Segmentation of Building Facade Domes

Gayane Shalunts[1,⋆], Yll Haxhimusa[2], and Robert Sablatnig[1]

[1] Vienna University of Technology, Computer Vision Lab
{shal,sab}@caa.tuwien.ac.at
[2] Vienna University of Technology, Pattern Recongition and Image Processing Lab
yll@prip.tuwien.ac.at

Abstract. Domes are architectural structural elements typical for ecclesiastical and secular grand buildings, like churches, mosques, palaces, capitols and city halls. The current paper targets the problem of segmentation of domes within the framework of architectural style classification of building facades. We perform segmentation of building facade domes by combining bilateral symmetry detection, graph-based segmentation approaches and image analysis and processing technics into a single method. Our algorithm achieves good segmentation results on buildings belonging to variety of architectural styles, such as Renaissanse, Neo-Renaissance, Baroque, Neo-Baroque, Neoclassical and Islamic.

Keywords: Building facade domes, bilateral symmetry, segmentation.

1 Introduction

Architectural styles are phases of development that classify architecture in the sense of historic periods, regions and cultural influences. Automatic classification of building facade images by architectural styles will allow indexing of building image databases into subdatabases belonging to certain historic periods. Such a semantic categorization limits the search of building image databases to certain category portions for the purposes of building recognition [17,16], Content Based Image Retrieval (CBIR) [6], 3D reconstruction, 3D city-modeling [2] and virtual tourism [14]. Architectural style classification system may also be applicable in real tourism, provided with smart phones. Our main focus is on historic styles, which combine style-typical architectural elements and obey to certain design rules for building construction. Unlike historic architecture, modern architecture is not confined by any rules and is difficult to categorize.

Facade images either do not have labels related to styles or such labels are inaccurate. To know the style of an observed building, one should search for the building name. Since most buildings lack names, visual information of facades remains the only clue to their styles. While an automatic system for classification of facade images by architectural styles still does not exist, the first steps towards creating such a computer vision system are done in [12,13,9]. The authors in [12]

⋆ Supported by the Doctoral College on Computational Perception.

L. Alvarez et al. (Eds.): CIARP 2012, LNCS 7441, pp. 324–331, 2012.

classify facade windows of Romanesque, Gothic and Baroque styles. The approach proposed in [13] classifies architectural element tracery into Gothic class and elements pediment and balustrade - into Baroque class. In [9] classification of Flemish Renaissance, Haussmannian and Neoclassical styles is performed on complete facade images.

Our method of architectural style classification of facades consists of 3 major steps: (i) facade segmentation by architectural structural elements, (ii) classification of the segmented elements by architectural styles and (iii) style voting of the classified elements. The algorithm is capable to classify partly occluded facades by a single style-typical element and facades, which are a mixture of styles. Buildings of historic, religeous and cultural importance are of special interest to us. And as it is the privilege of such buildings to feature domes, we focus on segmentation and classification of domes. The previous work, related to facade segmentation by an architectural element, is limited to detection of windows [1,11,10,5]. The current paper addresses the problem of segmentation of facade domes and is the first to do so. We present a multi-step algorithm, integrating bilateral symmetry detection, graph-based segmentation approaches and image analysis and processing technics. Our approach manipulates the visual features of domes, such as specificity of bilateral symmetricity, raising out of the main building and roundness, to reach robust segmentation of domes. The experiments prove that the method is capable to handle buildings in complex scenes and achieves accurate segmentation on 96% of the test images.

The paper is organized as follows: Sect. 2 gives architecture review of the types of domes, which are segmented by our methodology. Sect. 3 explains the proposed methodology for the segmentation of domes. The experiments and results are presented in Sect. 4. And finally Sect. 5 concludes the paper.

2 Building Facade Domes

Dome is a convex roof. Hemispherical domes have a circular base with a semicircular section and are characteristic for grand buildings of Renaissance, Neo-Renaissance, Baroque, Neo-Baroque and Neoclassical architecture. Here Neo-styles refer to revived styles, e.g. Neo-Baroque refers to Baroque Revival. The essence of the phenomenon called architectural revivalism is the imitation of past architectural styles. In Fig. 1a, Fig. 1b, Fig. 1c are shown respectively St. Charles's Baroque Church in Vienna, California Neoclassical Capitol in Sacramento and San-Francisco Neoclassical City Hall featuring this type of dome. Onion domes have a circular or polygonal base and an onion-shaped section. This type of dome is a typical feature of Islamic mosques, palaces, etc. Taj Mahal in India (Fig. 1d) is the most famous landmark featuring an onion dome. Architectural definitions are taken from the Illustrated Architecture Dictionary[1].

