A Scaling Method of Sensitive Objects Based on Loss Constraint Triangle Mesh Deformation

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***Abstract*—At present, most of image scaling methods have problems such as loss of smaller sensitive information, easy deformation of sensitive objects, the paper proposes a scaling method of sensitive objects based on loss constraint triangle mesh deformation. Sensitive objects mainly include buildings, cars and vegetation. First to identify the sensitive objects, calculate the sensitivity value of each object using the area size and position relations of objects in the image, then get the initial triangular mesh of the image using the Delaunay mesh subdivision, and the method combines scaling loss function with triangle mesh deformation. The experiment results show the method can scale image-objects at different proportions according to the size of the sensitivity value, reduce the deformation of high sensitivity area and get better scaling effect.**

***Index Terms*—sensitive objects, Delaunay triangulation subdivision, scaling loss function, image scaling**

I. Introduction

Image is the main carrier to pass information and an important means for human interaction. With the enhancement of portable performance for the mobile devices and video capture equipment, high-quality display images and videos on a variety of mobile terminals need a higher standard. For example, when display images in mobile phones, tablet computers and other equipments, they will be zoomed because of various sizes. It is hoped the content of image is perfectly displayed on any size of terminal devices.

Because image scaling has important theory value and broad application prospect, it arouses strong interest of research institutions and scholars at home and abroad. According to different research ideas, image scaling methods can be divided into image scaling method based on window clipping, image scaling method based on mesh deformation, resampling-based image scaling method, and the scaling method combined with multiple image scaling methods.

The basic idea of image scaling method based on window clipping is to look for a window of the same size in the original image through some selection strategies, then cut out the contents of image in the window as the final scaling results [1], [2]. The method simply discards the area outside the window directly, and causes the loss of information.

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Mesh deformation-based image scaling methods mainly adopt the idea of mesh deformation. Cover the image with a same size of rectangular grid, and deform the sensitive target regions using similarity transformation or remain the same, deform the mesh of other areas, and obtain deformation grid with the same size as the target image. Then according to the coordinates of each pixel in the original target mesh grid, generate the pixel values of the target grid from the pixel values of original image by certain interpolation approach, and get a scaled target image [3]-[5]. The existing mesh deformation methods are so easy to introduce larger deformation distortion not fully considering the relationship between the integrity and correlation of the grid units in mesh deformation.

Resampling-based image scaling methods primarily resample the pixels of the original image based on a certain strategy, and generate the final target image, and the methods are currently more [6], [7]. Resampling-based approaches are easy to cause deformation of stronger structural sensitive objects in the image, resulting in loss of information.

Image scaling methods based on the integration of a variety of methods are new scaling methods which mainly combine a few of scaling methods into a new method according to certain strategies [8]. The methods need larger amount of calculation, and are not conducive to the application on mobile devices with limited processing capabilities.

The main problems of these four methods are smaller sensitive information may be lost, and sensitive objects are easy to be deformed. Aiming at these problems, this paper calculated sensitivity value for each object through image recognition, and then scaled image in different proportions based on sensitivity value size of the objects. The scaling algorithm is based on triangular mesh deformation constrained by loss energy function, it can reduce distortion of highly sensitive areas as far as possible, and achieve better scale effects.

II. An Identification Method of Sensitive Object

When looking at an image, the visual attention of people is not generally focused on a particular object, but scattered in several sensitive objects. The existing image recognition methods often identify a given object, and cannot well meet the demand. The paper proposes a

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sensitivity object recognition method using the remarkable feature selection of sensitive objects.

The main idea of the sensitivity object calculation method is to segment image combined with color, texture and shape features, roughly determine the area of each object. After determination of each target region, calculate the object sensitivity according to the context relationship between objects in the image scene. Finally, select and predict image objects based on the preset sensitive value of the original image objects, initial sensitive value is set by the image application and personal preferences.

The object sensitivity in the image depends on the application scenario, individual preferences of the users, and the context relationship among each object. The former two factors are relatively fixed, and can give the object original sensitivity using the initial predefined way according to the common sense of browsing images. Table I gives the initial object sensitivity definition table in the paper.

