of comparison with the corresponding measures in the model to be caricatured. Deformations are applied to the features that differ most from the corresponding features in the reference model. This method is independent of mesh topology. Unlike other techniques, it is possible to generate variations of caricatures, adopting different sequences of deformations, application of asymmetry and expressions. Our method also does not need 3D model databases to be used as a base of combinations or comparisons of models.**

***Keywords*-Caricature, anthropometry, virtual character.**

I. Introduction

A caricature is a model or a drawing made by an artist that exaggerates the subject's distinguishing features. Three-dimensional caricatures are often used to generate funny models for virtual reality applications, games, cartoons, etc. This work is concerned with a strategy for automatic generation of three-dimensional caricatures, using concepts of anthropometry and deformations based on influence zones (Figure 1). The strategy is intended for 3D models with topologically distinct meshes. In the proposed strategy, measures taken from a reference model serve as means of comparison with the corresponding measures in the model to be caricatured. The features that differ most from the corresponding features in the reference model suffer larger deformations. Hence, when a measure in a model is very different (much bigger or much smaller) from the corresponding measure in the reference model, that difference is exaggerated according to some predefined deformation pattern. The remainder of this work is structured as follows. In Section 2, some closely related works are discussed. Section 3 is devoted to a brief exposition of the concepts of anthropometry. In Section 4, the proposed strategy of mesh deformation for generating caricatures is detailed. In Section 5, an algorithmic view of the proposed strategy is applied to some case studies. In Section 6, conclusions are drawn.

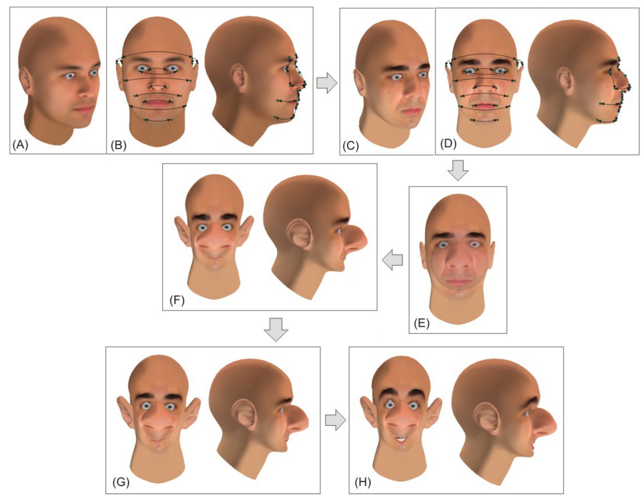

Fig. 1. Steps for caricature generation. (A) Reference model. (B) Measure identification. (C) Studied model. (D) Measures compared with those of the reference model. (E) Application of deformations. (F) Caricature. (G) Application of asymmetry. (H) Application of expressions.

II. Related Work

Several authors have explored the problem of automatic computer generation of caricatures [1], [2], [3], [4], [5]. The generation of caricatures of 3D models requires modeling techniques and manipulation of meshes. Noh and Neumann [6] produced a survey of the various techniques used in modeling and manipulation of models for generating facial animations: morphing techniques, anthropometry, free-form deformation, deformation-based muscles, etc. DeCarlo [7] pioneered the use of anthropometric techniques for the automatic generation of faces with different measures. They applied their techniques to the construction of avatars for virtual reality applications. Blanz, in [8], [9], proposed the concept of face vector space, and used Principal Component Analysis (PCA) to determine a set of facial basis vectors that were linearly combined in order to generate new faces in the face vector space. These techniques make it possible to compare the position of each vertex in a model, with the position of the corresponding vertices in an average model, and to apply translations to the vertices, proportional to the difference from the average model. Vertices with the largest position differences are shifted more strongly, thereby emphasizing the characteristics that differ most from the average. The results are interesting, however, the mesh of the model to be caricatured needs to have the same topology of the mesh associated to the average model. This method also does not provide enough freedom to create caricatures with different styles. Chen and his coauthors [10] created a system that identifies patterns in 2D cartoons drawn by artists in order to reproduce the styles automatically. Liu and his coauthors [11] developed a learning system standard, based on PCA, using a database of 3D models generated from 2D cartoons drawn by artists. The database of 3D caricatures is used to construct a vector space of 3D caricatures with which the techniques proposed by Blanz and his coauthors [8], [9] can be applied in order to generate caricatures with artistic styles. However, it is still necessary to have a database of models and meshes with the same topology. Other systems based on learning patterns have been proposed as well [12], [13]. Noh and his coauthors [14] used the technique of RBF (Radial Basis Functions) to deform models in order to generate facial expressions in real time for videoconferencing systems. In this work, we present a technique for facial deformation based on moving points in an influence region. The technique was inspired by the work of Noh [14]. However, our influence zone is free to move, and is not attached to a node of the mesh. As a consequence, it does not generate discontinuities and can be applied to any mesh topology.

