Generating Occlusion-free Textures for Virtual 3D Model of Urban Facades by Fusing Image and Laser Street Data

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Abstract

In this paper we present relevant results of a work in progress[1] that deals with the texturing of 3D urban facade models by fusing terrestrial multi-source data acquired by a Mobile Mapping System (MMS). Some of current 3D urban facade models often are textured by using images that contain parts of urban objects that belong to the street. These urban objects represent in this case occlusions since they are located between the acquisition system and the facades. We show the potential use of georeferenced images and 3D point cloud that are acquired at street level by the MMS in generating occlusion-free facade textures. We describe a methodology for reconstructing texture parts of facades that are highly occluded by wide frontal objects.

Index Terms: I.4.8 [Image Processing and Computer Vision]: Scene Analysis—Sensor Fusion; I.4.7 [Image Processing and Computer Vision]: Feature Measurement—Texture; H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, Augmented, and Virtual Realities

1 Introduction and Problem Statement

Nowadays, we observe active developments of Mobile Mapping Systems equipped with direct georeferencing devices. These MMS's allow the acquisition of multi-source raw data at street level and provide novel perspectives for enhancing the quality of the terrestrial urban model at wide scale.

In the literature, some researches have been conducted for the generation of facade model from terrestrial data. Notably, a classic facade representation is given by georeferenced quadrilaterals (e.g., [1], [3]). Here, our work deals with the generation of facade textures adapted at this frequent level of representation (planar models). More precisely, our interest is focused on the texturing of occluded facade since it constitutes a major challenge for producing complete virtual 3D facade models. This problem is particularly visible in the urban environment in reason of the quantity, the density and the consistency of the street objects.

Indeed, the facade models often are textured by a mapping with frontal or oblique views of buildings (e.g., [4]). However, these images can be strongly occluded as shown in Figure 1(a). First questions that come to mind in case of an automatic occlusion-free facade texturing can be as follows: **How could we detect facade occlusions in street images? How could we recover occluded facade image parts and reconstruct a complete occlusion-free texture?** (result shown in Figure 1(b)) In the next section, we will propose a methodology for answering parts of these open questions.

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(a) Frontal image of a facade strongly occluded by tree foliage.

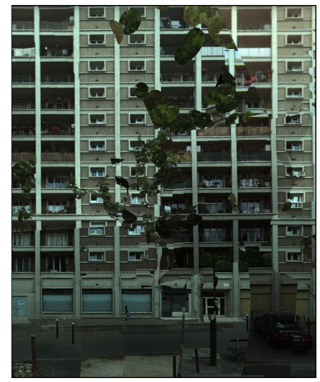

(b) Multiview reconstructed occlusion-free facade texture

Figure 1: Occlusion-free facade texture reconstructed from a set of multiple facade images acquired by the MMS in displacements along the street. Figure 1(a) depicts a worm's-eye view that has been used in the occlusion-free texture computation. It illutrates the problem complexity in case of direct facade texturing.

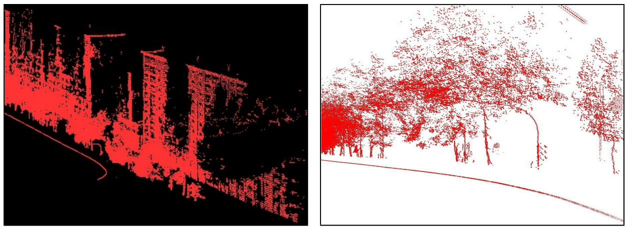
2 Proposed Approach and Results

The proposed methodology employs the data fusing and is in part inspired by [2]. Here, georeferenced terrestrial laser data have been acquired by a MMS conjointly to a set of calibrated and georeferenced multi-view facade images. The key idea is to exploit the set of optical images acquired by the MMS in order to produce image transfer that is not affected by occluding objects. Since the view point of the MMS will change, one can hope that the occluded parts of a given facade in a set of images will be visible in another set.

2.1 Detecting Occuding Objets of Urban Street Facades

The occluding objects that are observed in the images of facades can be detected in the laser data at facade level in the sense that the laser beam is intersected by intermediary urban occluding objects located between the point of acquisition and the previously estimated facade planes such as the vegetation or streetlights. The missing facade laser parts can be qualified as laser shadows and this effect is strongly visible in case of occluding trees since they clearly cause ecliptic holes in the facade point cloud (see Figure 2(a)).

