

# Sketch-Based Image Editing Using Clothoid Curves

Gunay Orbay, Mehmet Ersin Yumer, Levent Burak Kara\*  
Mechanical Engineering Department  
Carnegie Mellon University  
Pittsburgh, PA 15213  
Email: \*lkara@cmu.edu

**Abstract**—We present a sketch-based image editing technique that allows users to modify an image using a set of strokes drawn on the image. The proposed approach uses clothoid curves to beautify the sketched deformation curves. A deformation diffusion algorithm then spatially distributes the user specified deformations through out the image to produce smooth transformations from the original image to the resulting image. We demonstrate the technique on a variety of image types including photo-realistic images, real product images, and sketches.

## I. INTRODUCTION

Image editing tools are becoming increasingly more ubiquitous with the wide availability of a variety photo editing software [1]. However, such tools remain difficult to master due to the complex nature of their user interaction methods and the parameters that need to be controlled to achieve the desired effects. While many projects no doubt require advanced skills, experience, and appropriate task planning, even relatively simple modifications become difficult to implement with such tools.

This paper presents a new image editing method that enables users to apply desired image modifications through simple sketched strokes. The proposed method allows input images to be smoothly deformed into new ones with the specification of only a few strokes. As such, it advances existing image editing methods that uses fixed deformation masks, curve-based deformation handles or area-based deformation lattices. The proposed approach allows complex deformations to be specified through an intuitive interface, while ensuring globally smooth image deformations.

At the heart of our approach is an aesthetic curve construction, followed by a deformation diffusion algorithm. On the input image, users sketch the curves they want to deform, as well as the new shapes of these curves. They can also sketch the curves that are to be precisely preserved. To suppress the undesirable artifacts that may arise due to the free-form nature of our sketch-editing method, the user input is beautified into *clothoid* curve segments through automatic curvature profile processing. With this input, a spatial deformation vector field is calculated and subsequently applied to the original image that results in the final image.

Figure 1 shows the usage of our system. Shape variations can be intuitively and fluidly explored on different kinds of images including photo-realistic images, real product images, and sketches.

## II. RELATED WORK

The main focus in image editing have been in cut-and-paste type operations and image enhancing. Elder *et al.* [2] presented a contour based image editing technique where modifications are applied directly in the image contour domain. These modifications are then transferred to the final image using edge based image reconstruction [3]. This approach enables robust cut-and-paste type operations. Saund *et al.* [4] have introduced a perceptually-supported editing tool where they combine a variety of previously studied image editing methods [5], [6] deployed in an interactive environment. In an earlier work [6], the authors studied decomposing simple images into geometric primitive based shapes for enabling simple shape based editing. In 2002, Seitz *et al.* [7] introduced a set of image editing techniques which enable a sequence of images to be modified through operations applied to one of the images in the sequence. Their method makes use of the plenoptic function through which the modifications are propagated in a physically-consistent way. Perez *et al.* [8] presented a set of image editing operations based on second order discrete Poisson equations in image domain. Their approach enables seamless region mapping between images and modification of original illumination, color and texture in arbitrary regions of a given image, our method focuses on nonlinear warping of a single image through user defined strokes. Closely related to our method is the work by McCrae and Singh [9], where a sketching interface is described that replaces the input strokes with clothoid curve segments. This approach enables strokes to be beautified into smoothly varying curve segments, but does not aim to edit an underlying image or geometric space.

Our approach differs from the above works in a number of ways. Our target is rapid image editing where users' strokes can be used to derive a smooth deformation field on the image. Specifically, the curves dictated by the user are interpreted as clothoid curves that allow the regions corresponding to those curves to attain aesthetic curvatures. The remaining regions of the image are then modified based on the diffusion of the deformation vectors computed between the original image and the users' strokes. This approach provides close control over image editing, while allowing arbitrarily many constraints and target shapes to be specified by the user.

## III. OVERVIEW AND USER INTERACTION

Our system takes as input an image and a set of strokes drawn on the image. Figure 1 shows the image editing process.