TABLE I. THE INITIAL OBJECT SENSITIVITY DEFINITION TABLE

Kinds	Sensitivity (range: 0-1.0)	Kinds	Sensitivity (range: 0-1.0)
Cars	1	Buildings	0.8
Sky	0	Grass	0.2

According to the general experience, image object sensitivity is not only related to the types of the object, but also affected by the contextual relationship among objects in the image scene, such as the area of the object, and the distance from the image center to the object. The background regions usually occupy larger area in the image with lower sensitive degree, the distance is farther from the image center to the object with lower sensitive degree [9], [10]. The paper finds out the contextual factors affecting object sensitivity based on experiments and analysis, uses (1) and gives the calculation formula of image context sensitivity.

$$SD_T = W_1 * A_T + W_2 * L_T$$
$$W_1 + W_2 = 1 \tag{1}$$

where SD_T is an image object context sensitivity, W_1 and W_2 as the weight of influence factor, A_T is the ratio of this object area and all sensitive object areas, and L_T expresses the level of distance from the object to the image center.

In order to better identify sensitive objects in the image, the paper constructs a scene classifier to recognize the objects in the image. The specific method is to get a lot of image object samples as the training images, extract visual features of objects, construct the object classification characteristics using multi-feature fusion, then get the image object classifier with high accuracy using the machine learning method. The sensitive object recognition flowchart is shown in Fig. 1.

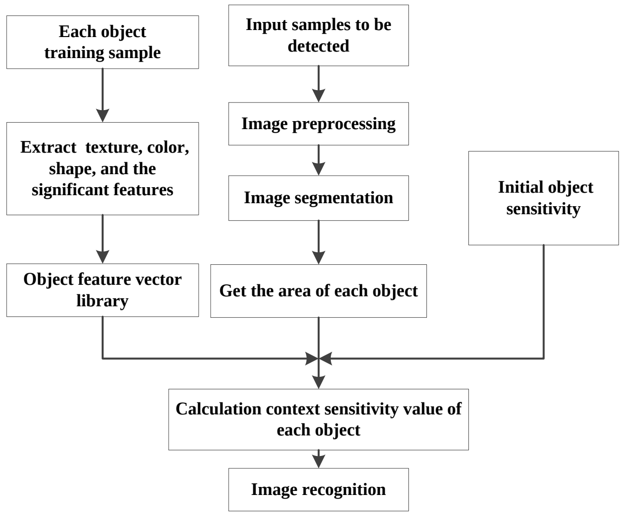
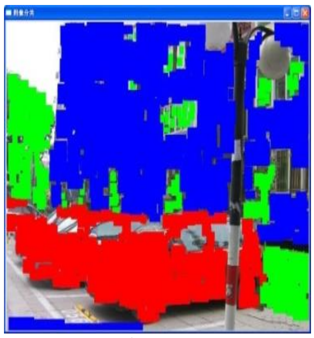


Figure 1. Sensitive object recognition flowchart.

In this paper, adopt the one-to-many SVM classification method on scene recognition, and compare the experiment results with other methods. 300 images are trained to get car, vegetation and building image samples, and the sample image size is 30*30, then select the radial basis kernel function (penalty factor C is 1, the width of the radial basis kernel function σ is 1) as the SVM parameters to train samples. For all samples, respectively extract the texture, color, shape, and license plate features, and put the set of feature vectors in the subsequent identification characteristic library. After the training, sensitive objects in the input images can be recognized. In order to detect and identify the sensitive objects of unknown size in images, the paper sequentially scans images using the search window of 30*30, optimizes detected results, finally obtains the recognition results, Fig. 2 shows the recognition results.


(a) Original image


(b) Classification results


(c) Sensitive object marked figure

Figure 2. The sensitive object recognition results.