[1] Illustrated Architecture Dictionary:
`http://www.buffaloah.com/a/DCTNRY/vocab.html`

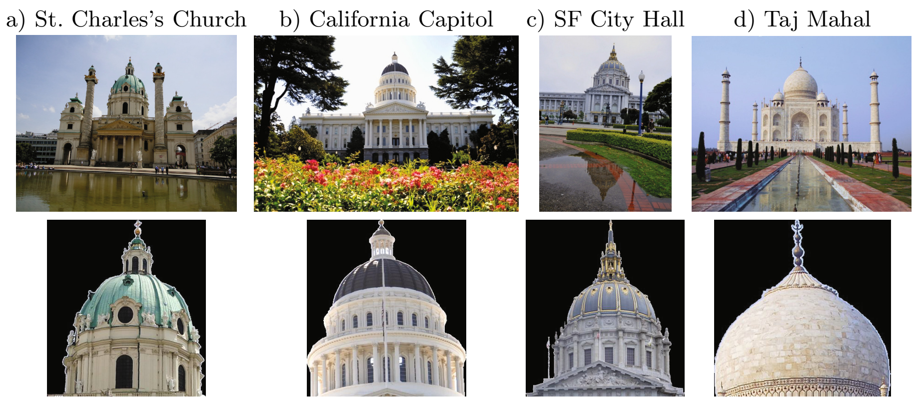


Fig. 1. Examples of buildings with domes and segmentation of domes

3 Segmentation of Domes

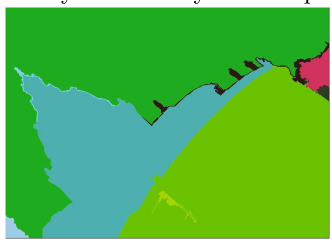
Building facade dome segmentation is a highly complex task, being a high-level semantic segmentation by an architectural element. Color-based segmentation approaches are not applicable, since color is not a distinctive feature and a single dome contains multiple color segments. Though domes have certain geometric forms, defined as hemispherical, onion, etc, shape analysis is also not suitable for segmentation, as these shapes may not be modeled owing unlimited variety.

Using symmetry as a feature is logical, since facades, like any artefacts, are highly symmetrical. Facades have symmetry specificities. Firstly, dominant symmetry axes are vertical. Secondly, whereas bilateral symmetry is common for historic facades, translational and rotational symmetries also take place. For dome segmentation purpose bilateral symmetry is of interest to us, since domes are 3D objects preserving bilateral symmetry related to the vertical axis passing through their center in 2D projections. Thus at the first step the image bilateral symmetry axes are detected using the method proposed by Loy et al [8]. In [8] matches of symmetric points are found using modern feature-based methods, such as [7], from which bilateral symmetry axes or centers of rotational symmetry are determined. The method is independent of the feature detector and descriptor used, requiring only robust, rotation-invariant matching and an orientation measure for each feature [8]. This method is sucessfully used also for detecting repeated structures on facades [15]. Fig. 2a shows an example image with a tilted dome. Image bilateral symmetry axes and supporting symmetric points are displayed in Fig. 2b. In case multiple symmetry axes are found, we choose the axis with the strongest symmetry magnitude (supported by the biggest number of symmetry points). As the dominant symmetry axis passes through the dome center and is vertical, we rectify the image by rotation, making the strongest symmetry axis vertical (Fig. 2c). Images, whose strongest symmetry axis is vertical, skip this step. Bilateral symmetry detection [8] is performed once more on the rotated image to find the position (column) of the strongest symmetry axis. At the second

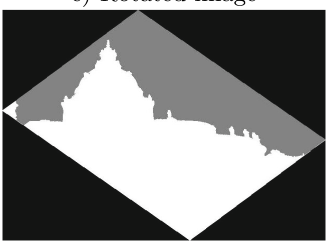
a) Original image

b) Symmetry axes and symmetric points [8]

