A New Computer-aided Technique for Planning the Aesthetic Outcome of Plastic Surgery

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ABSTRACT

Plastic surgery plays a major role in today health care. Planning plastic face surgery requires dealing with the elusive concept of attractiveness for evaluating feasible beautification of a particular face. The existing computer tools essentially allow to manually warp 2D images or 3D face scans, in order to produce images simulating possible surgery outcomes. How to manipulate faces, as well as the evaluation of the results, are left to the surgeon's judgement. We propose a new quantitative approach able to automatically suggest effective patient-specific improvements of facial attractiveness. The general idea is to compare the face of the patient with a large database of attractive faces, excluding the facial feature to be improved. Then, the feature of the faces more similar is applied, with a suitable morphing, to the face of the patient. In this paper we present a first application of the general idea in the field of nose surgery. Aesthetically effective rhinoplasty is suggested on the base of the entire face profile, a very important 2D feature for rating face attractiveness.

Keywords
Plastic surgery, rhinoplasty, face profile, automatic beautification.

1. INTRODUCTION

A number of behavioural, social and psychological studies, as well as everyday common experience, suggest that facial attractiveness is extremely important in social life. Attractive people are likely to be regarded as better in a broad social sense then unattractive people [Ada03a], [Etc99a]. Communication media and social pressure to conform enhance the role of a pleasing, or at least normal, appearance in such a way that it is perceived not far from a social obligation.

Improving attractiveness also involves large expenditures. According the American Society of Plastic Surgery, 2,131,019 surgical cosmetic procedures were performed in 2005 in the USA, with a total average expenditure greater than 8.1 billion dollars. Among them, 200,924 were nose reshaping

[web05].

Planning reconstructive and cosmetic surgery requires taking into account a number of physiological and psychological constraints, ranging from patient's expectations to age, sex, health state, structure and shape of the face. The frequency of secondary rhinoplasty, that is nose operations carried out to correct or revise an unsatisfactory outcome from a previous rhinoplasty, is estimated around 8%-15%, showing that correct planning is far from simple [Bra05a].

Clearly, planning the aesthetic outcome, and then choosing a more appealing shape for some face feature is a crucial activity. This requires a careful and tactful interaction between a skilled surgeon and the expectation of the patient. A number of computer tools have been proposed for supporting the aesthetic judgement of surgeon and patient in this phase. Most of these tools allow presenting images of the possible outcomes of the surgery. They are based on 2D front and profile images, as [Ozk04a], [Rab06] or on 3D scans of the patient's face, as [Gao01a], [Lee99a] and [Lee01a]. Various manual interfaces allow morphing in 2D or 3D the patient's face and producing images simulating various possible surgery outcomes. Some of these systems also take

into account to some extent surgical constraints [Ozk04a]. This research is at the basis of several commercial systems. How to manipulate faces, as well as the evaluation of the results, are left to the surgeon's judgement.

As far as we know, no attempt has been made till now to implement computer systems able to support the human judgement by *suggesting* how to enhance attractiveness. This paper is a first step toward this goal. For this purpose we do not need a quantitative approach to *assess* beauty as much as we need a quantitative approach to *improve* beauty. As we will see, the second task is simpler.

The paper is organized as follows. In Section 2 we survey previous work on measuring human attractiveness, and present a general approach for automatically suggesting changes able to improve attractiveness. In Section 3 we describe a first application of this approach to nose surgery and face profiles. The results obtained and future work are discussed in Sections 4 and 5 respectively.

2. MEASURING AND IMPROVING ATTRACTIVENESS

Philosophers, artists and scientists, such as Aristotle, Leonardo and Darwin, have debated the elusive concept of beauty for centuries. A controversial long lasting question is whether beauty is objective or subjective, or if "Beauty is in the eye of the beholder", according to an often quoted sentence of the writer Margaret Wolfe Hungerford (1878).

