Deformation Method for 3D Identikit Creation

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Abstract: An identikit is a model of a head created for a purpose of identification. Nowadays, the police use mostly 2D portrait identification, which is simple but has limited possibilities. Therefore, 3D head models have started to be used as identikits. In this paper, we propose small improvements of Free-Form Shape Deformation (FFSD) for 3D identikits creation, which allow modeling new shapes and keeping important details. With these improvements the FFSD method is able to create various and realistic deformations of a human head model which are necessary to make and identikit is a bit quicker. The improved method has been implemented and used in software prepared for the police.

1 INTRODUCTION

The problem of modeling a human head in 3D according to the original is very important in several areas: gaming and film industry, medicine and criminology. In criminology, a portrait of the head of an offender created according to the eye-witness is called an identikit. Most of the available software for identikits works with 2D images. The 2D identikit has the disadvantage that the offender is viewed only from the front. It makes impossible to model some details that may be on the side of the head. When modeling 2D identikit, the user needs more imagination, because it is not possible to look from the side. On the other hand, 2D identikit construction is already worked out and large databases exist.

The deficiencies of the 2D identikit led to attempts to create the identikit in 3D.

This paper suggests to use an improved method Free-Form Shape Deformation (Yoshizawa et al., 2002), which allows to model the 3D identikit by deforming the model consisting of a triangular mesh. Modifications are oriented to prevent from artifacts witch might appear in this special FFSD and to speed up the method. The method has been implemented, consulted and tested in a close cooperation with a police department, with their positive response.

Content of the paper is as follows. Section 2 describes State of the art. Section 3 shows the original method of Free-Form Shape Deformation. Section 4 presents improvements suggested in this paper. Section 5 is devoted to experiments and results. Section 6 concludes the paper.

2 STATE OF THE ART

There are three basic methods in 3D how to create a human head model usable as an identikit: a morphing of other, existing models, a composition from pieces and a modeling using deformations.

The morphing is a technique, which allows obtaining new models by an interpolation of two existing objects (Botsch et al., 2004). The main drawback of the morphing method for creation of an identikit is a necessity to work with a large amount of different models. Human faces are various and complex. Different models are available, it may seem easy to create a new face, but it is not easy to predict the morphing result. On the other hand a possibility of an easy creation of "random" faces from existing ones is an advantage.

Next possibility of creating a human head model is putting previously created parts together (http://fidentis.cz/). This method has two drawbacks. First of all a relatively large database is needed. The problem of creating many varieties of a human face is present again. The database of particular face parts can never be complete and thus perfect. Putting pieces together is the second and a very essential

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problem.

The third option of how to create a human face is a model deformation. The model can be quite general, e.g. a sphere or a previously prepared human head. It is quite difficult to deform a general-shape object, because the deformations needed are too complex. On the other hand, deforming a previously prepared reference model requires only small changes. However, to create the reference model is not very simple, and its quality is fundamental.

There is a number of different deformation methods and it is important to choose a suitable one. Deformation methods are divided into two groups according to the affected area: local and global.

Global deformation methods do not allow modeling details. These methods are suitable for bending, stretching and animating objects. Methods based on cage or lattice deformations (Botsch et al., 2010, Ch 9.5.1 and Ch 9.5.2; Tao et al., 2005) and methods deforming an object using a skeleton (Yoshizawa and Belyaev, 2007) are main representations of this group. These methods are not suitable for an identikit creation due to their inability model details.

Local deformation methods, as the term implies, are intended to small changes in the model and therefore to details modeling. The biggest drawback of local methods is their incompetence to create required deformations on more complicated objects authentically. There are several different approaches as follows.

The first local approach is based on curve deformation (Singh and Fiume, 1998) or surface deformation (Hu et al., 2001). The curve or the surface lead the deformation or define the surface of the model. It is important to give a correct number of control elements. The biggest problem arises during setting the control points' position and the area of influence. Curves and surfaces ensure a smooth transition between the deformed and the non-deformed model surface. This smoothing limits the deformation locality.

Deformations using control points are used in (Yoshizawa et al., 2002; Atrian-Cruz and Tubig; 2013; Botsch and Kobbelt, 2004). Most of these methods are based on the principle of adding vectors to the vertices of the mesh. A shift vector is calculated using a basis function and the position of a control point relative to the mesh. The methods of this group often enable to define a control area, a deformation area and a fixed area, see e.g. (Botsch and Kobbelt, 2004). Fixed areas are the areas that are not to be deformed. These methods allow a very detailed mesh manipulation. The problem here is to specify a proper number, position and power of influence of the control points.