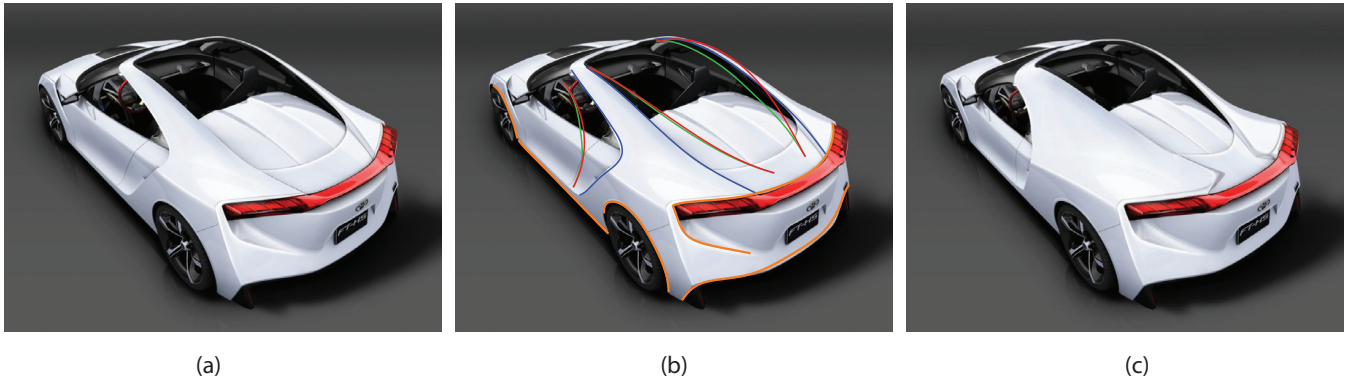


Fig. 1. (a) A car image, (b) The set of curves defining the desired modifications, (c) Final result.

Users may draw three types of strokes:

**Anchor Strokes:** Orange color. These strokes indicate regions of the image that remain unchanged. Any potential deformation ceases at these strokes.

**Source Strokes:** Blue color. These strokes demarcate curves in the image that will undergo user-specified deformations. Input source strokes are first modified under local image gradients that precisely aligns them with the salient image features.

**Target Strokes:** Green color. For each source stroke, a target stroke indicates the new desired shape. Each target stroke is automatically beautified into a clothoid curve using a functional regression on the stroke's original curvature profile.

Once processed, each kind of stroke is internally represented as a corresponding *curve* of the same type. Given the anchor, source, and target curves, a smooth vector deformation field is calculated on the image. The computed deformation field is then applied to the image, resulting in the modified image. The key property of the deformation is that the image attains the precise curve shape dictated by the target curves, while the remainder of the image deforms in visually smooth fashion.

#### IV. PREPROCESSING THE INPUT

For image deformations to be visually meaningful, our approach seeks to satisfy two requirements. First, the source strokes must accurately identify the salient curves in the image. Second, the target strokes must be beautified into aesthetically pleasing curves to eliminate artifacts that may arise from a literal interpretation of the raw strokes.

##### A. Source Curve Construction

We use active contours [10] to align the raw source strokes with the intended image curves. During this process, an edge map is extracted from the image using Canny Edge Detection [11], and the curves are pulled toward these identified edges. The process is initialized by anchoring the end points of the source curve to the nearest stable points on the edge map, and using the regular active contours method on the resulting configuration as given by Kass *et al.* [10].

##### B. Target Curve Beautification

In this step, the target strokes are beautified into smooth curves through a curvature profile modification. Previous studies have proposed a set of differential properties and related functionals for generating aesthetic geometries [12], [13], [9]. Nearly all arguments regarding aesthetic properties involve an analysis of the curvature of the curves or surfaces. In this work, we use *clothoid curves* [9] for beautifying the target curves as they readily produce  $G^2$  continuous curves with simply varying curvature profiles.

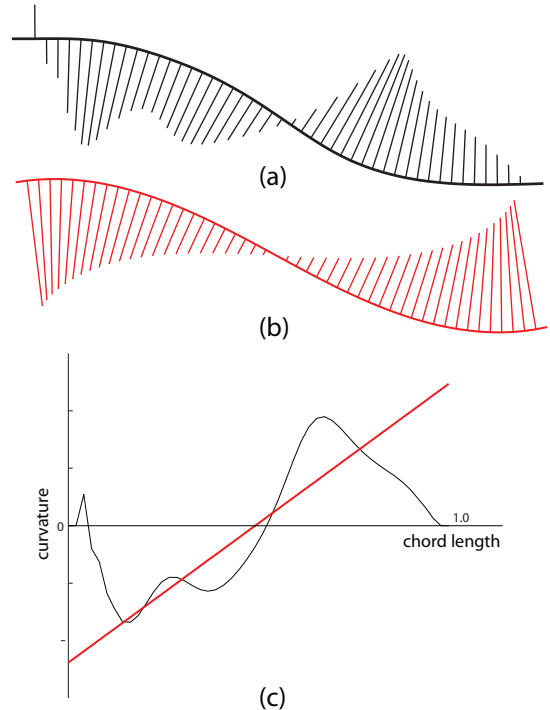


Fig. 4. Curvatures of target curves are rectified into clothoid profiles using linear regression. (a) The original target curve, (b) the rectified curve, (c) the linear regression line on the original curvature profile of the target curve.