TABLE II. SENSITIVITY PARAMETER TABLE OF EACH OBJECT

	Buildings	Vegetation	Cars
Object area	254932	55960	102875
Distance from the image center to the object	153	282	489
Sensitivity value	0.852	0.122	0.347

Table II shows the sensitivity parameter table of each object in the image. It can be seen from Table II, the results of the sensitivity calculation method presented in the paper are similar in significant degree with the sensitive objects of human eye actual observation. The paper determines significant degree based on the sensitivity values, it is benefit to realize the global image scaling according to the sensitive degree of the image object.

III. AN IMAGE OBJECT SCALING ALGORITHM BASED ON TRIANGLE SUBDIVISION

A. *Delaunay Triangular Mesh Subdivision Principle*

D-Triangle has two very important properties of empty circle, and the largest minimum angle. “Empty circle” refers to the circumcircle of any triangle contains no other data points. “The largest minimum angle” refers to in all possible generated triangulation, the minimum interior angle of a triangle in Delaunay triangulation is the largest. This will effectively ensure the Delaunay triangulation is the optimal triangulation which is closest to equiangular or equilateral. These two properties are the fundamental basis to establish Delaunay triangulation.

Since the two properties determine the great application value of D-triangulation. Meanwhile, it is also the unique and the best two-dimensional plane triangulation. Miles proved that D-triangulation is “good” triangulation; Sibson found “in a finite point set, there is only a partial isometric of the triangular network, which is D-triangulation; Lingas further demonstrates that “in general, D-triangulation is optimal”; Tsai think that, “in Euclidean plane, there is no more than three adjacent points in a circle, D-triangulation is unique”.

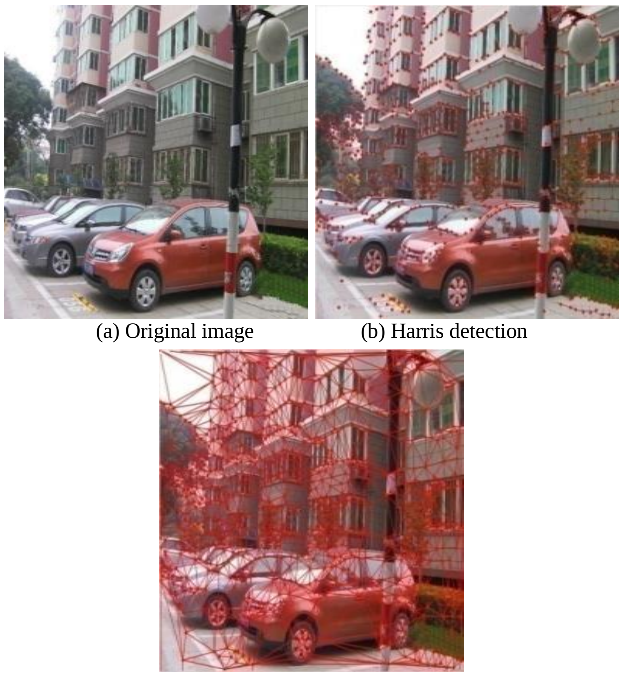
Delaunay triangulation helps to avoid narrow or too small acute triangle in the case of points evenly distributed. Triangles in triangulation should be acute triangle, or three edges roughly equal to each other, the triangles do not cross and overlap. Delaunay triangulation is the closest to equilateral triangulation. In a variety of two-dimensional triangulation, Delaunay triangulation can only meet the global and local optimization.

There are many Delaunay triangulation algorithms, among which interpolation point incremental algorithm represented by Lawson algorithm and Bowyer-Waston algorithm opens the research and application of Delaunay triangulation method. Then Voronoi diagram method and divide and conquer algorithm are successively proposed [11].

B. *The Generation Method of the Characteristic Grid*

If you want to better represent and protect the significant areas of the image, you need to generate feature structure related to the feature structure of source image. The generation of the characteristic mesh includes reasonable distribution the grid points within the calculation regions according to the image characteristics, effective connection grid points and formation triangle grid cells.