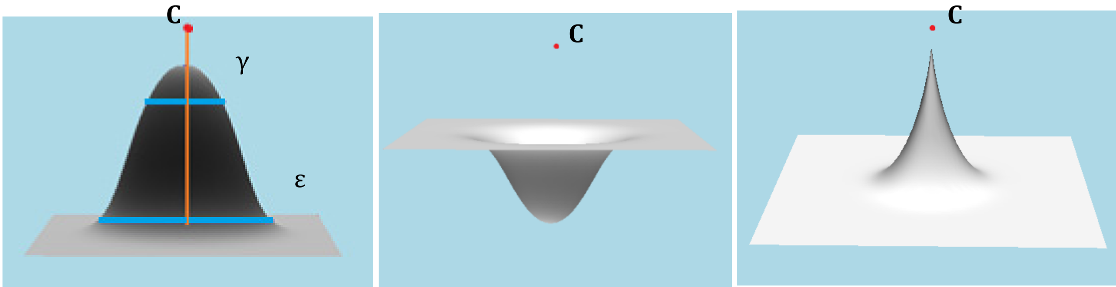
Some methods are a combination of both groups, e.g. (Masuda et al., 2006; Botch et al., 2006; Yoshizawa et al., 2003). The method (Yoshizawa et al., 2003) deforms the model by manipulating its skeleton. This allows global deformations. It is possible to introduce new branches of the skeleton. The disadvantage of this method is a need to find a skeleton and it is difficult to generate new branches. Methods (Masuda et al., 2006; Botch et al., 2006) deform a part of the mesh bounded by two areas. They are rather concentrated on a more correct deformation then on a modeling of various shapes, which is not appropriate for the intended identikit application.

Let us stress identikit creation specifics. For identikit modeling it is necessary to keep some details but not to define a fixed area, which reduces the variability of a method. Such an area has to be defined for each deformation which is limiting as a high number of deformations are necessary. The deformation method must allow creating any shape intuitively and simply, using a minimal number of control elements, because the increasing number of these elements increases the calculation time.

For identikit creation the methods of local deformations are more suitable as they deform object using control points. None of the presented methods satisfies the requirements completely. They are best met by (Yoshizawa et al., 2002; Botsch and Kobbelt 2004). The Free-Form Shape Deformation method (FFSD) (Yoshizawa et al., 2002) was chosen in this paper as a base for further modification, because it is more intuitive and easier to use and improve. The original FFSD method will be described in the next section, improvements of the method in section 4.

3 FREE-FORM SHAPE DEFORMATION (FFSD)

Consider a triangle mesh M = {**V**, T} where **V** is a set of vertices, $\mathrm{V} = \{\mathbf{V}_i\}_{i=1}^{N}$, $T = \{T_i\}_{i=1}^{M}$. Results of deformation are dependent on the position of a control point **C** and parameters γ, α and ε (selected by the user).



(a) (b) (c)

Figure 1: Deformation of a plane: (a) the parameters γ, α and ε, (b) γ positive: deformation is round-repelling (the deformation is repelling and rounded), (c) γ negative: deformation is sharp-attracting (the deformation is attracting and sharp). The red point is the control point **C**.

3.1 Basic Deformation

Given a mesh M = {V, T} as above and a control point **C**, let us translate a mesh vertex $\mathbf{V_i}$ into its new position $\mathbf{P_i}$ defined by

$$\mathbf{P}_i = \mathbf{V}_i + d(\mathbf{C}, \mathbf{V}_i),$$

with the displacement vector *d* given by

$$d(\mathrm{C,V_i}) = \frac{\gamma}{\sigma} \mathrm{W(C,V_i)(V_i\text{-}C)}, \qquad (1)$$

where

$$\boldsymbol{W}(\mathbf{C}, \mathbf{V}_i) = \exp\left(-\frac{|\mathbf{C} - \mathbf{V}_i|^\alpha}{2\varepsilon^2}\right),$$

$$\sigma = \boldsymbol{W}(\mathbf{C}, \mathbf{V}_{\min}),$$

and $\mathbf{V}_{min}$ is the vertex closest to the control point **C**, γ, α and ε are parameters. The parameter γ indicates how much the triangle mesh is pulled to the control point **C** (see Fig 1), α indicates sharpness of the deformation (Fig. 1a) and ε determines how large region is influenced by the deformation (Fig. 1a). The parameters work as follows. The width of the upper part of the deformed mesh grows with α, the width of the lower part with ε. Typical values of parameters are $\gamma \in$ <-1,1>, $\alpha \in$ <0,1> and $\varepsilon \in$ <0,1>. The displacement (1) is computed for all mesh vertices $\mathbf{V}_i$.