III. Anthropometry

Anthropometry is the scientific study of measurements and proportions of the human body. Taking facial measurements requires a set of well-defined points on the face, the Landmarks [1].

There are five types of facial measurements [7], [15] in anthropometry: the shortest distance between two landmarks; the axial distance between two landmarks; the tangential distance between two landmarks; the angle between landmarks and one of the coordinate axes; and the angle between two alignments of points.

Measures of human faces from different places of the world have been collected over the years, resulting in databases that provide the outstanding characteristics of individuals from different ethnic, age and sex groups. The anthropometric measures stored in a database are valuable resources for simulating variations of a 3D facial model.

In this study, we use the anthropometric landmarks to determine measures of a reference model (Figure 2). When the model to be caricatured is compared with the reference model, the farther away a given measure is from that of the reference model, the more exaggerated it will be.

IV. Manipulation of Facial Measures

Noh and his coauthors [14] used the concept of influence zones for the generation of facial expressions. However, there are important differences between their approach and ours. In Noh's approach, a fixed region of the face is manually delimited by the user and selected vertices move inside that region in order to deform their neighborhood. The vertices

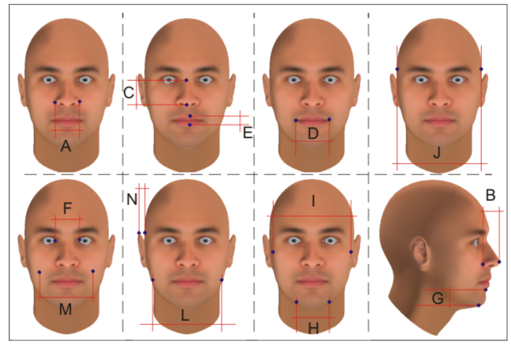

Fig. 2. Measures of a reference model.

that are outside the zone do not move. When a vertex moves outside the influence zone, discontinuities are generated.

Our proposed system for measure adaptation was designed to be simple and generic, and to be used with any triangularized mesh. The manipulation of measures consists in combining the operations of translation and scale over moving spherical influence zones positioned and dimensioned to cover areas that need to be adjusted. In our method, neither are deformation control vertices necessary, nor has the center of the spherical influence zone to be coincident with a given vertex of the mesh. Rather, it is the sphere of influence that moves, forcing the internal vertices to adjust their positions. The method works as if the center of the sphere was a vertex of the mesh, and its movement changes the position of the influence zone, thus solving the problem of possible discontinuity described by Noh. The system is simple and flexible, producing satisfactory results.

The manipulation by translation of influence zones is illustrated in Figure 3 and described in Equations 1, 2, 3 and 4.

$$\mathbf{x}_i(t+\delta t) = \mathbf{x}_i(t) + \delta\mathbf{v}.f_i(t) \quad (1)$$

where

$$f_i(t) = \begin{cases} \frac{R-\|\mathbf{x}_i(t)-\mathbf{x}_c(t)\|}{R} & \text{if } \|\mathbf{x}_i(t)-\mathbf{x}_c(t)\| < R \\ 0 & \text{if } \|\mathbf{x}_i(t)-\mathbf{x}_c(t)\| \geq R \end{cases} \quad (2)$$

$$\mathbf{x}_c(t) = \mathbf{x}_c(0) + t.\mathbf{v} \quad 0 \leq t \leq 1 \quad (3)$$

$\mathbf{x}_c$ is the center of the sphere and R is the radius

$$\delta\mathbf{v} = \frac{1}{N}.\mathbf{v} \quad (4)$$

The applied translation is achieved in N steps as the equations show. For each step, the algorithm is applied again to recalculate the new position of the vertices. In Figure 3, two influence zones move in opposite directions in order to change the width of the nose. The initial configuration is depicted in Figure 3A, and the final configuration, showing the new positions of the affected vertices, is depicted in Figure 3B.

The deformation caused by the spherical influence zone in each step of the movement is limited to the vertices of

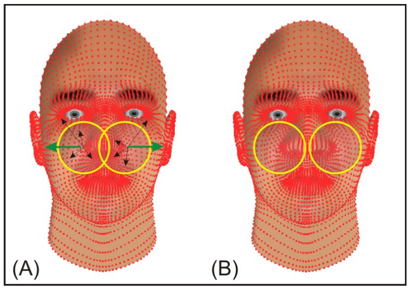

Fig. 3. Widening the nose by translation. (A) Before. (B) After.