The beautification process begins with the calculation of the curvature profile of a target stroke. Since clothoids' curvature profiles are linear with respect to the curve length parameter,

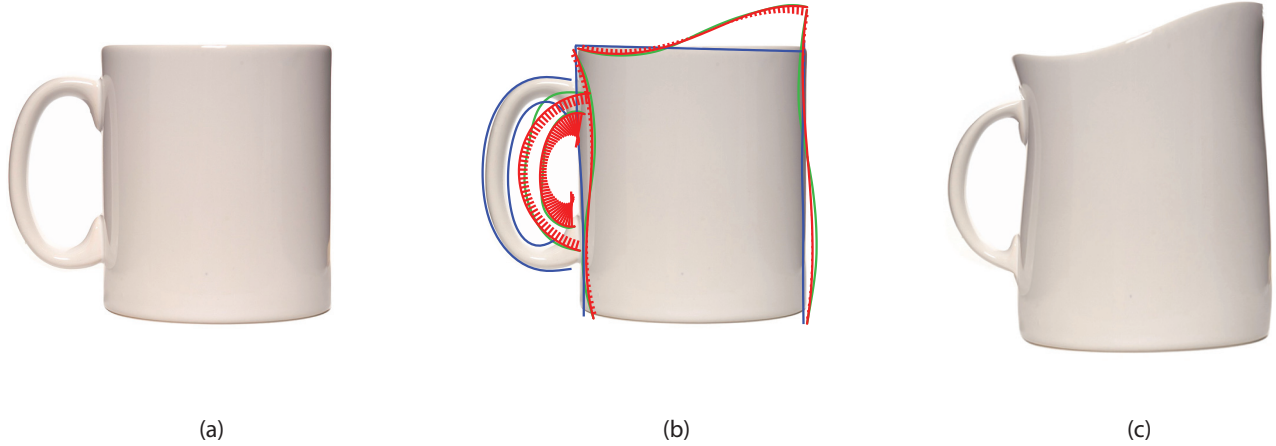


Fig. 2. (a) A mug image. (b) The set of source and target curves that define the intended modifications. Note that there are no anchor curves in this case. (c) Final result.

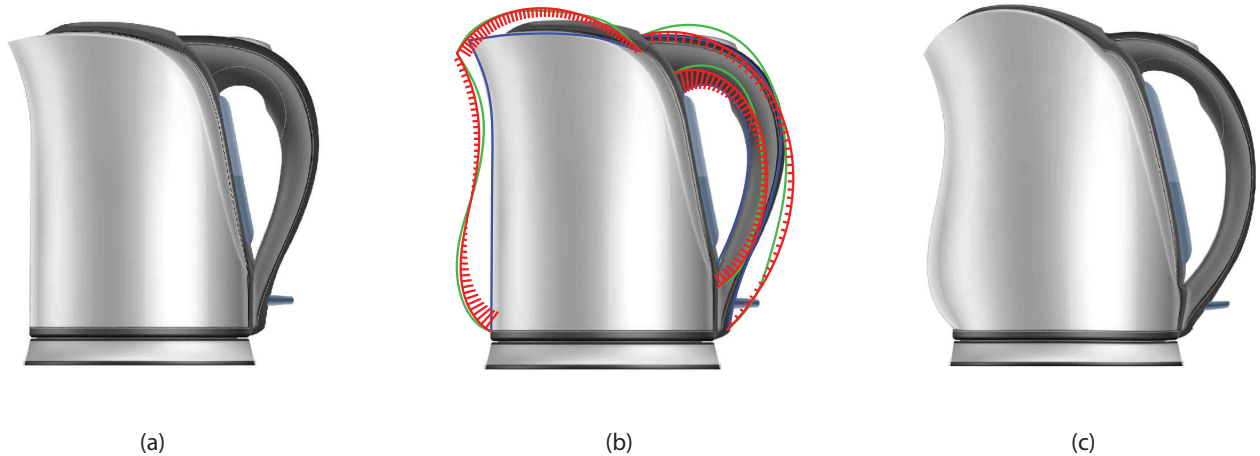


Fig. 3. (a) A kettle image. (b) The set of curves that define the intended modifications. (c) Resulting modification.

a linear regression to the original curvature profile produces a clothoid that best represents the original stroke. Figure 4(c) illustrates the idea.