Harris operator gives the matrix M associated with autocorrelation function. Eigenvalues of the matrix M is the first order curvature of the autocorrelation function, if the two curvature values are higher, the point is considered a characteristic point. Harris operator has simple calculation, better stability and robustness, and it can accurately detect the feature points in the case of image rotation, gray level variation and noise disturbance, the false detection rate is very low. The paper realizes triangular mesh subdivision through Lawson algorithm. First form the convex hull of a set of discrete points, construct an initial Delaunay triangulation on the boundary nodes of convex hulls, and then form new Delaunay triangulation by adding in a convex hull, join the internal points of the convex hulls in turn, form new Delaunay triangulation until all the points in the convex hulls have been processed. The paper detects the angular points by using Harris operator, shown in Fig. 3. It can be seen from Fig. 3, the detection effects of Harris operator are obvious to characteristic points near the significant objects.



(a) Original image (b) Harris detection

(c) Delaunay triangular mesh

Figure 3. Feature points and feature grids.

C. *The Sensitive Object Scaling Method Based on Loss Constraint Triangle Mesh Deformation*

In the paper, scaling method needs to decide its zooming scale according to the sensitivity of each object in the image. Irregular shape of the object itself and different scaling easily cause proportion imbalance among the objects, and visual distortion effects. In order to reduce the information loss in the scaling process of sensitive objects and maximizing maintain the shapes of the sensitive objects, a sensitive object scaling method based on loss constraint triangle mesh deformation is proposed in the paper.

The image is represented as a triad *M*, $M = \left(V, E, F\right)$, where *V* represents the triangle subdivision vertex set, $V = [v_0^T, v_1^T, v_2^T], v_i \in R^2$, *V* represents the initial position coordinates of the collection point, *E* is the edge set of triangular mesh, *F* is triangular mesh set. In order to scale the $m \times n$ image to any zooming $m' \times n'$ image, fix the upper left corner vertex v_0 in the image, move the bottom right vertex v_{end} to a new location v'_{end}. To minimize the distortion of triangular mesh, the other image boundary points can be determined according to the movement positions from the fixed coordinates to the vertex of v'_{end}, so the scaling problem is converted into looking for the new grid vertex positions $V' = [v_0'^T, v_1'^T, \dots v_{end}'^T]$ satisfied the geometrical constraint conditions, each triangle mesh is moved according to the uniform size.

It will inevitably bring some triangular mesh deformation or stretching for any size of image zooming. The paper disperses the deformation based on the sensitivity of each triangular mesh, tries to make the deformation occur in the low background areas, and achieves the optimal scale results. That is to say, the size of triangular mesh deformation is inversely proportional to the sensitivity of image objects.

In this paper, the variable of mesh shape is represented through the distance between a new calculation grid and the uniform scaling grid closest to the original mesh. The scaling factor is from the new location in each cell grid $f(f \in F)$ closest unified scaling version, the uniform scaling vertex positions can be expressed as $v' = s_f v + t$, where *t* represents the grid shift, *v* is the initial position of a vertex, then use (2) and give the variable of mesh shape.

$$D_u(f) = \sum_{\{i,j\} \in E(f)} \left\| (v'_i - v'_j) - s_f (v_i - v_j) \right\|^2 \tag{2}$$

Considering the fixed point of the same edge, the translation vector *t* is eliminated for the same translation vector. In addition, *E*(*f*) is the edge set of the grid unit, the subscript *i* and *j* denote the triangular mesh vertex numbers, v_i and v_j represent the number is *i* and *j* triangular mesh vertices in the original grid coordinates, v_i' and v_j' are the corresponding coordinates of mesh vertices in deformation grid coordinates corresponding. Best scaling s_f is entirely defined by v_i and v_i', minimize the deformation of the unit grid $D_u(f)$, use (3) and (4), get s_f namely get $D_u(f)$ for s_f partial derivative, and then make it equal to zero.

$$\frac{\partial D_u(f)}{\partial s_f} = \sum_{\{i,j\} \in E(f)} 2(\left\| v_i - v_j \right\|^2 s_f - (v_i - v_j)^T (v'_i - v'_j)) \tag{3}$$

$$\frac{\partial D_u(f)}{\partial s_f} = 0 \Rightarrow s_f = \frac{\sum_{\{i,j\} \in E(f)} (v_i - v_j)^T (v'_i - v'_j)}{\sum_{\{i,j\} \in E(f)} \left\| v_i - v_j \right\|^2} \tag{4}$$

s_f is entirely defined by the deformation of the mesh vertices. The total grid deformation can be obtained through multiplying the summing all grid deformation energy terms by the corresponding mesh sensitivity weights, so that the distortion can occur in lower sensitivity areas, D_u is defined using (5).