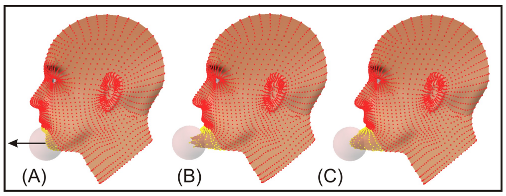

Fig. 4. Deformation of the chin by translation. (A) Initial position (t_0). (B) Single-step translation. (C) Gradual translation.

the mesh that are strictly inside the influence zone. The deformation is more pronounced at points that are closer to the center of the sphere and is exactly zero at the edge of the sphere. Figure 4 shows two different results for the translational deformation. Figure 4A shows the initial position (t_0) of the spherical influence zone. Figure 4B shows the result of moving the sphere to the final position in a single step. In that case, vertices located inside the sphere in its initial position will suffer a translation, which is directly proportional to their distances to the center of the sphere before translation. As can be seen, the result is discontinuous – a behavior similar to that of a fixed region where only the vertices inside the sphere in the initial position move. Figure 4C shows the final result (same translation used in Figure 4B) obtained by applying the total translation incrementally. Thus, when the influence zone moves in small increments (simulating a continuous motion), some vertices slowly cross the border into the sphere and their displacements are smoothly increased as they approach the center of the moving zone. Some other vertices slowly leave the moving zone and smoothly come to a halt (Figure 7). This type of adjustment generates deformations with smooth transition between regions inside and outside the influence zone. The radii of the influence zones may also vary when it is necessary to affect a larger or a smaller area of the manipulated model. Therefore, since the final result depends on the radius of the influence zone, the caricaturist is allowed to play with this parameter in order to evaluate different effects.

The manipulation by scaling influence zones (also divided into N steps) is illustrated in Figure 5 and described in Equations 5, 6, 7 and 8.

$$\mathbf{x}_i(t+\delta t) = \mathbf{x}_i(t) + \delta\mathbf{v}_i(t) f_i(t) \tag{5}$$

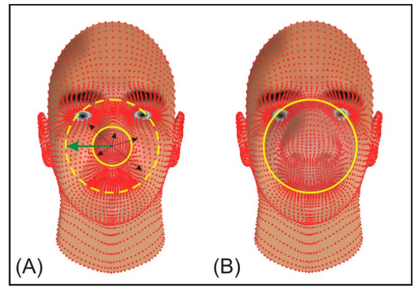

Fig. 5. Widening of the nose by scaling. (A) Before. (B) After scaling.

where

$$\delta\mathbf{v}_i(t) = \mathbf{x}_i(t) - \mathbf{x}_c \tag{6}$$

$$f_i(t) = \begin{cases} S.\frac{R(t)-\|\mathbf{x}_i(t)-\mathbf{x}_c\|}{R(t)} & \text{if } \|\mathbf{x}_i(t)-\mathbf{x}_c\| < R(t) \\ 0 & \text{if } \|\mathbf{x}_i(t)-\mathbf{x}_c\| \geq R(t) \end{cases} \tag{7}$$

$$R(t) = R_0 + t(R_n - R_0) \tag{8}$$

S is the scaling factor and R is the sphere's radius.

In the example shown in Figure 5, a measure of the nose is changed by applying scale in their influence zones. Figures 5A and 5B illustrate, respectively, the initial situation and the position of the vertices after scaling the influence zone.

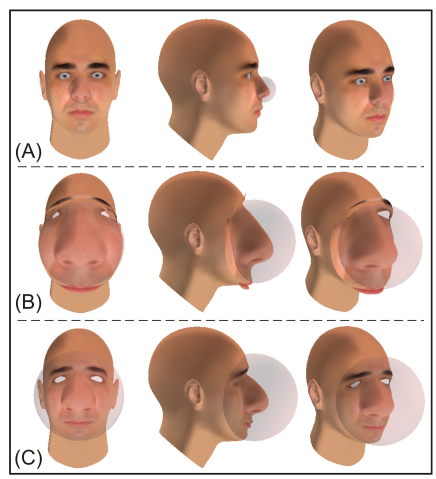

Fig. 6. Scaling the nose. (A) Initial radius (t_0). (B) Single-step scaling. (C) Gradual scaling.

Figure 6 illustrates some effects that can be obtained with scaling. Figure 6A shows the initial positioning of a spherical influence zone with its original radius. Figure 6B shows the results of a single-step scaling, and Figure 6C shows the results of a gradual scaling. The analysis of these types of scaling is similar to those of single-step and gradual translations.

Notice that, as the sphere is translated or scaled, some vertices that are close to the border of the influence zone will go outside the sphere while some will go inside (Figure 7).

In Figure 7A, the points shown in yellow entered the influence zone as it moved to the position indicated in Figure

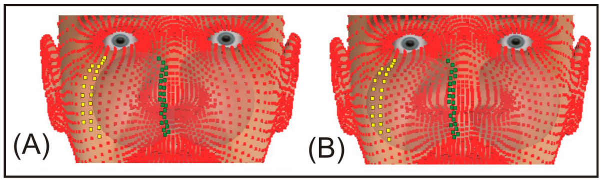

Fig. 7. Moving influence zones.