In the recent decades, the scientific study of facial attractiveness has been a major issue for researchers in fields such as psychology, psychobiology, anthropology, evolutionary biology, behavioural and cognitive sciences, as well as aesthetic and reconstructive plastic surgery and orthodontics. Since 1970, more than 2000 papers on the subject are reported. One important result is that *beauty is not, or not only, in the eye of the beholder*. Many empirical rating studies have demonstrated high beauty rating congruence over ethnicity, social class, age, and sex (see for instance [Bas06a], [Ber82a], [Cun95a], [Etc94a] and [Jon96a]). Then, *the human perception of facial attractiveness is essentially data-driven, and largely irrespective of the perceiver*.

These findings put assessing beauty on a firmer ground, and suggested using objective facial measures for this goal, acquired using Computer Vision and Image Processing techniques. Which kind of measures are more representative of
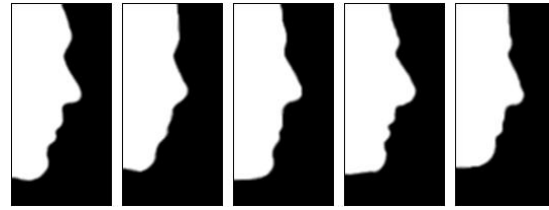

Figure 1 Several profiles with rather different noses

attractiveness, and how to extract them is object of current research.

For assessing beauty, as for identity recognition [Zha03a], two approaches are mainly used: the *feature* approach and the *holistic*, or *appearance based* approach. The former stems from the ideal proportions, or beauty canon, for the human body, dating back to the Greek sculptor Polycletus, and used for centuries by sculptors, painters and, as a rough working guide, by plastic surgeons [Edl06a], [Far85a]. Recent computer vision and image processing research construct a feature vector using the distances between face landmarks, and angles between lines joining the landmarks [Aar01a], [Bas06b], [Edl06a], [Eis06a], [Gun04a] and [Mos95a]. This vector, a point in a multidimensional *face space*, can be compared with ideal proportions or with samples of beautiful faces. The holistic approach reduces the dimensionality of the image pixel vector with the principal component technique (PCA) [Eis06a], [Val06a]. Only one research aimed at 2D face images beautification for photo retouching is reported [Ley06a].

The ongoing research shows that automatically rating attractiveness with results similar to those provided by human observers is a complex matter, and it is far from establishing which face features are more effective to this purpose. However, *our goal is not beauty rating, but approaching harmonious shapes, which fortunately is easier*. In fact, several empirical results strongly support the idea that there is not a unique beauty prototype, as implicit in the neoclassic canons [Mos95a]. Average faces are usually rated attractive, but very attractive faces are not average [All91], [Per94a]. Beauty ratings have been found largely independent on ethnicity, but faces rated beautiful can be rather different, as well as their proportions, in Caucasian, Chinese or African groups [Bas06a], [Le02a], or even within these groups. Finally, also cognitive theory asserts that humans create and use several category prototypes for recognition [Ros78a].

On the basis of these results, our general idea for patient-specific beautification is to consider *many attractive, or at least regular, face prototypes,* and

Figure 2 The profiles of Fig.1 have been extracted from these images of movie actors rated beautiful or attractive.

to suggest surgical procedures able to *approach the prototypes closer to the patient's face*. Observe that the idea of many samples of attractive, or harmonic face also implies that in general there is *not a unique prototype of a beautiful facial feature* (e. g. mouth, nose,), but there could be different shapes that are more or less attractive, depending on the perceived general harmony and integration with the rest of the ace [Lee99a]. An example will demonstrate the importance of the general harmony in comparison with that of a single feature. Figure 1 shows several different face profiles with rather different noses. Figure 2 shows the corresponding images, which belong to actors usually rated beautiful or attractive.