$$D_u = \sum_{f \in F} w_f D_u(f) \tag{5}$$

f represents the element mesh, *F* is a set of grid, $D_u(f)$ represents element mesh deformation energy, w_f is the weight of element mesh. Most sensitive objects in the image will occupy multiple consecutive grids, and hope to minimize the bending degree of the grid lines in order to prevent deformation of sensitive objects. In particular, the optimization strategy changes the length of the mesh edges, but the deformation keeps the direction of the edge. l_{ij} is defined as the ratio of the same mesh edge length before and after the deformation, therefore the general grid line bending energy is defined using (6).

$$D_l = \sum_{\{i,j\} \in E} \left\| (v'_i - v'_j) - l_{ij} (v_i - v_j) \right\|^2 \tag{6}$$

Hope the deformation energy minimization *D* of whole image in some boundary conditions, *D* is defined using (7).

$$D = D_u + D_l \tag{7}$$

As the grid form variables, as bending energy grid lines, boundary constraints are the vertex positions of the upper left corner and the lower right corner.

D_u represents grid deformation variable, D_l is bending energy for the grid lines. Boundary constraint is the upper left and lower right corner vertex position.

$$v'_0 = (0,0)^T, v'_{end} = (n', m')^T \tag{8}$$

In addition, *y* coordinate value of the horizontal (vertical) boundary vertex (or *x*) is constrained to be a constant in order to ensure to obtain a triangular.

$$v'_{i,y} = \begin{cases} 0 & v_i \text{ is on the top boundary} \\ m' & v_i \text{ is on the bottom boundary} \end{cases}$$

$$v'_{i,x} = \begin{cases} 0 & v_i \text{ is on the left boundary} \\ n' & v_i \text{ is on the right boundary} \end{cases}$$

This paper adopts an iterative method for solving the deformation grid. Note that a scaling transformation s_f and the length of deformation edge l_{ij} are unknown, the latter is non-linearly dependent on the vertex position.

The iterative solution method begins with the initial guess of V', and determines each edge scaling transformation s_f and scaling transformation length l_{ij}. It is based on constraints by minimizing the total energy D and solving a new set of vertices V'. Holding s_f and l_{ij} fixed, energy D is quadratic function of V', thereby minimizing problem is linear. In addition, when s_f remains fixed, X and Y coordinates of the mesh vertices are not coupled, it can use the same matrix solve alone, reuse matrix decomposition, repeat the above steps until all the motion displacement of vertices is less than 0.5.

Due to significant objects typically spans multiple triangular meshes, as a result, the observed triangle mesh scaling transformation s_f nearby sensitive objects is similar. After determining s_f, it is recommended to reduce the difference between adjacent scaling factors, namely to smooth the s_f in each iteration. $N(f)$ is used to represent neighboring grids for grid f, W_g is represented the average of all grid sensitivity, and it can obtain a smooth scaling factor s_f after each minimize energy.

$$\sum_{f\in F}\sum_{q\in N(f)}\frac{1}{2}(w_f+w_q)(s'_f-s'_q)^2+\sum_{f\in F}w_g(s'_f\,|-s_f)^2 \qquad (9)$$

Generate optimized initial mesh in accordance with the following steps. Continuously take the points in the image, generate regular triangular mesh using the Delaunay triangulation subdivision, then, scale the grid according to the scaling target image size in the unified proportion, finally, optimize the scaled image by the above mentioned iterative method. In mesh deformation, use "(10)" and give the minimization objective function.

$$\Omega=\sum_{\{i,j\}\in E}(1+w_{ij})\left\|v'_i-v'_j\right\|^2 \qquad (10)$$

E is the set of grid edges, the subscripts i and j represent the number of mesh vertices, w_{ij} is the average grid weight of the edge ij, v'_i and v'_j are numbered by i and j coordinates of mesh vertices after initialization. Adding a constant value is used to reduce the proportion of such a weighting factor. In this paper, the specific steps of iterative method for deforming meshes are as follows.