Since the facade plane can be estimated as mentioned earlier, the set of 3D point located in a neighbouring defined by the facade plane and the vehicle trajectory is retained. Then, the retained set of points could also contain points of the ground according to the sensor orientation. The points of ground can be detected and removed



(a) Street point cloud with significant objects occluding facades. (b) Subset of occluding points detected in front of the facade planes.

Figure 2: Sets of points acquired by the MMS in displacements along the street (perspective views). The subset of points in Figure 2(b) has been extracted from the set of points shown in Figure 2(a). The curved line corresponds to the vehicle trajectory.

by examining their altitude since the facade bottom delimitation is assumed to be known. Also, accumulation maps such as described in [3] can inform on the presence of the occluding objects. Here, the sensor has been specifically oriented in order to avoid the acquisition of ground points. If the quantity of retained points is sufficiently high, then the points are extracted and labelled as occluding points. A result of the occluding point extraction is shown in Figure 2(b).

2.2 Generating Masks Hiding the Occluding Objects

(a) (b) (c) (d)

Figure 3: (a) and (b) show samples of the multi-view image set. Occluding points previously retained have been projected on. These points are faintly visible here except by zooming but (c) and (d) respectively illustrate the corresponding masks generated by using conventional techniques of mathematical morphology.

A set of facade images has been associated to each facade according to a visibility criterion based on the size of the image intersection with the projected 3D facade delimitations (georeferenced). Then, the detected 3D points that occlude the facades are projected onto the respective set of facade images that have been matched to the facade planes (zoom samples shown Figures 3(a) and 3(b)). We recall that the acquired images are calibrated and the whole of image and laser data are georeferenced. The 3D points are used to generate binary images (masks) with a size identical to the original acquired images (1080×1920). Then, these associated binary images undergo fundamental morphological operations as follows:
1. Amplifying Covering of Occlusions and Filling Gaps: A morphological dilation is applied onto each projected point in the binary images. The dilation of the binary image $\mathscr{B}$ by the structuring element (i.e., kernel) K_d can be defined by:

$$\mathscr{B} \oplus K_d = \{x \in \mathscr{B} \mid K_{d_x} \cap \mathscr{B} \neq \emptyset\} \quad (1)$$

where dilation of $\mathscr{B}$ by K_d can then be understood as the set of points x covered by K_d when the center of K_d (noted K_{d_x}) moves inside objects of $\mathscr{B}$. Here, K_d is a large circular Kernel (radius of 50 *pixels*) that operates

(a) (b)

Figure 4: (a) and (b) show generated images (stretched) with occluding objects removed (i.e., image segmentation).

onto the totality of the binary image—scattered single points.

2. Adjusting the Masks to the Occlusion Size: A morphological erosion is then applied to the dilated images with a small circular Kernel in order to reduce the amplified size of the masks at the contours. The eroding of the binary image $\mathscr{B}$ by the structuring element (i.e., kernel) K_e can be defined by:

$$\mathscr{B} \ominus K_e = \{x \in \mathscr{B} \mid K_{e_x} \subseteq \mathscr{B}\} \quad (2)$$

where the erosion of $\mathscr{B}$ by K_e can then be understood as the locus of points reached by the center x of K_e (noted K_{e_x}) when K_e moves inside $\mathscr{B}$. Here, K_e is a small disk (radius of 20 *pixels*) that operates onto the totality of the previous dilated binary image.
Here, the resulting binary masks are shown in Figures 3(c) and 3(d).
3. Reducing the edge effect caused by the Kernel patterns: Finally, a smoothing is applied to the contours of the masks in order to reduce the artificial visual effect (non-elegant) caused by the accumulation of circular Kernel patterns. In this way, the rendering of a mosaicking with facade images by subtracting the masks, i.e. reconstructed textures will be not too affected at the multiple recovered junctions (see results in stretched Figures 4(a) and 4(b)). By attentive examination of the Figure 1(b), certain mask junctions are curves and the kernel shapes are not directly visible.

Ortho-image of facade images (with masks) are generated. Finally, a raw mosaicking is achieved by overlapping all the processed facade images subtracted of the masks of occluding objects.

3 Conclusion and Future Works

This methodology fuses laser raw data and multi-view images and exploits fundamental image processing techniques for masking facade occlusions. Although a raw mosaicking is applied in the final stage, we observe in Figure 1(b) that the employed technique is able to extend the conventional workflow of occluded texturing (e.g., [4]). The observed results have been produced from a real set of multi-source urban street raw data. Next stages will be to improve the mask geometry (occlusion covering) and the texture radiometry (image equalization) as well as to optimize the number of images employed in the mosaicking method (set of problems close to the panoramic generation process).

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