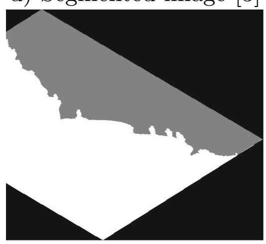
c) Rotated image



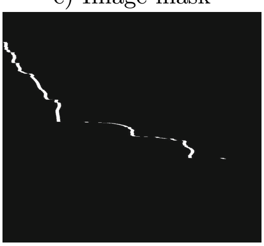
d) Segmented image [3]



e) Image mask



f) Fig. e) cropped from the main symmetry axis



g) (Half) Facade contour

h) Dome: final segment

Fig. 2. Dome segmentation algorithm steps

step segmentation of the original image background and foreground is performed. As domes are situated high above the buildings, the sky and clouds form their background. We segment the original image using the methodology introduced by Felzenszwalb et al. [3] (Fig. 2d). The pairwise comparison of neighboring vertices, i.e. partitions is used to check for similarities [3,4]. In [3] a definition of a pairwise group comparison function $Comp(\cdot,\cdot)$ is given, judging if there is evidence for a boundary between two image segments or not. $Comp(\cdot,\cdot)$ contains a scale parameter k, where bigger k prefers larger segmented regions. The function measures the difference along the boundary of two components relative to a measure of differences of components' internal differences. This definition tries to encapsulate the intuitive notion of contrast. Images are preprocessed by Gaussian blurring with σ before the segmentation, as well as postprocessed by merging small regions with the biggest neighboring one [3]. After the segmented image is also rotated to make the strongest symmetry axis vertical.

As our image is already justified so that the sky is on the top of it, we find the segment (color) of the sky by looking for the first non-black pixel starting from the first upper row, which is located on the strongest symmetry axis. Then the image foreground mask is obtained by setting all sky pixels to background color and non-sky pixels - to foreground color (Fig. 2e).

Having the image foreground mask found, our task is to analyze its shape in order to crop the dome. As domes are symmetric, for optimization we analyze only the image part cropped to the right from the strongest symmetry axis (Fig. 2f). The strongest symmetry axis is expected to pass through the center of the dome, i.e. through the highest point of the dome. For images, whose symmetry axis position is shifted left or right from the dome center due to perspective distortions, the symmetry axis position is corrected by looking on the image mask for the foreground maxima in the symmetry axis local neighborhood. This milestone of our methodology means, if the initial detected vertical symmetry axis lies on the dome, it justifies itself to the correct position, making the approach robust to high perspective distortions.

Now our purpose is to find the bottom row of the segmented dome. Here we use a visual feature of domes: domes raise out of the main building. This means that the facade contour, formed by the foreground pixel followed by a backgroud pixel in each row (Fig. 2g), has a leap on the row where the dome meets the main building. The observed leap is found by scanning down row by row the facade contour in Fig. 2g until the condition in Eq. 1 is satisfied:

$$\text{Leap} \; / \; (\text{Row}(k) - \text{Row}(1)) > 0.15 \;\&\&\; \text{Leap} > \text{minLeapThreshold} \quad (1)$$

where Leap is the column difference of contour pixels on kth and $(k-1)$th sequential rows: Leap $= \text{Col}(k) - \text{Col}(k-1)$.

$\text{Row}(k) - \text{Row}(1)$ is a normalization factor and is the difference of the kth and first rows of the contour. minLeapThreshold excludes too small leaps between two subsequent rows and is set to 18 pixels for images with resolution lower than 1 million pixels and to 26 pixels otherwise. After the image mask is cropped from the found row to discard the image part below, which does not contain the segment of interest. In order to obtain the final dome segment, we pick up the blob through which the main symmetry axis passes and discard all the other blobs formed by clouds, trees and any other objects present in the image. Multiplication of the blob mask with the same segment of the original image delivers the segmented dome (Fig. 2h).

Still we take a further step by incorporating feature roundness for domes, to address the following types of complex images: i) the strongest symmetry axis does not pass through the dome center, due to too high perspective distortions or other symmetric objects in the image, ii) the strongest symmetry axis is located on the dome, but is horizontal, iii) the facade is reflected in water, thus the strongest symmetry axis is horizontal. Feature roundness is calculated by Eq. 2.

$$\text{Roundness} = 4 * \text{Area} \ /(\pi * \text{MajorAxisLength}^2) \tag{2}$$

$$\text{Roundness} > 0.37 \ \&\& \ \text{DomeBoundingBox} > 1500 \tag{3}$$

If the dome blob roundness and bounding box resolution pass the thresholds in Eq. 3, the dome segmentation is considered successful. The thresholds in Eq. 1 and Eq. 3 were found by experimenting on multiple images. Setting a threshold for dome bounding box resolution excludes too small blobs. In case the condition in Eq. 3 is not met, the whole segmentation algorithm is rerun by taking the 2nd strongest symmetry axis in the initial step. After the condition in Eq. 3 is checked again and if not satisfied, the algorithm is rerun by the 3rd strongest symmetry axis and so on. We limit our dome segment search by the 5th strongest symmetry axis (if such exists), since experimentally was found (Sect. 4) that further search is useless.