3.2 Advanced Set of Controls Point

3.2.1 Virtual Control Point

The basic approach described above allows only round-repelling and sharp-attracting deformations. The opposite cases of these deformations are often needed, too. They are achieved using a virtual control point $\mathbf{V}_{cp}$ which is obtained as

$$\mathbf{V}_{\mathrm{cp}} = \mathbf{V}_{\min} - \mathbf{C}\,,$$

where $\mathbf{V}_{cp}$ is used in Eq. 1 instead of **C**:

$$d(\mathbf{C}, \mathbf{V}_i) = \frac{\gamma}{\sigma} \boldsymbol{W}(\mathbf{C}, \mathbf{V}_i)(\mathbf{V}_i - \mathbf{V}_{\mathrm{cp}}). \qquad (2)$$

3.2.2 Multiple Control Points

When more control points **C** are used, the deformation method is extended to

$$\mathbf{P}_i = \mathbf{V}_i + \sum_k d(\mathbf{C}_\mathrm{k}, \mathbf{V}_i), \qquad (3)$$

where the sum is taken over all the control points $\mathbf{C}_k$. Parameters γ_k, α_k and ε_k can be defined for each control point $\mathbf{C}_k$.

3.2.3 Directional Deformations

The procedure described above is able to deform a mesh only in the direction of the distance of the points **C** and $\mathbf{V}_{min}$. But in order to achieve various shapes, it is necessary to implement a directional deformation. Instead of the mesh vertex $\mathbf{V}_{min}$ closest to the control point **C,** we choose a reference point **R** (defined by the user). A virtual control point $\mathbf{V}_{cp}$ is now defined:

$$\mathbf{V}_{\mathrm{cp}} = 2\mathbf{R} - \mathbf{C}. \qquad (4)$$

(4) is to be substituted into Eq. (2). Instead of ***W*(C,V)** is used ***W*(R,V)** for directional deformations. An example of a directional deformation is shown in Fig. 2. The red control point **C** and the green reference point **R** in Fig. 2 are selected by the user to achieve the required directional deformation.

The method FFSD allows also an anisotropic deformation, but for the purpose of identikit construction the described deformations are sufficient.

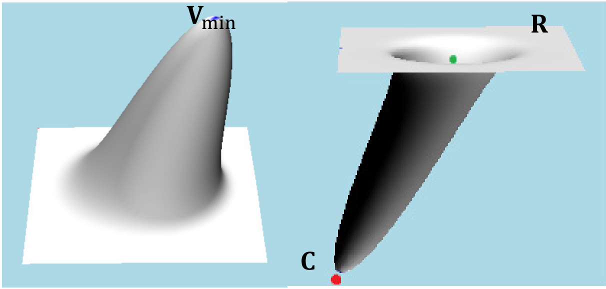


Figure 2: Directional deformations. Examples of directional deformation of plane. Red point is the control point **C**, the green point is the reference point **R** and blue point is $\mathbf{V}_{min}$.

4 THE PROPOSED MODIFICATIONS OF THE METHOD

To get better, more varied and more correct deformations for the identikits creation it was necessary to expand the original method. Critical deficiencies appeared mainly in the large deformation of a small region, when peaks arose in the mesh. These peaks are undesirable for the identikit creation. Peaks could be repaired by refining the triangular mesh, but this approach is very inefficient. Therefore, we added a new height parameter ϑ, which limits the height of the deformation by the specified value ($\vartheta \epsilon < 0{,}1 >$). It is true that after the height parameter is used, the resulting deformation is lower (the top of the extruded mesh is cut, see example in Fig. 3c) than the user has intended, but it can be easily dealt by increasing the parameter γ.

For identikit creation it is necessary to deal with the following techniques, not supported in the original method: to translate a part of the face without a deformation and to preserve detail when the mesh is deformed. These operations are enabled by the introduction of the parameter ϑ.

