# HOLE-FREE TEXTURE MAPPING BASED ON LASER REFLECTIVITY

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**ABSTRACT**

For creating a three-dimensional (3D) model of a real object using a laser scanner and a camera, texture mapping is an effective technique to enhance the reality. However, in case that the positions of the camera and the laser scanner differ from each other, some texture-less regions (holes) may exist on the object surface where the appearance information is missing due to the occlusion or out-of-sight of the camera. In this paper, we propose a new texture completion technique utilizing laser reflectivity for hole-free texture mapping. The laser reflectivity, which denotes the power of a reflected laser light/pulse, is obtained as by-product of the range information at laser scanning. Since the laser reflectivity captures the appearance property of the target as a camera image, it is reasonable that the regions with similar reflectance properties have similar color textures. Based on this idea, texture information in these holes is copied and pasted from the other texture regions according to the similarity and the order determined by the texture and laser reflectivity. To verify the performance of the proposed technique, we carried out texture completion experiments in real scenes.

***Index Terms***— Texture completion, Reflectance image, Texture mapping, Laser scanner

## 1. INTRODUCTION

In recent years, 3D geometric modeling of real-world objects with laser scanners has become very popular and widely used in many areas, such as robotics, landscape surveying, digital archive of cultural heritages[1], and so on. Once a 3D geometric model of a target object is obtained, a more realistic virtual model can be created by adding color information to the surface of the geometric model. For photo-realistic modeling, texture mapping is an effective technique and still remains one of important research topics in Virtual Reality (VR). In texture mapping, appearance information is added to a 3D geometric model by mapping texture images on the surface. However, in case that a 3D geometric model and a texture image are acquired from different viewpoints through two independent sensors such as a laser scanner and a digital camera, some texture-less regions (holes) may exist on the object surface where the appearance information is missing due to the occlusion by obstacles or out-of-sight of the camera (Fig.1).

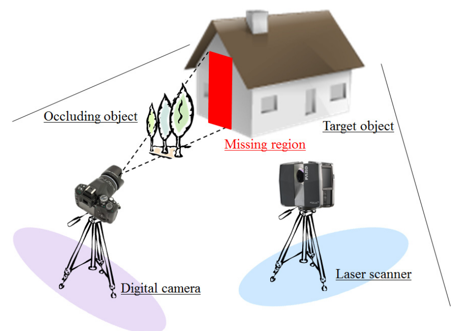



**Fig. 1**. In case that the positions of the camera and the laser scanner differ from each other, some texture-less regions (holes) may exist on the object surface where the appearance information is missing due to the occlusion or out-of-sight of the camera.

For hole-free texture mapping, it is necessary to copy or synthesize a proper texture image in the holes from the other regions or other camera images. Boehm[2] proposed a simple texturing method by capturing multiple texture images from different viewpoints to suppress occluded regions. Ortin et al.[3] proposed a similar technique employing the information of adjacent images. These methods, however, reconstruct a virtual texture from multiple images taken from different viewpoints by assuming a planar target object and calculating a homography matrix between images. Moreover, the quality of the synthesized texture depends on how proper images are taken from different points of view.

On the other hand, Kawai et al.[4] proposed a completion method that restores the shape and the color of the object with geometrical and photometrical holes simultaneously. They selected proper regions with geometrical or photometrical information from other parts of the object by minimizing energy functions based on the similarities of geometries and textures. However, if the resolution of the shape and the color differ, blurry artifacts are appeared since this technique is a point-based approach.

Meanwhile, texture (or shape) inpainting are quite effective techniques to solve this problem. Komodakis et al.[5] proposed a patch-exemplar based method that solves texture inpainting as a discrete global optimization problem utilizing a belief propagation to avoid undesirable artifacts. For proper inpainting, the order of the completion is also quite important. Criminisi et al.[6], Sun et al.[7], and Li et al.[8] developed image completion techniques that determined the order of the completion by extending some curves or lines from a known region to an unknown region manually or automatically. Although these methods offered some excellent results, unfavorable discontinuities are still remained due to the geometrical and photometrical complexity of the target.