Once the modified curvature profile is determined, the beautified curve is computed through double integration of the curvature profile. The first two derivatives of the curve with respect to the chord length define the tangent and the curvature as follows:

$$\vec{t}(s) = \frac{d\vec{C}(s)}{ds} \quad (1)$$

$$\vec{\kappa}(s) = \frac{d^2\vec{C}(s)}{ds^2} = \frac{d\vec{t}(s)}{ds} = \bar{\kappa}(s)\vec{n}(s) \quad (2)$$

where  $\vec{C}(s)$  is the curve parametrized with the chord length,  $\vec{t}(s)$  is its unit length tangent,  $\vec{\kappa}(s)$  is its curvature,  $\bar{\kappa}(s)$  is the magnitude of the curvature, and  $\vec{n}(s)$  is the unit normal orthogonal to the tangent. Starting from an arbitrary position ( $\vec{C}(0) = (0, 0)$ ) and an arbitrary tangent ( $\vec{t}(0) = (0, 1)$ ), the tangent and the position is computed iteratively using Euler's

method as:

$$\Delta\vec{t}(s) = \bar{\kappa}(s)\vec{n}(s) \quad (3)$$

$$\Delta\vec{C}(s) = \vec{t}(s)\Delta s \quad (4)$$

where  $\Delta s$  is the step in chord length. The resulting integration produces a curve with the desired shape and size, with its location undetermined. The curve is then situated between the start and end points of the original stroke through rigid body translations and rotations. In our experiments, this approach produced curves close to the input curves while successfully imposing linear curvature profiles.

Note that for each target stroke, a single clothoid is fit using a linear regression on the curvature profile. However, since the reconstruction through integration is insensitive to the underlying curvature functional, this approach can be trivially extended to a more precise beautification involving multiple piecewise continuous and linear curvature segments similar to the way described in [9], or other aesthetic curvature

functionals that are of interest.

## V. CURVE-BASED IMAGE DEFORMATION

The input to the image deformation step is a set of pre-processed source and target curves, and the set of anchor curves. This step calculates a smooth spatial deformation that transforms each source curve into the corresponding target curve, while preserving the anchor curves. For this purpose, we use an isotropic vector diffusion method to spatially diffuse the deformation vectors between the source and target curve pairs.

Although there are arbitrarily many vector fields that can produce the desired deformation, in this work we use a formulation similar to the gradient vector flow field (GVF) method [14]. This approach suitably diffuses the initial deformation vectors computed between each source-target curve pair, thus producing deformations that vary smoothly through the image space.

The GVF is defined as the continuous 2D vector field  $\vec{V}(x, y) = [u(x, y), v(x, y)]$  that minimizes the following energy functional [14]:

$$\epsilon = \iint \underbrace{\mu(u_x^2 + u_y^2 + v_x^2 + v_y^2)}_{\text{Smoothness}} + \underbrace{\|\nabla f\|^2 \|\vec{V} - \nabla f\|^2}_{\text{Pointing objects}} dx dy \quad (5)$$

where  $f(x, y)$  is a 2D scalar field,  $\nabla$  is the gradient operator in Cartesian coordinates,  $\vec{u}(x, y)$  and  $\vec{v}(x, y)$  are the  $x$  and  $y$  components of the vector field at point  $(x, y)$  while the subscripts denote partial derivatives.  $\mu$  is the coefficient which controls the amount of diffusion. In this energy functional, the first term forces the local smoothness of the calculated vector field while the second term forces  $\vec{V}(x, y)$  to converge to the original deformation vector in regions of high deformation. The vector field  $\vec{V}(x, y)$  minimizing this energy functional can be calculated using calculus of variation by solving the following two decoupled Euler equations:

$$\begin{aligned} \mu \nabla^2 u - (u - f_x)(f_x^2 + f_y^2) &= 0 \\ \mu \nabla^2 v - (v - f_y)(f_x^2 + f_y^2) &= 0 \end{aligned} \quad (6)$$

where the Laplacian operator is defined as:

$$\nabla^2 u(x, y) = \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \quad (7)$$

The two discretized equations can be solved independently to produce the vector field components in  $x$  and  $y$  directions. In this application, the discretization of the domain naturally comes from the pixelated image. In our implementation, we use an iterative multigrid solver that enables an efficient computation of the solution to the differential equations. We note, however, any conventional differential equation solver could be similarly adopted.