We have to multiply the sum in the equation (3) by the value of L, which represents the reduction:

$$\mathbf{P}_\mathrm{i} = \mathbf{V}_\mathrm{i} + L * \sum_\mathrm{k} d(\mathbf{C}_\mathbf{k}, \mathbf{V}_\mathrm{i})\,. \qquad (5)$$

Where the scaling factor L is given by

$$L = \frac{S_{max}}{S}\,,$$

where S_{max} is

$$\mathrm{S}_{\max} = \left\| \sum_\mathrm{k} d(\mathbf{C}_\mathbf{k}, \mathbf{V}_{\min}) \right\| * \vartheta$$

and S is

$$\mathrm{S} = \left\| \sum_\mathrm{k} d(\mathbf{C}_\mathbf{k}, \mathbf{V}_\mathrm{i}) \right\|.$$

S_{max} is the size of a maximum possible displacement (the distance between $\mathbf{C}_k$ and $\mathbf{V}_{min}$) scaled down by ϑ. S is a size of displacement of a mesh vertex $\mathbf{V}_i$. If Eq. (5) was used for all mesh vertices. the results would be still undesirable: deformation would look almost the same as with Eq. (3), it would be only smaller. To eliminate the inwanted peaks, we need to transform only those vertices V_i which satisfy relation (6):

$$|\boldsymbol{V}_{i\,new} - \boldsymbol{V}_i| > S_{max}, \qquad (6)$$

where $\mathbf{V}_{i\ new}$ is the new position of $\mathbf{V}_i$. $\mathbf{V}_{min}$, $\mathbf{C}_k$, d, $\mathbf{V}_i$ and $\mathbf{P}_i$ have the same meaning as in Section 3.

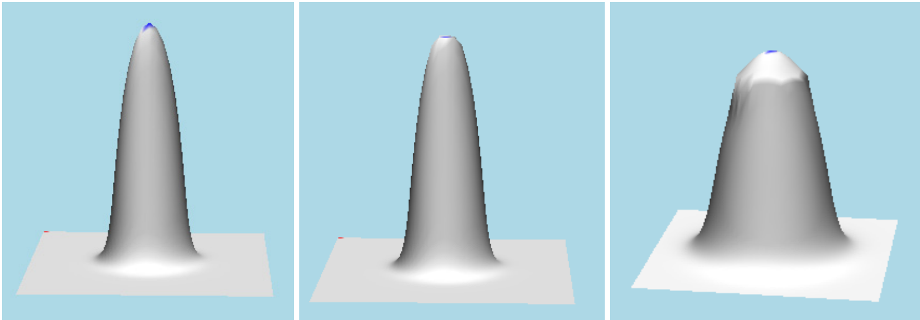
Examples of the use of the parameter ϑ are in Fig. 3. Figure 3c shows the composition of two previously impossible deformations.

The advantage of the parameter ϑ is its ability to keep a detail during a deformation. Part of the triangular mesh, which is located in the area governed by ϑ, retains its original shape. This fact is very useful in the identikit creation, see Figure 4. When comparing the images 4b and 4c we see that figure 4c is more realistic.

Another advantage of the parameter ϑ is the possibility of moving the part of the mesh without losing its detail or breaking the mesh topology. This ability is very useful when moving ears and eyes.

In addition to the restriction of the deformation from above it is possible to restrict the deformation from below or on both sides. The result would then be, in the case of restrictions below, only a small "mound", sharply cropped on the button and in case of restrictions on both sides only the center of the affected area would be deformed. For these two options we have no practical use at present, but we plan to use them to centre warts.

As described above, the deformation algorithm works with all mesh vertices for which the



(a) (b) (c)

Figure 3: Using parameter height: (a) deformation with a peak, (b) the peak eliminated using the parameter ϑ (ϑ = 0,9), (c) example of combined deformations using ϑ: a large deformation (extension) restricted by ϑ (ϑ = 0,8), followed by a small deformation (rounded top).

(a) (b) (c)

Figure 4: Preservation of the shape of the mesh in the important area of eyes: (a) a reference model, (b) a deformed model without the use of the parameter ϑ, (c) the deformed model using the parameter ϑ (ϑ = 0,8).

displacement is computed. This is not necessary because local deformations significantly influence only a very small area of mesh. The significant local deformations include editing tip of a nose, changing the size of eyes and changing the shape of lobe of the ear. This led us to introduce an area of influence defined for particular parts of the face, see Figure 5. Each deformation is performed only with the vertices in the area. The introduction of these areas significantly accelerated the computation. The area of influence does not change the shape of deformation, unlike the fixed area.