In this paper, we propose a novel hole-free texturing technique utilizing laser reflectivity. The laser reflectivity, which denotes the power of a reflected laser light/pulse, is obtained as by-product of the range information at laser scanning. By aligning the reflectivity according to the order of scanning, a reflectance image, which contains rich appearance information of the target surface, is obtained. This image is quite similar to a camera image since each pixel indicates the intensity on the surface of the targets under a single-frequency light source. Owing to this similarity, we first determine a completion order of a texture image in an occluded region according to the reflectance value, and then synthesize the partial texture by copying and pasting a proper texture patch from the other regions with similar color and laser reflectivity.

The rest of this paper is organized as follows. In Section 2, we describe the texture completion technique, including the details of reflectance images, the generation of database patches, the definition of completion priority based on the laser reflectivity, and the completion algorithm. In section 3, we show some experimental results to verify the effectiveness of the proposed method. In section 4, we conclude this paper and mention the future work.

## 2. PROPOSED METHODOLOGY

### 2.1. Reflectance image

A laser scanner (A time-of-flight range sensor) obtains a range value by measuring the round-trip time of a laser pulse reflected by a surface of a target object. Figure 2(a) shows an example of a range image acquired by a 3D laser scanner. On the other hand, most laser scanners provide the strength of the reflected light (reflectivity). Figure 2(b) shows a reflectance image that depicts reflectance values as a grayscale image. As mentioned above, an unique reflectance value is determined for each pixel in the range image. In other words, the range image and the reflectance image are precisely and fundamentally aligned.

(a) Range image (b) Reflectance image

**Fig. 2**. Range and reflectance images


(a) Scene 1 (b) Scene 2

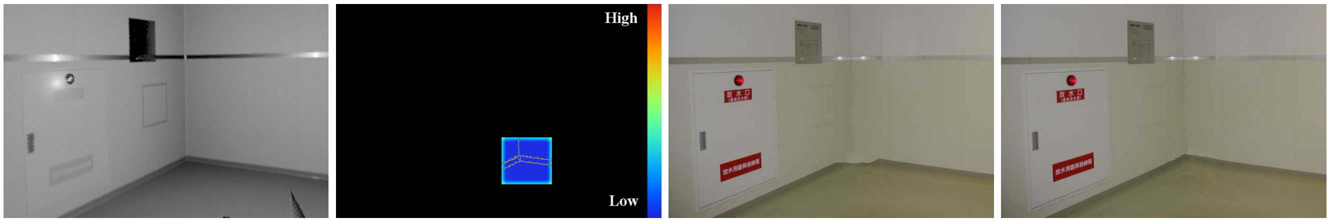
**Fig. 3**. Input textures

### 2.2. Texture completion utilizing laser reflectivity

In this section, we propose a new texture completion technique for a partially-occluded texture image, which extends patch-based completion techniques[5][6][7][8] to a reflectance image. In this paper, we assume that the texture image is aligned to the geometrical model precisely beforehand[9]. Our first step is generating a database of small image patches from non-occluded regions in the texture image. We define the region of occluding objects $\Omega$ manually so that the rest of the texture image is specified as a source region $\Phi$. Next, we determine the completion order (priority) of occluded region $\Omega$ taking into account structures in a reflectance image. Finally, we calculate the similarity between example patches in the database and the query patch centered at the top-prioritized pixel in $\Omega$, and complete the texture image copying the most similar database patch to the missing region.

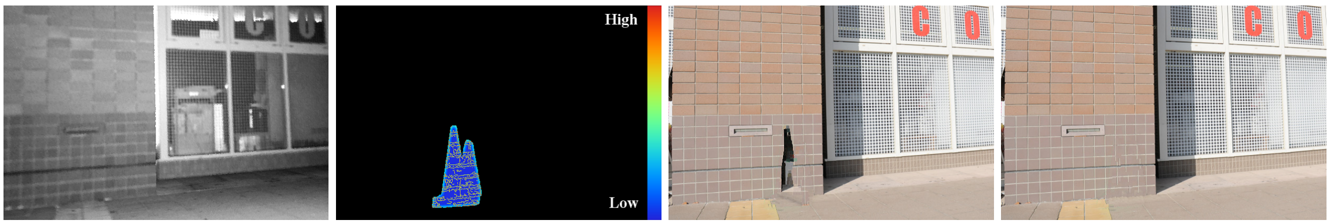
#### 2.2.1. *Generation of database patches*