Then we propose the following general approach to face feature beautification:

o consider a particular face feature, and compare the face of the patient with many faces rated beautiful, *excluding that particular feature*;

o find, minimizing some convenient metric in the *face space*, the nearest attractive face (or faces);

o blend the feature of the nearest attractive face (or faces) with the original face, automatically suggesting what with high probability is an aesthetic improvement.

This idea is rather general, and its implementation and effectiveness depends on many factors: such as the 2D or 3D approach, the parameters chosen for the face space and the quantity of attractive face samples.

In this paper we propose a first implementation of this general approach, aimed at supporting nose surgery.

3. SUGGESTING EFFECTIVE NOSE SURGERY ON THE BASIS OF PROFILES

The shape of the nose is one of the most distinctive face feature, and object of many plastic surgery procedures. Beauty ratings of front and profile images are strongly correlated [Val06a], and the nose shape dominates 2D profiles. Then, we will use 2D face profiles for applying the general idea presented in the previous section.

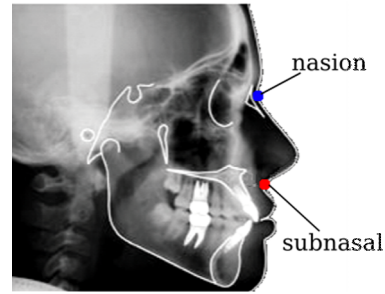The profile beautification process relies on a

Figure 3 Nasion and subnasal

database of attractive or harmonious profiles (in the following also addressed as *reference database*). In order to populate it, profile shots of people in neutral expression, not wearing glasses or beard, are needed. The candidates must then be rated in order to select the most attractive profiles.

The initial set of profiles to be rated was constructed from the CVL Face Database from the University of Ljubljana [Cvl00a] and the Bernard Achermann Database from the University of Bern[1], that we both thank. The first consists of 640x480 colour images and the second of 512x342 grey level images, for a total of 120 images. These images were rated by a panel of students of our Department, who were asked to express a vote for each subject, ranging from 1(unpleasant) to 10 (beautiful).

The reference database was populated with the top 15 profiles and enriched with 15 actors' profiles for a total of 30 images. The actors' profiles were downloaded from the web and rated.

Since the profiles have different sizes, orientation and extension, before comparison they must be *normalized*. As we will see later, the normalization is based on the position of two repere points in the profile contour: *nasion* (the point in the skull where the nasal and frontal bone unite) and *subnasal* (the point, above the upper lip, where the nasal septum begins). These two points, easy to identify, mark the beginning and end of the nose within the profile silhouette (see Figure 3). In this preliminary work they are identified manually.

Summarizing, the outline of the algorithm is the following:

• patient's and reference faces' profiles are extracted and normalized;

• the nose is removed from all profiles;

• profiles are compared by means of a suitable similarity measure in order to find
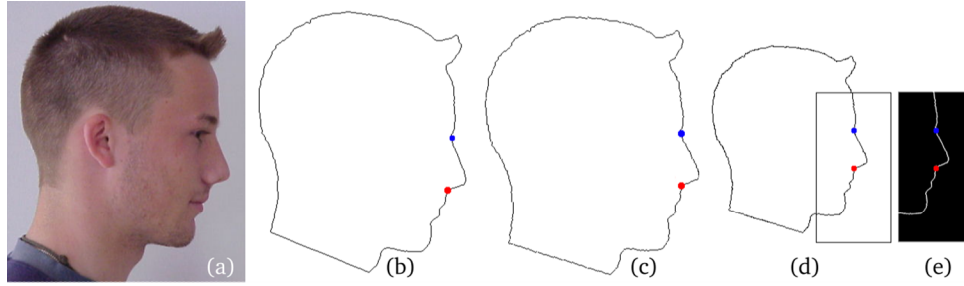

Figure 4 Input image and successive normalization steps.

the reference face most similar to the patient's face (*best candidate*);

- the nose of the best candidate is substituted to that of the patient with a suitable morphing

In the next subsections we will describe each step in detail.