(1) Obtain the uniform scale factor and grid line bending l_{ij} of each grid through initial mesh and grid lines curvature l_{ij}, then make Gaussian smoothing to s_f.

(2) Optimize the grid deformation energy D to determine the target grid vertex position to reach the minimum D, that is D seeks the partial derivative for mesh vertices v'_i, and then let it to be zero, get linear equations related to v'_i, solve this equation, get new target grid vertex coordinate v'_i, so complete iteration.

(3) Use the last result v'_i as the initial grid coordinate, repeat the above process, and obtain the new target mesh and the vertex coordinates, when the twice variation of the energy D is less than 1, consider the end of the iteration, the obtained results are the final deformed mesh.

Based on the relationship between the original image and the deformed mesh grid, calculate the deformation of each vertex grid coordinate translation using the above-mentioned method, then obtain coordinate translation of each pixel within grid through coordinate translation for the three vertices of the grid using polygon scan conversion method and bilinear interpolation. As shown in Fig. 4, assuming each vertex coordinate component and coordinate translation vector of the x-axis and y-axis for the deformation triangular mesh respectively to be $(v_x^k, v_y^k, v_{off}^k)$, $k=1,2,3$, counterclockwise select three vertices of triangle grid from the lower left corner, respectively is $v^1(v_x^1, v_y^1, v_{off}^1)$, $v^2(v_x^2, v_y^2, v_{off}^2)$, and $v^3(v_x^3, v_y^3, v_{off}^3)$. Intersect the current pixel $(v_x^k, v_y^k, v_{off}^k)$ straight edges and given edges of the vertices, two intersection points and tested pixel have the same abscissa coordinate, denoted by (v_x, y^1) and (v_x, y^2), in accordance with the principle of linear interpolation, the pixel shift of v_{off} can be expressed using (11).

$$v_{off}=(y^2-v_y)[(v_x^2-v_x)v_{off}^1+(v_x-v_x^1)v_{off}^2] \qquad (11)$$

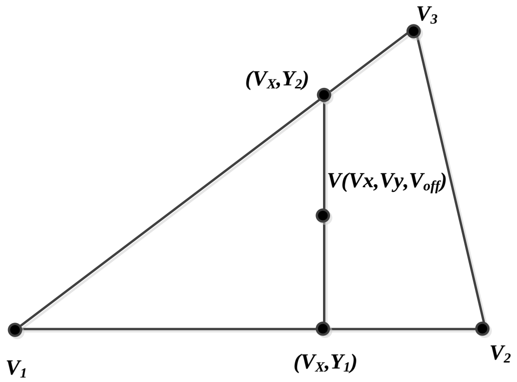


Figure 4. Interpolation model diagram of each pixel point coordinate translation in triangular mesh.

According to the principle of reverse mapping, the target image color values of each pixel in the image is the original image pixel coordinates of the target point coordinates and pixel color value of corresponding translation. Since the sum is real number for target image pixel coordinates and corresponding shifted coordinate values, get the final color values by linear interpolation for the pixel color of the original image real neighborhood coordinates. Provided real pixel coordinate value (x, y), (i, j), $(i+1, j)$, $(i, j+1)$ and $(i+1, j+1)$ are respectively its nearest neighbor coordinates, a and b represent the distance between the left and the lower boundary, shown as Fig. 5, I indicates the color value of the original image, use (12)and give the pixel value $I(x, y)$ of coordinate position (x, y) by bilinear interpolation.

$$I_{(x,y)}=(1-a)(1-b)I_{(i,j)}+a(1-b)I_{(i+1,j)}+(1-a)bI_{(i,j+1)}+abI_{(i+1,j+1)} \qquad (12)$$

