Title:
Curve-based Image Warping for Product Styling

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Introduction:
In early industrial product design activities, stylists are used to take inspiration from already existing products or elements present in nature. Nowadays, the world wide web offers a great amount of images which are easy available and usable for idea stimulation and generation. Easily accessing and modifying the content of these digital images would be very useful for the specification and visualization of new shapes and thus, for browsing alternative solutions. An effortless modification can occur only if the critical elements in the image can be handled as parametric curves and surfaces in CAD (Computer-Aided Design) systems. To this aim, various problems have to be faced and solved. First, parametric curves should be detected from the image. It is crucial that not all the curves detectable from the image are reconstructed, which would result in too many pieces, but only those effectively meaningful from the designer point of view. These curves are those corresponding to the main feature lines characterizing the product shape affecting either the overall and details' appearance [4]. Second, suitable image warping techniques have to be devised able to distorting the image elements to correctly simulate the surface modification according to the characteristic curve changes as it would result if changes were occurred in the real 3D surface. Image warping is the act of distorting a source image into a destination image according to a mapping between the source space (u,v) and the destination space (x,y). Among the various works present in literature aimed at modifying an image while considering constraints dependent on the image content, [7] presents a method to modify an image which preserves the shape both of visually salient objects and structure lines and at the same time minimizes visual distortions. Similarly, [11] presents a "scale-and-stretch" warping method that allows resizing images into arbitrary aspect ratios while preserving visually prominent features. [3] deforms and combines image regions by optimizing a shape distortion energy, while [9] minimizes the energy function in the gradient vector flow field. [6] minimizes the deformation energy defined in Euclidean space as rigid as possible. However, distortion of feature curves is unavoidable by common image warping methods. Even if proving good results these works cannot be used for supporting designers since they mainly address the resize of part of the image. On the contrary, for design purposes it is more important to drive the image changes on specific areas according to the modification of meaningful key elements such as the characteristic lines of the object under modification.

A localized user driven image warping method is presented in [12]. This work shows an easy-to-use image retouching technique for realistic reshaping of human bodies in a single image, driven by a 3D whole-body morphable model. However, it is only applicable to objects whose local modification

can be directly driven by numerical parameters and it is not immediately extendable to arbitrary objects.
For styling products, such as consumer appliances or cars, their parameterization is not easy and it involves high-level parameters, such as the characteristic lines [4]. [10] introduces a method for reshaping car body images driven by a morphable model of parametric curves. Unfortunately, this method is relatively complex since it requires the decomposition of the car body into patches with four edges to use Ferguson function and texture gap problems are almost inevitable.
To improve the curve-based image warping in the product design context, this paper presents a method to get image modification driven by curves, without constraints related to the number of the edges limiting the deformed areas. The proposed method uses the inverse mapping to find the corresponding location in the original image for every pixel in the destination image to eliminate potential texture gaps possibly occurring with forward mapping approaches.

<u>Image modification through editing of parametric curves detected from car images:</u>
Even if the complete specification of a product shape is made through the fully detailed specification of its defining 3D surfaces, 2D drawing and sketches, either hand-made or digital, are still largely used either for the solution browsing or as the first step to create the 3D model of the product. With the purpose to support car designers to edit car images, we recover from the images the parametric curves corresponding to the main character lines representing the most important curves for the car aesthetic character. To this aim, we exploit a template model (Fig. 1) in which characteristic curves are decomposed in shorter elements to better adapt to the car shape variations. The template model corresponds to a SUV car, since testing demonstrated that it better suits to the various car categories. These characteristic elements are referred as key curves, whose extrema are denoted as key points.

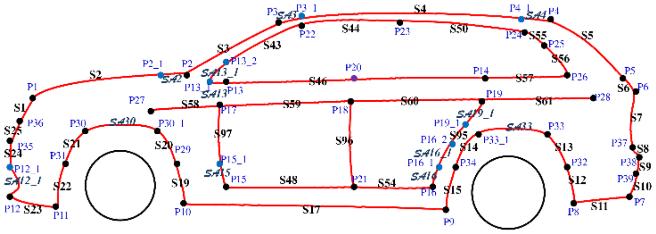


Fig. 1: 2D parametric model to represent the main character lines of a car.