Profile extraction and normalization

The silhouettes of the head are extracted by background subtraction. The profiles are the boundary lines of the silhouettes. Figure 4-a shows a subject of the reference database and Figure 4-b shows the outlined profile.

Initial images are different in size and orientation. A normalization of the full head profile is necessary for performing meaningful comparisons. The normalization is essentially aimed at selecting and delimiting the same section of all profiles for all heads, including the most significant features (forehead, nose, mouth and chin).

The final result of the normalization process is a standard *normalized profile* enclosed within a fixed area of interest (*standard area*) with nasion and subnasal vertically aligned and coincident with two predefined fixed points (*reference positions*).

The transformations involved are rotation and translation, to align the line joining the repere points with the corresponding vertical line in the standard area, scaling to make the repere points coincident, and cropping. In the current implementation, the standard area is 200x100 pixels,
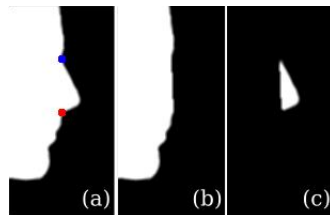

Figure 5 (a) Normalized silhouette, (b) noseless normalized silhouette, (c) removed nose.

the nasion and subnasal reference positions are at pixel (50, 50) and (50, 100) respectively

The normalization steps are illustrated in Figure 4. The full head profile (b), extracted from the input image (a), is rotated (c), scaled and translated (d), and finally cropped to obtain the final normalized profile (e).

Best candidate search

Once profiles have been normalized, comparing them requires defining a suitable similarity function.

According to our general approach, the feature to be beautified must be removed from the patient's face and from all the faces in the reference database. Second, the noseless profiles must be compared to find the best candidate.

The nose is removed from the normalized profile by simply deleting all contour points in between nasion and subnasal and connecting them with a straight line. An example can be seen in Figure 5, where the normalized silhouette (a), the noseless normalized silhouette (b) and the removed nose (c) are shown.

For finding the most similar noseless profile in the reference database, we minimize, by rotating, translating and scaling a convenient measure of distance between profiles. This distance is defined as the area, measured in pixels, of the region between the two profiles. A convenient way of computing this area is by logically XORing their corresponding noseless silhouettes in the standard area and counting the number of non-zero (non-black) pixels.

Given P, the noseless silhouette of the patient, and Q_k, that of the kth face in the database, their distance is given by:

$$D(P, Q_k) = area(P \text{ XOR } Q_k)$$

This distance is minimized by looking for the transformation that leads to the minimum distance $D_{k,MIN}$:

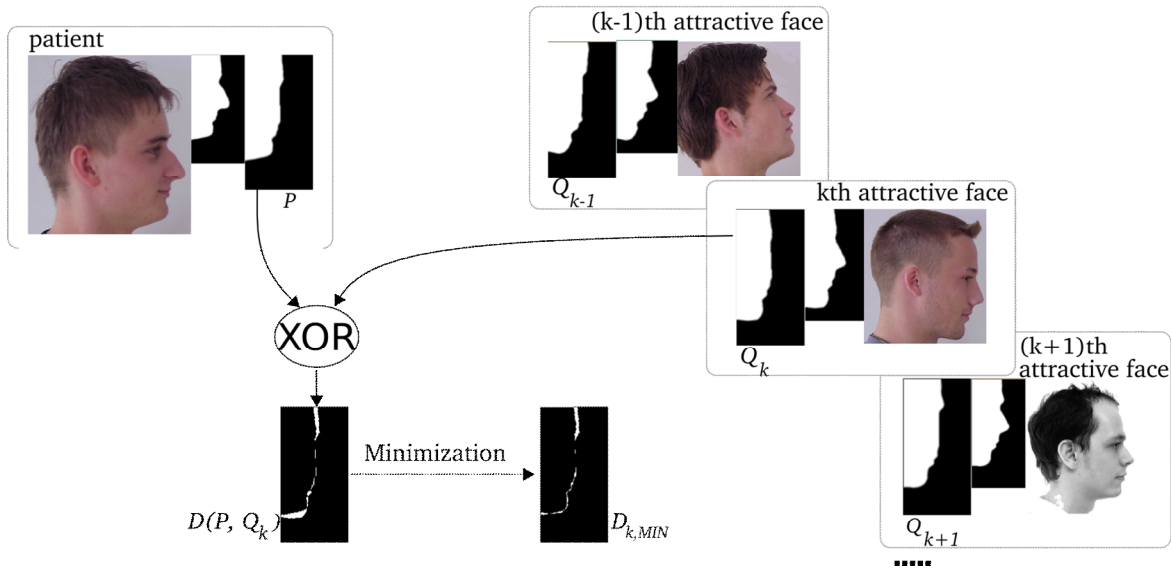$$D_{k, MIN} = D_{MIN}(P, Q_k) = \min \{ D(P, \Gamma(v, Q_k)\}$$