7B, and have their position adjusted. Similarly, the points highlighted in green went outside the influence zone after the translation of the sphere. This gradually-moving influence zone system presents no discontinuity.

With this mesh deformation system, we are able to generate distortions in measures of three-dimensional models, as illustrated in Figure 8.

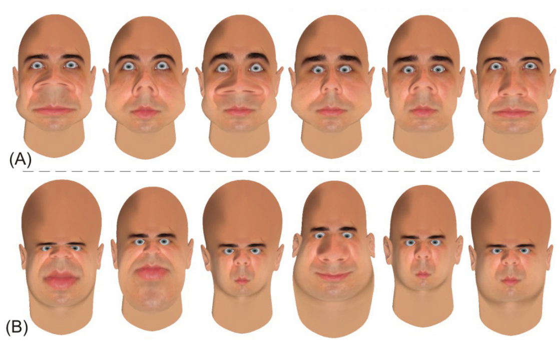

Fig. 8. Arbitrary deformations. (A) Translation of influence zones. (B) Scaling of influence zones.

The distortions shown in Figure 8A were generated by random manipulation using only translation. The distortions shown in Figure 8B, likewise, were generated by random manipulation using only scale.

V. Proposed System

The deformations in Figure 8 were caused by arbitrary application of translation and scaling of influence zones. So, they do not represent acceptable caricature models of a person. In this section, we describe systematically our process of caricature generation.

Step 1: Identification of the reference model.

In this step, one chooses a reference model, relative to which the model to be caricatured will be distorted. In the examples shown in this paper, two reference models were adopted: a male reference model (Figure 9A) and a female reference model (Figure 9B).

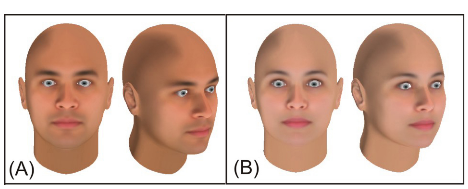

Fig. 9. Reference Models. (A) Male. (B) Female.

Step 2: Identification of facial landmarks and storage of the anthropometric measures taken from the reference model.

In this step, the facial landmarks of the reference model are identified and the associated measurements are stored. In the generation of male caricatures, the measurements are compared with the male reference model. In case of female caricatures, the female reference model is used. Figure 2 shows the measures used in this paper's case study.

Step 3: Identification of facial landmarks and storage of the anthropometric measures taken from the model to be caricatured.

This step is identical to Step 2 applied to the model to be caricatured (Figure 10). The landmarks identification are made by a simple picking system. When the models have point-to-point association and the meshes are sufficiently refined so that the landmarks coincide with vertices of the mesh, the process of defining landmarks is automatic.

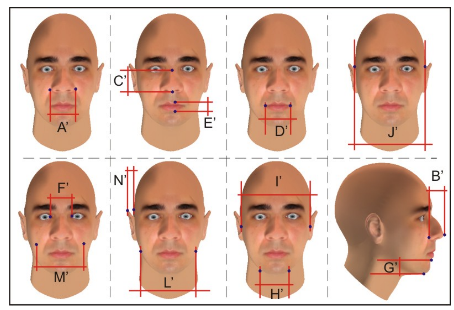

Fig. 10. Identification of facial landmarks and measures.

Step 4: Comparison of the reference model with the model to be caricatured.

In this step, the measures of the models to be caricatured are compared with the corresponding measures of the reference model stored in Step 2, as illustrated in Figure 11. Table 1 shows the ratios of the measures of the selected model to those of the reference model (measures are shown in Figure 2).

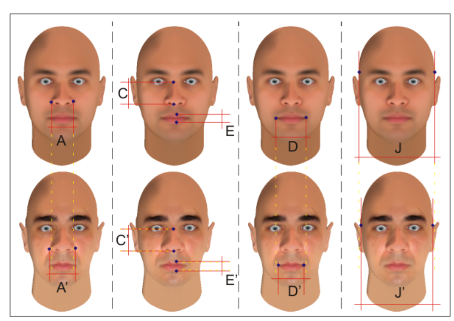

Fig. 11. Comparison of measures of the selected model with the reference model.

Step 5: Application of the deformations to the model to be caricatured.