4 Experiments of Dome Segmentation and Results

To test for robustness and evaluate our segmentation approach we created an image database of buildings featuring domes, as to the best knowledge of the authors such a database did not exist so far. The database is collected from our own and Flickr[2] image databases and exhibits Renaissanse, Neo-Renaissance, Baroque, Neo-Baroque, Neoclassical and Islamic buildings. Our database includes 550 images of 77 buildings, among those the most famous world landmarks, like St. Peter's Basilica in Vatican, Florence Cathedral, St. Paul's Cathedral in London, Pantheon in Paris, United States Capitol in Washington, capitol buildings of 24 US states and Taj Mahal in India. The resolution of the images ranges from 108×82 to 3681×5522 pixels, proving the algorithm to be resolution-independent. We handle both day and night images, since our method is color-independent. The only limitations of our methodology are: 1) segmentation of occluded domes is not supported, 2) the rare cases when the dome background is formed by cityscape, not the sky, as a result of shooting from a level higher than the ground (building roofs, helicopter, etc) are also not handled. The allowed tilt of the dome is (-90 to 90) degrees related to vertical axis. We do not consider this a limitation, since our search showed that building images taken upside down or tilted more than 90 degrees related to vertical axis are very rare.

The default value for both parameters of graph-based segmentation algorithm [3] σ and k is 2000. The chosen big value is explained by the fact that we need a coarse segmentation of sky and non-sky segments. For images taken by night illumination, foggy weather condition or having low resolution the values of σ and k should be tuned down to obtain the non-sky segment with the precise dome edge. Whereas for images with strong cloud edges in the dome vicinity the values of σ and k should be tuned up to blur the cloud edges. Clouds not

[2] http://www.flickr.com

Table 1. Segmentation rate vs. symmetry axis magnitude

	1st	2nd	3rd	4th	5th	Segmented domes	Total
Segmentation rate	504	11	7	5	1	528 (96% of Total)	550
% of segmented domes	95.45%	2.08%	1.33%	0.95%	0.19%	100%	

touching the dome do not affect the segmentation output, as they are discarded segments. For our database both σ and k are in the range from 50 to 16000.

We domonstrate our segmentation results on building examples in complex scenes - St. Charles's Church (Fig. 1a), California Capitol (Fig. 1b), San-Francisco City Hall (Fig. 1c) and Taj Mahal (Fig. 1d) and the respective segmented domes located below each image in Fig. 1. The accurately segmented dome was obtained on 528 out of the 550 tested images, which yields an average 96% rate for our approach (Table 1). On 504 out of 528 images, i.e. on 95.45% of the correctly segmented images, the segmentation was accomplished by looking for the dome in the vicinity of the 1st strongest symmetry axis (Table 1). And it is only on 4.55% of the correctly segmented images that the dome is segmented by trying symmetry axis weaker in magnitude than the 1st strongest symmetry axis, i.e. on 11 images the dome segment was found in the neigbourhood of the 2nd strongest symmetry axis, on 7 images - 3rd, on 5 images - 4th and on 1 image - 5th (Table 1). We also analyzed the reasons of unsuccessful segmentation for all 22 images. On 18 images the symmetry axis passing through the dome was not detected or was weakly detected, due to too high perspective distortions, other dominant symmetries present in the image vast panorama or building reflection in water. Images, where the dome top touches the image top fail, since the segmentation algorithm [3] fails to deliver 1 sky segment, but ends up with 2 sky segments on each side of the dome. This leads to attachment of one of sky segments to the foreground mask, further resulting in either delivering the dome segment with having one sky segment on the background or failing to obtain the dome due to not overcoming the roundness threshold. Our database happened to contain 2 such images. 1 image failed because of clouds touching the dome, the strong edges of which segmentation method [3] failed to ignore. As a result they appeared as a part of the foreground mask, leading to analysis of a false facade contour. And on 1 image finding the leap row between the dome and the main building was unsuccessful owing high perspective distortions.