Figure 6 Patient comparison with the *k*th subject of the database for best candidate search.

where $\Gamma(\nu, Q_k)$ is the transformation applied to Q_k according to the parameter vector $\nu=[t_x, t_y, \theta, s]$, t_x, t_y define a translation along x and y axis, θ is a rotation angle and s a scale factor. The best candidate is the one having the minimal $D_{k,MIN}$ value, where $k\in[1..N]$ and N is the cardinality of the database. The gradient method is used for distance minimization, starting from a position where the repere points are coincident.

Figure 6 shows the basic steps performed during the best candidate search. For each subject, the normalized and noseless normalized silhouettes are shown. On top left is the patient, while three samples from the reference database are on the right. The patient's noseless normalized silhouette (P) is compared with that (Q_k) of the *k*th subject in the database. Their distance D_{kMIN} is obtained

minimizing the initial distance $D(P,Q_k)$. The patient's best candidate is shown in Figure 7-(b_0).

Nose substitution and reconstruction.

Once the best candidate has been identified, its nose is applied to the patient's profile, giving a new (hopefully) beautified version of it.

This is simply performed by taking the selected nose profile and making its end points to fit the repere points of the original profile with a suitable translation, rotation and scaling. Figure 7 shows an example of this process: the best candidate's nose (b_3) is extracted from the associated profile (b_1) and adapted to fit into the patient's noseless profile (p_2). The new suggested profile is shown in Figure 7-(p_3).

Observe that, in order to obtain a more complete and pleasant result, the nose texture has been
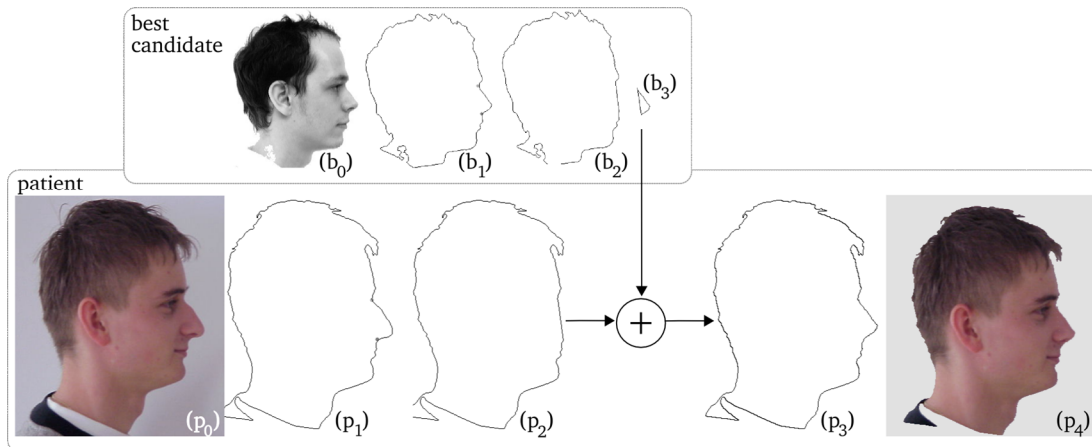