In this step, deformations by translation or scaling of influence zones are applied. Notice that the radii of the spheres

Prop.	A'/A	B'/B	C'/C	D'/D	E'/E	F'/F	G'/G	H'/H	I'/I	J'/J	L'/L	M'/M	N'/N
Model	1.056	1.064	0.999	0.873	1.002	1.027	0.957	0.927	0.921	0.970	0.871	0.944	1.047

TABLE I
PROPORTIONS OF THE SELECTED MODEL MEASURES RELATIVE TO THE REFERENCE MODELS.

can be defined by the caricaturist, or based on the distances between landmarks. Measures that affect larger regions require larger spheres. The caricaturists are free to create illustrations by choosing to exaggerate certain measures over the others, thus defining their own artistic styles. To do so, they can apply deformations by translating influence zones (Figure 3), by scaling influence zones (Figure 5), or by a combination of both. Hence, when the measures are greater than the corresponding measures of the reference model, the system increases the measure by translation or scaling of influence zones in order to cause expansion. When the measures are smaller than the ones in the reference model, the system decreases the measure by manipulating the influence zones in order to cause reduction.

The caricaturist can choose to apply translation of influence zones to some measures and to apply scaling of influence zones to other measures or randomly chose one of the two methods. The caricaturist can also define different radii to the spheres. Figure 12 shows one possible sequence of deformation using the proportions of Table 1. Figure 12A uses a translational deformation applied to measure A, Figure 12B used scale deformation applied to measure B, and so on.

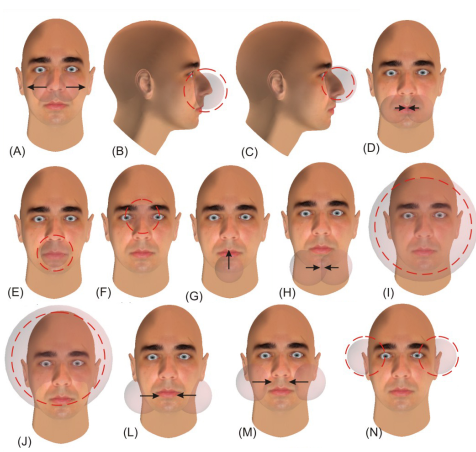

Fig. 12. Possible combination of deformations.

After applying a sequence of deformations to the model, the resulting caricature can be further modified by applying another sequence of deformations. The caricaturist can be in control of the complete sequence by choosing a new radius for the influence zone and by deciding what type of deformation to apply (Figure 13 illustrates possible outcomes).

Notice that, although the process can be fully automated, the caricaturist always has the power of choice and control.

Figure 14 is a graph showing the proportions of measures relative to the reference model, of the initial model (in blue)

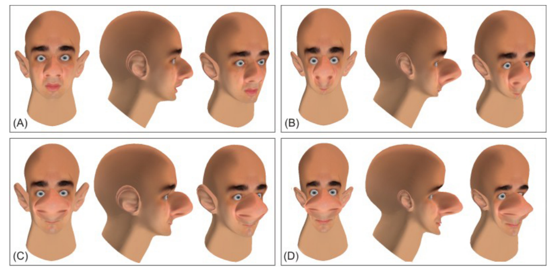

Fig. 13. Some possible results.

and the caricatured model proportions (in red) relative to the same reference model. Notice that the measures with proportions greater then 1 are increased and measures with proportions smaller than 1 are reduced. Again, that final result depends on the sequence of applied deformations.

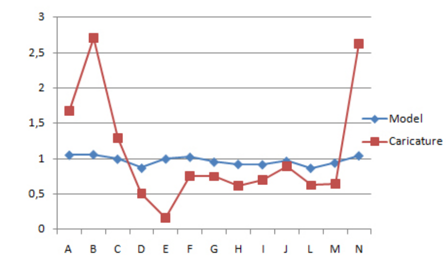

Fig. 14. Comparison of the measures' proportions before and after caricaturing.

Step 6: Application of asymmetry.

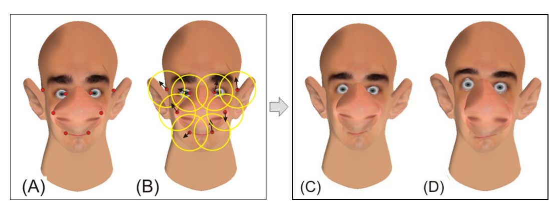

Fig. 15. Application of asymmetry. (A) Points to apply asymmetry and (B) aplication of perturbation. (C) and (D) Possible results after assymetry.

Since caricatures are comic representations, the artists usually resort to asymmetry in order to give a natural look to the caricature. To exemplify that, asymmetry is applied to the caricature of Figure 13C. First, eight points are defined as centers of spherical influence zones (Figure 15A). Next, one sphere at a time suffers a random translational deformation (Figure 15B).

Figures 15C and 15D show some possible asymmetry outcomes. Again, although asymmetries can be automatically generated, it is always possible to let the user be in control of the process. Notice that, in traditional caricature drawings, artists use different styles of deformations in order to achieve different results, but they always respect the global characteristics of the person being caricatured. Our method is flexible enough to give the artist the choice either to exercise complete control over every step of the caricature process, or to allow the system to run automatically to generate different options of caricatures and then make controlled adjustments to a selected caricature. In this example, the caricature shown in Figure 15C was chosen to go on to the next step.