The boundary conditions to the above set of equations arise from the anchor curves (zero deformation), and the deformation vectors from each source curve to the corresponding

target curves. These vectors are preserved throughout the computation. The remainder of the vector field is computed using the above two equations.

Prior to initializing the boundary conditions, we resample the target and source curves to have the same number of points along their paths. The sampling density is chosen such that the distance between adjacent sample points is always less than the pixel length. This ensures all pixels along the curves to attain a unique deformation vector. Moreover, a simple direction check is performed to map each end of the source curve to the intended end of the target curve, thereby eliminating sensitivity to drawing directions.

A problem arises if the computed deformation field is applied directly to the original image, as the deformation vectors do not guarantee a complete mapping from the original image to the yet-to-be computed deformed image. To overcome this difficulty, we utilize deformation vectors that originate from the target curves and point toward the source curves. The subsequent diffusion is then applied in this new configuration. This allows, for every pixel in the deformed image to point to a real-valued location in the original image (through the deformation vector) and attain a value as an interpolation from the original image. For smoothness, we use a bicubic spline interpolation for this purpose.

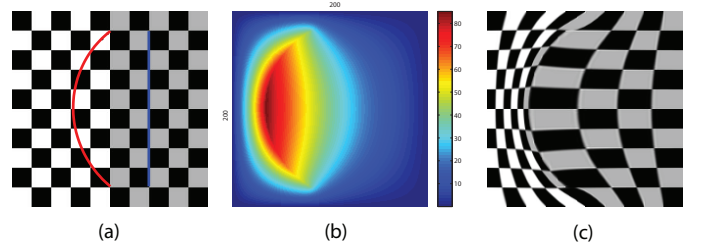


Fig. 5. Calculation of a spatial transformation field from source and target curves. (a) The displacement vectors from the source curves (blue) to the target curves (red) are diffused. (b) The calculated spatial deformation field in  $x$  direction. (c) The deformed image.

## VI. IMPLEMENTATION AND EXAMPLES

The proposed method is implemented in MATLAB. The user sketches the input curves on the original image. We are using a multigrid solver for the deformation field calculation. For a typical image of size  $1024 \times 768$ , the computation of the deformation field and its subsequent application to produce the deformed image takes on the order of 10 seconds on dual core 2.5 GHz laptop with 3 GB of memory. However, especially when deformations are large, it might be desirable to apply the deformation in successive smaller steps, which will proportionally increase the processing time.

In Figure 1, intended modifications are sketched in the form of anchor, source and target curves. The resulting deformation is shown in Figure 1(c). Note that the deformations cease at the regions marked by anchor curves. Figure 2 and 3 present similar modifications for a mug and a kettle, respectively. Note that there are discrepancies between the target strokes and their

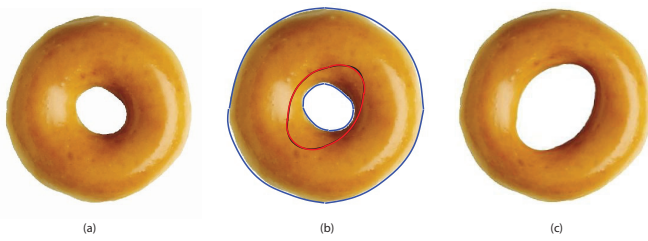


Fig. 6. Modifying the interior of a donut.

beautified versions. This arises as a result of using a single clothoid during curvature beautification. Such discrepancies can be trivially alleviated by regressing multiple clothoid pieces along the target curves instead of a single one. Figure 6 shows the editing an image with an interior loop. The loop is drawn in multiple strokes.

A sketched concept car is shown in Figure 7(a). This sketch is first modified through a set of user drawn curves that define the modifications and constraints on the image (Figure 7(b)). The result of these modifications (Figure 7(c)) have gone through a second set of modifications (Figure 7(d)), resulting in the final image (Figure 7(e)).

## VII. CONCLUSION

We present a sketch-based space deformation technique for aesthetic image editing. The proposed approach enables a stylus-based, fluid edits to an image, making the approach suitable for exploring variations to an underlying image. Our method uses a target curve beautification method using clothoid curves that ensures the deformation to be smooth and visually pleasing. Our current studies indicate that the approach works well for a variety of different image types. Future work will include extending the curvature-based stroke beautification to multiple piecewise continuous aesthetic segments rather than a single curve.