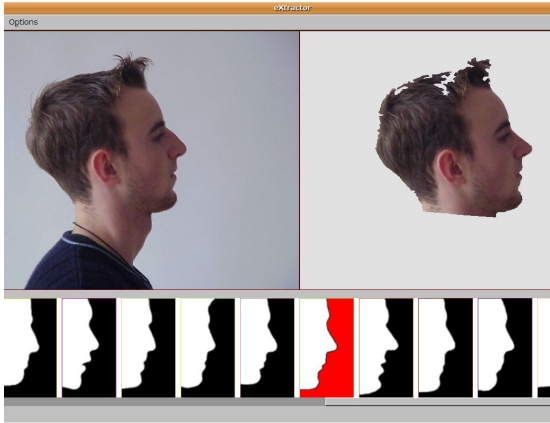**Figure 7 Patient's nose substitution and reconstruction.**

Figure 8 The application screen

reconstructed by morphing the original nose texture into the new nose shape. The final result is shown in Figure 7-(p_4).

4. EXPERIMENTAL RESULTS

The described algorithm has been implemented and tested. Figure 8 shows an example of the application screen. At top left the original patient is shown, at top right the patient after beautification and at the bottom some of the attractive normalized profiles, where the best candidate is highlighted.

Many tests have been performed using the profiles of the CVL Face and Bernard Achermann databases not included in the reference database. Some beautification results are illustrated in Figure 9: input images are in columns (1) and (3) and resulting outputs are in columns (2) and (4) respectively. As expected, the nose shape heavily influences the overall profile appearance and its reshaping might result in a totally different look. Although these results must be considered only preliminary, a qualitative evaluation is undoubtedly positive. Many profiles show a õclearö improvement, consisting either of a totally new nose shape (e.g. first three rows of Figure 9), or of smaller but effective changes (e.g. Figure 9, row (d)). Some cases might be considered õuncertainö or õquestionableö, meaning that there are no significant differences between the original profile and the suggested one (e.g. Figure 9, row (e)).

5. CONCLUSIONS

This paper introduces a new general approach to planning plastic surgery procedures and presents a preliminary application. The main idea relies on the prudent but safe assumption, supported by several recent studies, that there are many attractiveness prototypes, where the single features may be rather different but harmonize with the other features.

Then, suggesting aesthetically effective surgery can be done as follows: remove an unpleasant or disharmonic feature from a patientøs face model; retrieve the most similar face model from a database of attractive faces excluding that feature; apply to the patientøs face with suitable morphing the feature of the selected face. This procedure, that can be performed with 2D images or 3D scans, will suggest aesthetically effective patient-specific surgery.

The preliminary application presented in this paper for demonstrating the general idea is aimed at supporting rhinoplasty, which according to American Society for Aesthetic Plastic Surgery [web05, web06], is the 2nd top surgical procedure performed on male patients in the past years. The application works on 2D images and profiles. Although the results presented appear encouraging and support the effectiveness of the proposed approach, some improvement must be forecast. A main point is that an effective practical tool requires a much wider database, encompassing several ethnicities and physiognomic types, and the two genders. Second, a procedure for evaluating and validating the effectiveness of the algorithm must be defined.

Future work will be aimed at extending both the attractive database and the testbed, and issuing a wide rating campaign for pre- and post- õsurgeryö beauty. In this way, it would be possible to unquestionably classify an output as beautified or not and, furthermore, quantify the obtained improvement in terms of attractiveness.

In addition, it is clear that, for fully exploiting our approach, further work must consider 3D scans and models of faces and bodies.

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(a)

(b)

(c)

(d)

(e)

(f)

(1)　　　　　(2)　　　　　(3)　　　　　(4)

Figure 9 Nose substitution results.