Step 7: Application of expressions.

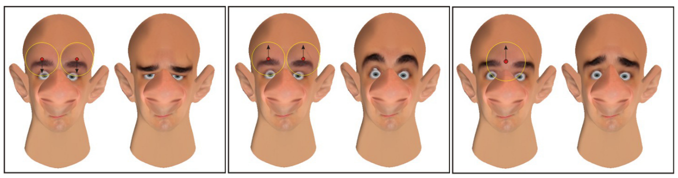

Fig. 16. Some expressions with deformation in regions near the eyes.

The last step consists in applying deformations in order to generate facial expressions that give the final artistic touch to the caricature. Using the translational deformation method it is possible to define rules of translation, based on landmarks, in order to generate the intended facial expressions. Figure 16 illustrates facial expressions obtained by deformations applied to the region of the eyebrows. Figure 17 shows facial expressions generated by a combination of deformations around the eyebrows, the nose and the mouth. To open the mouth, a restriction between the lips is applied, using an approach, which is similar to that presented in (Noh, 2000). When moving the sphere down, positioning the sphere in the center of the mouth, the upper lip's vertices do not move.

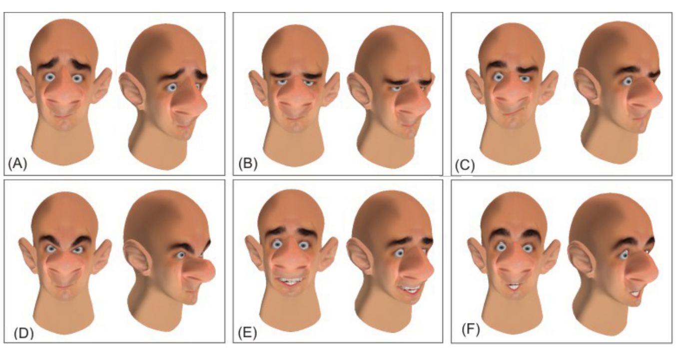

Fig. 17. Expressions with combination of deformations.

VI. Case Studies

In this section, for comparison purposes, we generated caricatures for the same five subjects presented in (Liu et al., 2009). The caricatures are shown in figures 18 to 20. The 3D models were constructed using, as input, the frontal views of the faces. The pictures used to generate the 3D models were different from Liu's paper because the 3D construction

Prop.	C01	C02	C03	C04	C05	C06
A'/A	0.93	0.97	1.02	0.98	1.14	1.61
B'/B	0.96	1.19	1.06	1.15	0.76	0.51
C'/C	1.00	1.04	1.05	1.04	0.93	1.42
D'/D	0.93	0.99	1.01	0.98	0.99	1.08
E'/E	1.07	0.88	0.91	1.13	1.16	0.16
F'/F	1.03	0.99	0.98	0.98	1.17	0.98
G'/G	1.02	1.13	1.08	1.02	1.02	1.49
H'/H	0.89	1.05	1.08	1.05	1.02	1.26
I'/I	0.92	0.98	1.01	1.09	1.00	1.16
J'/J	0.92	0.98	1.02	1.09	1.02	0.96
L'/L	0.92	1.01	1.06	1.11	0.98	1.65
M'/M	0.94	1.00	1.02	1.09	1.00	1.40
N'/N	0.92	1.01	1.03	1.09	1.08	6.98

TABLE II
Proportions of the case studies measures relative to the reference models.

we used requires pictures without expressions and with good resolution. Table 2 shows the proportions of the measures, relative to the reference models, of each case study (C01 = Case 01; C02 = Case 02, etc.).

The graphs in figures 18 to 20 show that most proportions met the expected behavior - measures that were greater than the reference measures were enlarged and those that were less than the reference measures were made smaller. Since the measures are not completely independent of each other, certain measures may suffer enlargement when reduction is expected and vice versa. With the five case studies, it is possible to see that the proposed technique generated different types of noses, mouths, face formats, etc. Similar to what was done in the work by Liu et al. (2009), we submitted the caricatures of the five subjects to an evaluation that took in consideration the aspects of: Similarity, Artistry, and Exaggeration. The evaluation was performed by 23 volunteers that were asked to assign a score, in the scale from 0 to 5, to the three aspects: Similarity, Artistry, and Exaggeration). The average scores are recorded in Table 3. The columns M1, M2 and M3 correspond, respectively, to our method, to the MR method presented by Liu et al. (2009), and to the traditional morphing method, which was also used for comparison in Liu's work.