## REFERENCES

- [1] Photoshop. Adobe Systems Incorporated. [Online]. Available: <http://www.adobe.com/products/photoshop.html>
- [2] J. Elder and R. Goldberg, "Image editing in the contour domain," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 23, no. 3, pp. 291–296, Mar. 2001.
- [3] J. Elder and S. Zucker, "Space scale localization, blur, and contour-based image coding," in *IEEE CVPR*, 1996, pp. 27–34.
- [4] E. Saund, D. Fleet, D. Larnar, and J. Mahoney, "Perceptually-supported image editing of text and graphics," *ACM Transactions on Graphics*, vol. 23, no. 3, p. 728, Aug. 2004.
- [5] S. Bagley and G. Kopec, "Editing Images of text," *Communications of ACM*, vol. 37, no. 12, pp. 63–72, 2001.
- [6] E. Saund and T. P. Moran, "A perceptually-supported sketch editor," *Proceedings of the 7th annual ACM symposium on User interface software and technology - UIST '94*, pp. 175–184, 1994.
- [7] S. Seitz and K. Kutulakos, "Plenoptic image editing," in *Sixth International Conference on Computer Vision IEEE*. Narosa Publishing House, 2002, pp. 17–24.
- [8] P. Pérez, M. Gangnet, and A. Blake, "Poisson image editing," *ACM SIGGRAPH 2003 Papers on - SIGGRAPH '03*, p. 313, 2003.
- [9] J. McCrae and K. Singh, "Sketching piecewise clothoid curves," *Computers & Graphics*, vol. 33, no. 4, pp. 452–461, 2009. [Online]. Available: <http://linkinghub.elsevier.com/retrieve/pii/S0097849309000843>

- [10] M. Kass, A. Witkin, and D. Terzopoulos, "Snakes: Active contour models," *International Journal of Computer Vision*, vol. 1, no. 4, pp. 321–331, Jan. 1988. [Online]. Available: <http://www.springerlink.com/index/10.1007/BF00133570>
- [11] P. Bao, L. Zhang, and X. Wu, "Canny edge detection enhancement by scale multiplication," *IEEE transactions on pattern analysis and machine intelligence*, vol. 27, no. 9, pp. 1485–1490, 2005. [Online]. Available: <http://www.computer.org/portal/web/csdl/doi/10.1109/tpami.2005.173>
- [12] G. Farin, *Curves and Surfaces for CAGD*. Morgan-Kaufmann, 2002.
- [13] N. Sapidis, *Designing Fair Curves and Surfaces*. SIAM, 1994.
- [14] C. Xu and J. Prince, "Snakes, shapes, and gradient vector flow," *Image Processing, IEEE Transactions on*, vol. 7, no. 3, pp. 359–369, Mar. 1998.

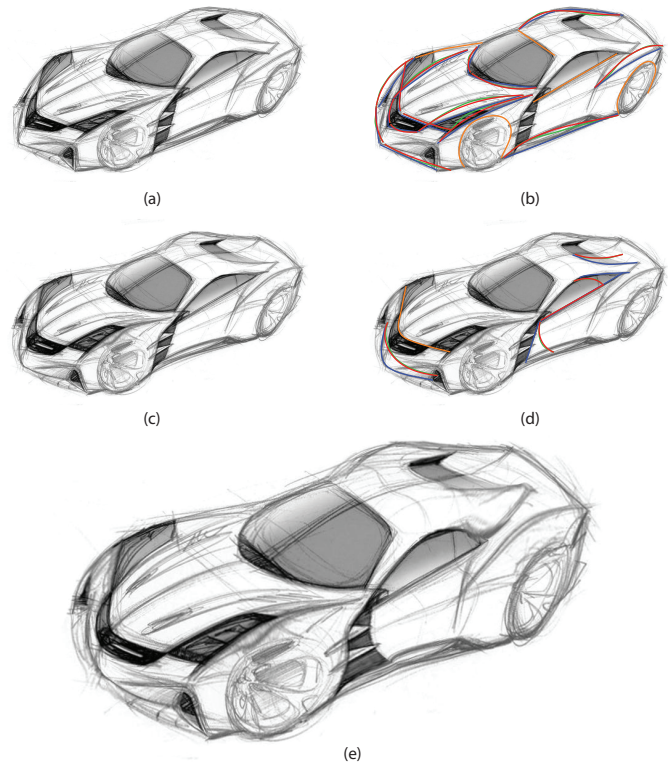


Fig. 7. The original car sketch (a), set of curves that define the first set of intended modifications (b), intermediate result (c), set of curves that define the second set of intended modifications (d), final result (e).