The proposed approach for the automatic recovery and annotation of editable character curves from car images consists of a series of processes aimed firstly at cleaning and making compatible the edge curves detected in the image with the template and secondly at constructing the important curves as present in the template. Initially images are normalized to a standard size (width = 1500). Then an edge detection algorithm, using a combination of the SFE [2] and Canny [1] methods, is applied to identify the important edge points and to cluster them into chains (see Fig. 2). Chains are split in elementary chains to obtain pieces with low curvature variation that can be well approximated by quadric curves with the fitting error of each piece lower than a given threshold (here set to 3). Quadric curves rather than cubic curves are used because character curves of a car can be decomposed in few smooth subparts with coherent curvature. Smallest chains are removed, since they normally correspond to details, as lights or shadows. The remaining chains are then used to identify the curves and the centers of the wheels, which are exploited for registering the template model [8]. Wheels are the parts with a specific shape (i.e. circle) always present in car body; they usually are easily extracted because of the big difference in color of the rim with respect to the tires. The Hough transform algorithm [5] is used to detect them. Chains internal to the detected wheel curves are removed. The remaining elementary chains are then combined together with longer quadric curves (Fig. 3) considering a larger fitting error threshold (=5), thus obtaining curves more similar to the ones in the image.

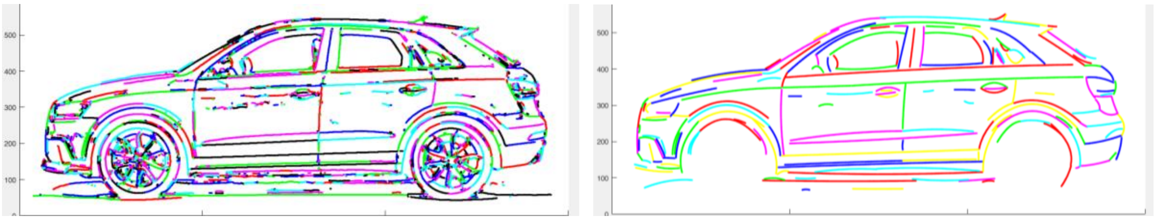
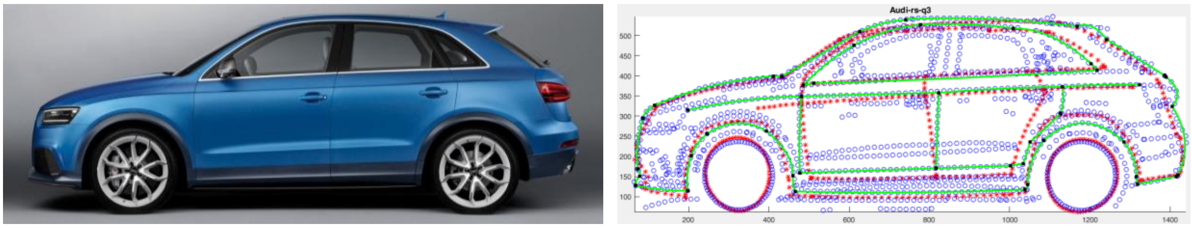


Fig. 2: Point chains (a) and quadric curves obtained from the feature points (b).

Lastly, the curves corresponding to the ones of the template are created, exploiting the registered template key points, by imposing the widest coverage of the image edge points, and conditions peculiar to each specific key curve.

Fig. 3 shows the result obtained for an Audi RS Q3 car downloaded from Google images.



(a) (b)

Fig. 3: An example of the precise model matching for the car in the image (a). In (b), blue points are edge points; red points are those of the warped template model; green lines are the obtained curves; black points are the obtained key points.