There should be a balance between similarity and exaggeration. In other words, if the similarity is too high, the caricature looses its characteristics of exaggerating important features. However, if the exaggeration is out of bounds, it is difficult to associate the caricature with the real subject. In our method, a good initial 3D model is required in order to obtain good caricatures. The MR-Based method was much better evaluated with regard to artistry than the other methods. That was expected, since the method uses a database of caricatures drawn by artists and uses professional modelers to build 3D models for the caricatures in the database. Notice that, in Case 04, our method generated a caricature, which was considered too exaggerated and, therefore, was poorly evaluated with regard to similarity. However, as mentioned before, a pool of different caricatures could have been generated and a less exaggerated caricature could have been chosen. We also could

Evaluation metrics	Case 01			Case 02			Case 03			Case 04			Case 05		
	M1	M2	M3	M1	M2	M3	M1	M2	M3	M1	M2	M3	M1	M2	M3
Similarity	2.78	2.22	2.35	2.48	3.52	3.48	2.70	1.91	3.96	1.65	2.96	4.09	2.96	2.74	4.35
Artistry	2.39	3.52	2.43	2.91	3.96	2.87	2.87	3.00	3.17	2.48	3.43	3.22	2.83	3.39	2.74
Exaggeration	3.04	4.09	2.83	3.57	3.52	2.26	3.83	3.57	2.74	3.70	3.65	2.87	3.04	3.74	2.00

TABLE III

EVALUATION OF THE RESULTS GENERATED BY OUR METHOD - M1, MR-BASED METHOD (LIU ET. AL, 2009) - M2 AND TRADITIONAL METHOD (LIU ET. AL, 2009) - M3. SCORES VARY FROM 0 TO 5.

have used a better initial model. In the other cases, our method showed good harmony among the three metrics and had comparable results to the other methods. However, our method did not require 3D databases nor the help of skilled artists.

We also asked the 23 volunteers to assign a score to indicate if they considered important the inclusion of asymmetries and expressions in the caricatures. The average score to that question was 4.2.

As a final case study, we used the same reference model and a toon cat, to generate a caricature. The result is shown in Figure 20 and its initial proportions are in Table 2 in the C06 (Case 06) column. With this case study, we show that our method does not need models with the same topology, as other methods do, and that the method is versatile enough to be applied to other creatures, even with different facial characteristics.

VII. CONCLUSIONS

In this paper, we presented a method for caricature generation based on anthropometry and deformations by manipulation of moving spherical influence zones. The system used landmark points to define measures of a reference model to be collected and compared with corresponding measures of a model to be caricatured. The proportions of measures of the reference model and the model to be caricatured determine the level of deformation to be applied by translation or scaling of the influence zones. This method is independent of mesh topology. Unlike other techniques, we can generate variations of caricatures, adopting different sequences of translation and scaling, as well as defining larger or smaller areas to be deformed, with the use of influence zones of different radii. Our method also does not need 3D model databases to be used as a base of combinations or comparisons of models.

Application of asymmetry and expressions, using the same deformation techniques, makes the technique simple and gives the possibility of generating more interesting results. The flexibility of our solution enables the user to easily apply the technique to other creatures, or even mix the comparison of measures with different creatures, like we did in case study 06 with an human reference model and a cartoon like cat, to be caricatured. Thus, it is possible to generate caricatures, which highlight characteristic features of a personage to be used in virtual reality applications, games, cartoons, etc.

To improve our solution, the number of anthropometric measures can be increased (only 13 measures were used) in order to get more pronounced effects, and to highlight other characteristics of the face. We could also do some analysis to see how the sequence in which the deformations are applied affects the final result (the deformations were done from measure A to N). With this analysis we could define a better order or even let the order be defined by the user or randomly, giving more variability to the final results.

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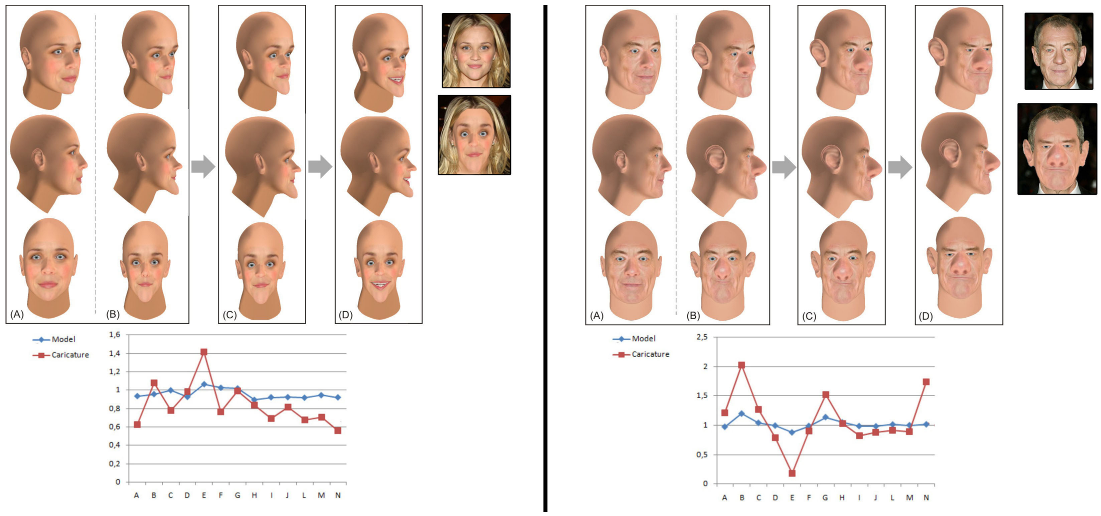