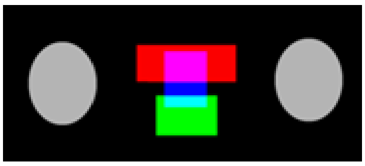


Figure 5: Areas of influence: ears (grey), mouth (green), eyes (red), nose (blue).

5 RESULTS

We have created a prototype of a software for an identikit creation based on the described improved FFSD method. The software is written in C# using SlimDX and DirectX 9. The tested model has 13 909 vertices and 83 127 triangles and the tested deformations use three and more control points. Tests were performed on Intel Core2 Quad CPU Q6600 2.4GHz with 4GB RAM. The software is operated by combined deformations of a basic head model. The combined deformations are, e.g., enlarging of the mouth, ears shift, eyes rotation and are programmed as macros. Macros define all necessary control points and parameter values, so the user does not need to define them. The only exception is the parameter γ by which the user controls the size of the required deformation.

Besides macros, the user may do free deformations by defining control points and parameters.

For greater clarity the results are presented on extreme deformations, which borders on caricature. In real use the deformations are milder.

Most obvious improvement is evident in the large deformations, such as a big smile in Figure 6. The expression already reminds a caricature, but as seen in Figure 6, even such an extreme deformation can be achieved.

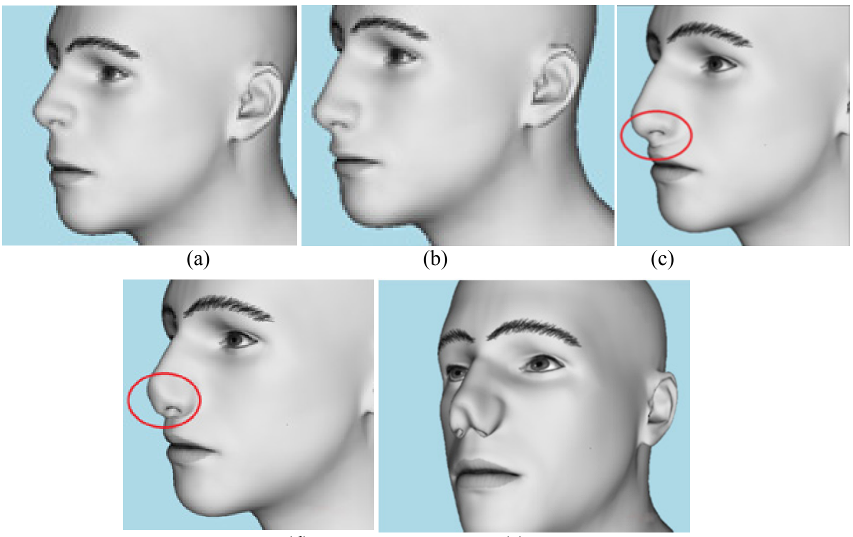
Significant differences are evident in the areas of a nose and eyes. In these areas it is necessary to keep details. For example when the size of the nose is changed, it is important to retain its original shape.

(a) (b)

Figure 6: Big smile: (a) the original method caused a mesh intersection and self-intersection at the corners of the mouth, (b) the improved method ($\vartheta = 0{,}9$).

(a) (b)

Figure 7: Eyes shift: (a) the old method - eyes are considerably deformed, (b) the improved method ($\vartheta = 0{,}9$).



(a) (b) (c)

(d) (e)

Figure 8: Elongation of the nose: (a) a reference model, (b) the correct result achieved by an improved method ($\vartheta = 0{,}85$) (c-e) attempts to create a longer nose with the old method. Red ellipses highlight the important areas.

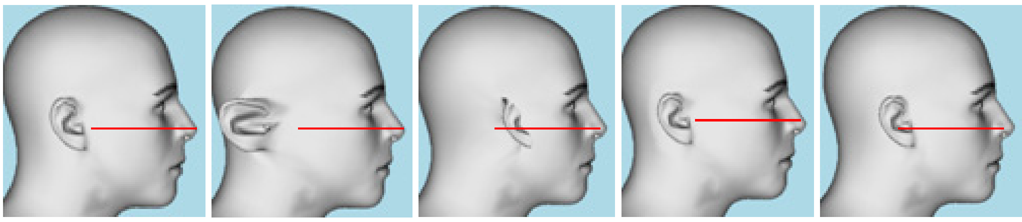


Figure 9: Shift of ears: (a) a reference model, (b, c) the old method, (d, e) the new method ($\vartheta = 0{,}3$).