5 Conclusion

We presented a pioneer method for segmentation of building facade domes, as a milestone in a computer vision system for architectural style classification of building facades. Taking into account the visual features of domes, our methodology integrated bilateral symmetry detection, graph-based segmentation approaches and image analysis and processing technics. We proved experimentally that accurate dome segmentation is performed on images of facades of a variety of architectural styles, in complex scenes and under high perspective distortions. Future work in the scope of architectural style classification of facades includes segmentation and classification of other architectural elements.

References

1. Ali, H., Seifert, C., Jindal, N., Paletta, L., Paar, G.: Window detection in facades. In: Proc. of 14th ICIAP, pp. 837–842. Springer (2007)
2. Cornelis, N., Leibe, B., Cornelis, K., Gool, L.V.: 3d urban scene modeling integrating recognition and reconstruction. IJCV 78, 121–141 (2008)
3. Felzenszwalb, P.F., Huttenlocher, D.P.: Efficient graph-based image segmentation. IJCV 59(2), 167–181 (2004)
4. Guigues, L., Herve, L.M., Cocquerez, J.P.: The hierarchy of the cocoons of a graph and its application to image segmentation. PRL 24(8), 1059–1066 (2003)
5. Haugeard, J.E., Philipp-Foliguet, S., Precioso, F.: Windows and facade retrieval using similarity on graphs of contours. In: ICIP, pp. 269–272 (2009)
6. Li, Y., Crandall, D., Huttenlocher, D.: Landmark classification in large-scale image collections. In: Proc. of IEEE 12th ICCV, pp. 1957–1964 (2009)
7. Lowe, D.G.: Distinctive image features from scale-invariant keypoints. IJCV 60(2), 91–110 (2004)
8. Loy, G., Eklundh, J.-O.: Detecting Symmetry and Symmetric Constellations of Features. In: Leonardis, A., Bischof, H., Pinz, A. (eds.) ECCV 2006. LNCS, vol. 3952, pp. 508–521. Springer, Heidelberg (2006)
9. Mathias, M., Martinovic, A., Weissenberg, J., Haegler, S., Gool, L.V.: Automatic architectural style recognition. In: Proc. of the 4th International Workshop on 3D Virtual Reconstruction and Visualization of Complex Architectures. International Society for Photogrammetry and Remote Sensing, Trento, Italy (2011)
10. Recky, M., Leberl, F.: Window detection in complex facades. In: Proc. of 2nd EUVIP, pp. 220–225 (2010)
11. Recky, M., Leberl, F.: Windows detection using k-means in cie-lab color space. In: Proc. of 20th ICPR, pp. 356–360 (2010)
12. Shalunts, G., Haxhimusa, Y., Sablatnig, R.: Architectural Style Classification of Building Facade Windows. In: Bebis, G., Boyle, R., Parvin, B., Koracin, D., Wang, S., Kyungnam, K., Benes, B., Moreland, K., Borst, C., DiVerdi, S., Yi-Jen, C., Ming, J. (eds.) ISVC 2011, Part II. LNCS, vol. 6939, pp. 280–289. Springer, Heidelberg (2011)
13. Shalunts, G., Haxhimusa, Y., Sablatnig, R.: Classification of gothic and baroque architectural elements. In: Proc. of the 19th IWSSIP, Vienna, Austria, pp. 330–333 (2012)
14. Snavely, N., Seitz, S.M., Szeliski, R.: Photo tourism: exploring photo collections in 3d. ACM Transaction on Graphics 25, 835–846 (2006)
15. Wenzel, S., Drauschke, M., Föstner, W.: Detection of repeated structures in facade images. Pattern Recognition and Image Analysis 18(3), 406–411 (2008)
16. Zhang, W., Kosecka, J.: Hierarchical building recognition. Image and Vision Computing 25(5), 704–716 (2004)
17. Zheng, Y.T., Zhao, M., Song, Y., Adam, H., Buddemeier, U., Bissacco, A., Brucher, F., Chua, T.S., Neven, H.: Tour the world: building a web-scale landmark recognition engine. In: Proc. of ICCV and PR, pp. 1085–1092 (2009)