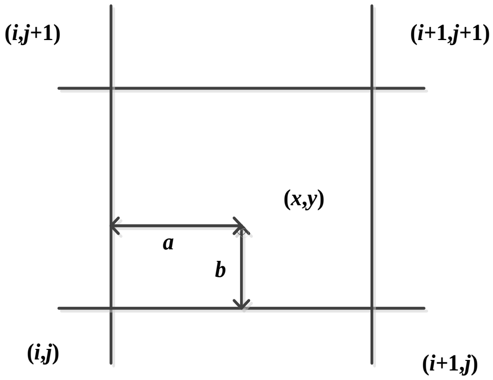
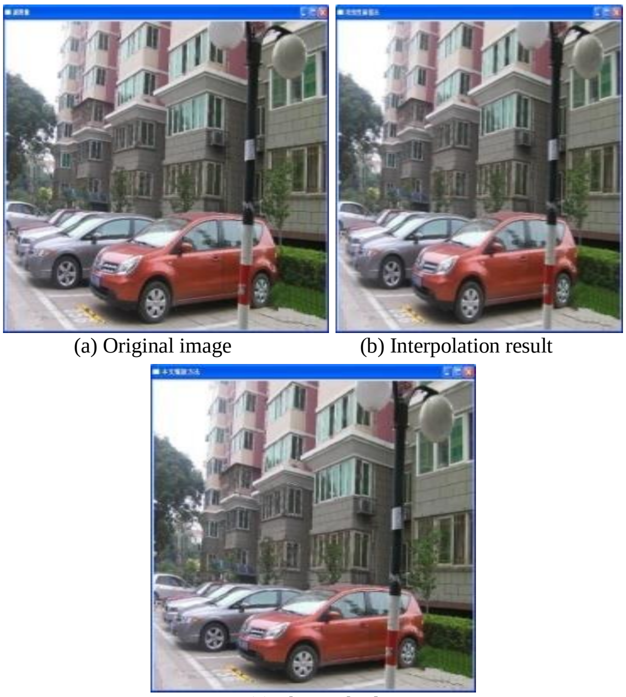


Figure 5. Bilinear interpolation model diagram for real coordinates corresponding to the image color values.

IV. The Experiment Results and Analysis

This paper realizes bilinear interpolation scaling, and compares the method with the sensitive object scaling method based on loss constraint triangle mesh deformation, the experimental results shown in Fig. 6, the method presented in this paper obtained the target image with smaller distortion. From Fig. 6, in the process of bilinear interpolation zooming, deformation and distortion of image object is very serious, such as buildings, car, the proposed method can better maintain the buildings, cars and other large sensitivity value objects to avoid the occurrence of deformation in the scaling process when image scaling, and the scaling effect is better than the bilinear interpolation method.



(a) Original image (b) Interpolation result

(c) The method

Figure 6. The scale experiment result.

In the process of triangular mesh deformation, this paper considers the mesh deformation loss function, the scale function is related to the shape of the grid deformation and deformation of the mesh size, scale results achieved by the deformation energy optimization function can get better visual effects. Table III respectively gives average energy loss of buildings, cars and vegetation object scaling of interpolation method and the method for 300 test images.

TABLE III. Average Energy Loss of Each Object Scaling

	Average energy loss of interpolation method	Average energy loss of the method
Buildings	690.552	575.453
Cars	438.653	258.765
Vegetation	720.108	530.189

Table III shows the method loses smaller energy than the corresponding interpolation method for high sensitivity objects, and in the process of scaling, the greater sensitivity is the object, the energy loss is smaller, the image object deformation is also smaller. On the other hand, the energy loss is large and the deformation of the scaling process is relatively greater for the small sensitivity object or background regions.

V. Conclusions

This paper presents a sensitive object scaling method based on loss constraint triangle mesh deformation. Unlike conventional saliency detection or importance identification, the paper calculates the sensitivity values for the sensitive objects, combines the scaling loss function and the triangular mesh deformation, scales at different proportions through the sensitivity value, and maximize the image sensitive objects unchanged. The experiment results show the method can reduce scale deformation for large sensitivity object, better keep the visual effect of the original image，and demonstrate the proposed method is capable of maintaining clear borders of source images and efficient in computation for image zooming.

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