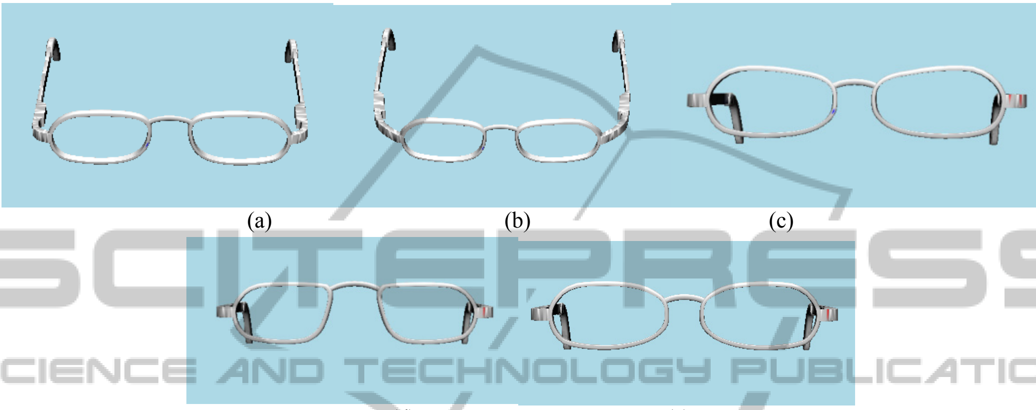


Figure 10: Examples of deformations on the glasses: (a) a reference model, (b) narrow frames, (c-e) a change of the frame shape.

If not, the user would have to perform some additional modification to keep the nose shape, which would be a difficult and time-consuming task. Figure 7 shows an operation when eyes are shifter further apart: in the proposed method distortion was avoided.

Figure 8 shows an elongation of a nose: the original model (a), the result of the improved method (8b) and problems with the original method (8c-e).

Figure 8c shows the influence of a larger area for the deformation ε, which caused an overlap between the nose and the upper lip. Figure 8d shows the influence of a smaller ε which prevents the overlap, but a peak in the nasal septum appeared. Figure 8e uses a small ε and more control points, which results in unrealistically deformed nostrils. In this case the change of the parameter α is not very helpful either, because to reduce spikes, it would be necessary to refine the mesh. Figure 8b shows the use of one control point and the height parameter, the change affects a smaller area mesh, thus avoiding an overlap and the height parameter prevents from peaks and a loss of the original shape of the nose.

The new method is able to translate larger parts of the mesh without losing its shape. Figure 9 shows a shift of the ears. A red line segment of a constant length is placed in the figure for better understanding.

Figure 10 illustrates some deformations of glasses done by the modified method, which were not possible with the old method.

After the introduction of areas of influence, some deformation showed up to 84% speedup, see Table 1. Fig. 11 shows a reference photo and the identikit of the same person created by our software.

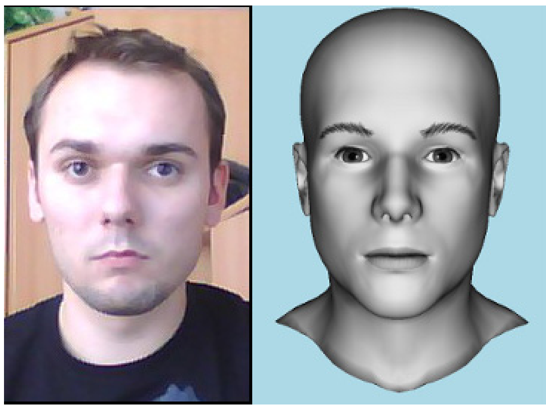


Figure 11: Photo and example of an identikit

Table 1: Runtimes for computation of a deformation with influence areas.

Deformation	Original FFSD [ms]	Improved FFSD [ms]	Speedup [%]
Change of the mouth shape	48	24	50
Enlarging of the mouth	41	16	61
Eyes shift	32	10	69
Ears protrusion	135	21	84
Ears shift	132	28	79
30 predefined deformations	1281	475	63

6 CONCLUSIONS

In this paper, we presented improvements of the Free-Form Shape Deformation for identikits creation. Improvements allow to model new shapes and transform a part of the mesh without introducing artifacts and a loss of detail. The modified method not only did not lose its variability but, vice versa, its possibilities have been extended. Also a speedup has been achieved. The modified FFSD was incorporated into an application which is at present tested by the police. In the near future, we will concentrate on modeling of hair, bread, skin and aging of the models.

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