Since Bezier curves offer more flexibility for shape modification, the quadric curves are refitted to cubic Bezier curves.

<u>Curve-driven image warping:</u>

The modification of an image using some characteristic lines as modification handles can be seen as a warping process of an image (ImgSource) to another image (ImgWarp) obtained by considering as constraints the correspondence of original characteristic curves in ImgSource and the modified curves. To obtain a uniform warping effect, each curve is discretized and points are put in according to their distance with respect to the curve end points.

Inverse warping is adopted to avoid potential gap problems. Images are then seen as a grid mesh. The constraint points we use are the curve points coincident with the grid points. To avoid losing too many curve points, the mesh is refined near them. When there are many curve points (10 is selected as the limit number in this paper) sharing the same x (or y) value, then we refine the grid along the x (or y) axis near that value. In addition to the curve points, also the image boundaries are treated as constraints.

The inverse warping function, which is expressed in matrix form, exploits the specification of the coordinates of the points in the grid in terms of their neighboring points, see Fig. 4, and the values of the pixel color in the constraint points.

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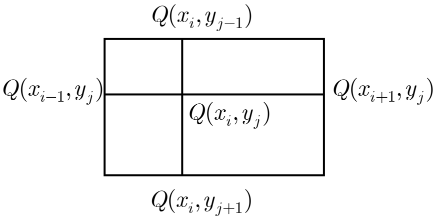
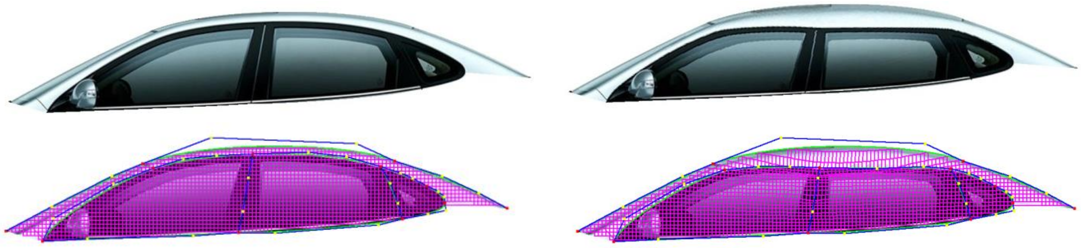


$$Q(x_i, y_j) = \frac{(x_{i+1} - x_i)Q(x_{i-1}, y_j) + (x_i - x_{i-1})Q(x_{i+1}, y_j)}{x_{i+1} - x_{i-1}}$$

$$Q(x_i, y_j) = \frac{(y_{i+1} - y_i)Q(x_i, y_{j-1}) + (y_i - y_{i-1})Q(x_i, y_{j+1})}{y_{i+1} - y_{i-1}}$$

Fig. 4: Irregular mesh grid points relation.

A regular sparse matrix can be constructed according to the mesh grid points' relation. Solving the sparse matrix, points in the final image can then be put in correspondence to the ones in the original one. Fig. 5 shows the regular grids' warping effect and the corresponding image results obtained from reshaping some curves of the window part of car body.



(a) (b)

Fig. 5: Example of curve-driven warping result (b) obtained from (a)

Conclusions:

The work presented here provides a contribution towards the direct usage of images for evaluating shape alternatives guided by the modification of the characteristic curves of the product. The work focuses on the identification and modification of car profile images. The characteristic curve identification exploits a model template to detect among the curves identifiable in the image the more important from the design point of view. The warping method used for the image modification has proven to work well with other type of products as well. Differently from similar methods, it does not require any constraints on the warping region or on the number of modifiable curves thus allowing the user to manipulate the image according to his own preferences. Therefore, the method well suits to the editing of industrial design product images. The method described in this paper uses irregular meshing for the source and destination images according to the constraint curves firstly; secondly, the inverse mapping is obtained by solving a sparse matrix. The application of inverse mapping allows the avoidance of color gaps, thus overcoming similar methods.

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