Fig. 18. Results of Cases C01 and C02. (A) Initial model, (B) Caricature, (C) Application of asymmetry, (D) Application of expression and Comparison of the measures' proportions before and after caricaturing.

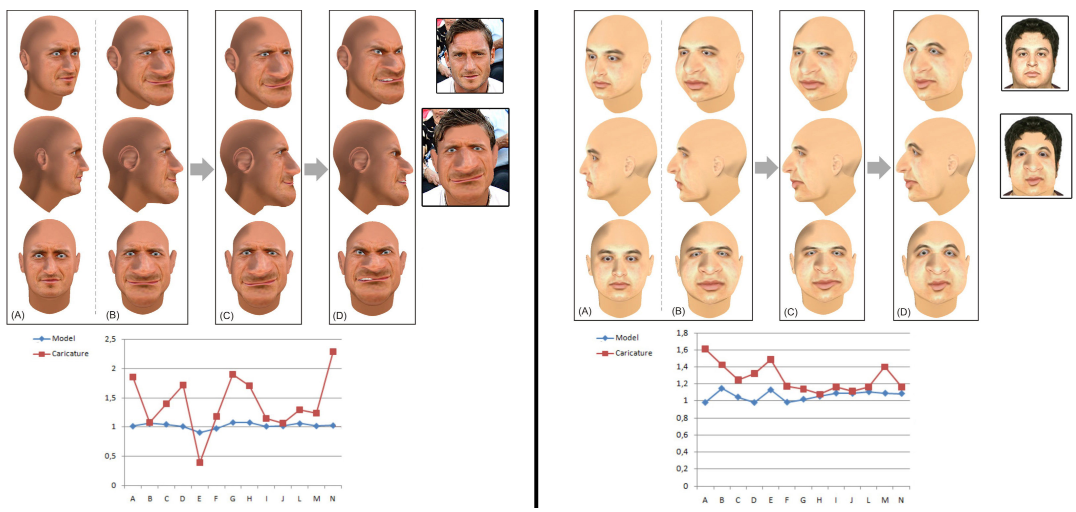

Fig. 19. Results of Cases C03 and C04. (A) Initial model, (B) Caricature, (C) Application of asymmetry, (D) Application of expression and Comparison of the measures' proportions before and after caricaturing.

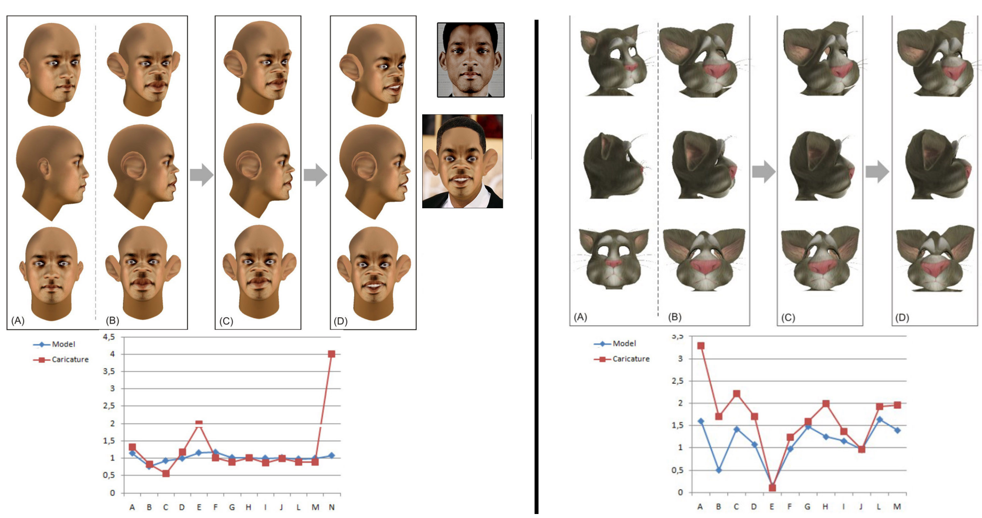

Fig. 20. Results of Cases C05 and C06. (A) Initial model, (B) Caricature, (C) Application of asymmetry, (D) Application of expression and Comparison of the measures' proportions before and after caricaturing.