At the beginning of the proposed technique, we divide a input texture image $I$ into a missing region $\Omega$ and a source region $\Phi(=\bar{\Omega})$ manually(Fig.3(a)(b)), where the former is supposed to have only reflectivity and the latter is supposed to have reflectivity and texture. Next, we create a example patch consisting of $k \times k$ pixels centered at a pixel in $\Phi$, and construct a database $D$ for all pixels in $\Phi$. Note that we discard patches including pixels in the missing region. Moreover, each patch holds not only partial texture image but also the corresponding reflectance image, and both information describe the characteristic of each example patch.




(a) Reflectance image (b) Priority map (c) Completed texture without reflectance image (d) Completed texture with reflectance image

Experimental result (Scene 1)




(e) Reflectance image (f) Priority map (g) Completed texture without reflectance image (h) Completed texture with reflectance image

Experimental result (Scene 2)

**Fig. 4**. Texture completion results

#### 2.2.2. *Completion priority based on laser reflectivity*

A noteworthy fact of image inpainting is that the completion order significantly affects the quality of the restored image[5][6][7][8]. Inspired by these researches, we define ”Priority map”, shown in Fig.4(b)(f) utilizing reflectivity. Since reflectance images have appearance information of the target objects, the structures of the scene can be extracted by detecting edges in the reflectance image. By applying Canny filter to the reflectance image, the priority is calculated as follows:

$$Priority(m) = \left\{ \frac{1}{k^2} \sum_{p \in N(m)} M(p) \right\} + C(m) \tag{1}$$

$$M(p) = \begin{cases} 1 & (p \in \Phi) \\ 0 & (otherwise) \end{cases}$$

Where, $m$ denotes a pixel in the missing region $\Omega$, $N(m)$ denotes a patch with $k \times k$ pixels centered at pixel $m$, and $C(m)$ is a value of pixel $m$ in the canny-filtered reflectance image. According to $M(p)$, the pixel $m$ on the boundary between the source region $\Phi$ and the missing region $\Omega$ has high priority. Furthermore, when the pixel $m$ is located on a structural edge in the canny-filtered reflectance image, the priority becomes higher.

#### 2.2.3. *Completion algorithm*

We complete the deteriorated texture image by copying the most similar example patch to the missing region. The similarity between a query patch $q$ centered at the top-prioritized pixel in $\Omega$ and one of database patches $p$ is calculated based on texture and reflectivity as follows:

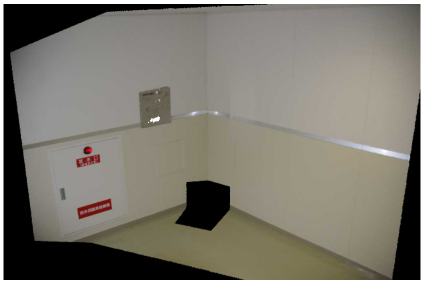
$$Similarity(p, q) = \sum_{p \in D} \{SSD(T_p, T_q) + \alpha SSD(R_p, R_q)\}^{-1} \tag{2}$$

$$SSD(I, J) = \sum_{u=0}^{k} \sum_{v=0}^{k} \{I(u, v) - J(u, v)\}^2 \tag{3}$$

Where, $T_p$ and $R_p$ denote the texture and reflectance image belonging to patch $p$, and $\alpha$ is a gain parameter. Note that we synthesize a reflectance image taken from the viewpoint of the texture image by interpolating the reflectivity on 3D points (Fig.4(a)(e)). The best patch $b$ for the query patch $q$ is determined by finding the patch in $D$ that maximizes the similarity, and complete the missing region in $q$ by copying the texture image of $b$.

## 3. EXPERIMENTS

This section introduces the results of texture completion experiments. Range and reflectance images are captured by a laser scanner (SICK, LMS151) and a turn table. The size of these images is $760 \times 1135$ pixels. Texture images are taken by a digital camera (Nikon, D300) and registered on the corresponding 3D geometric models[9]. We set parameters as $k = 15$, $\alpha = 1.0$ in the first experiment, and $k = 13$, $\alpha = 0.7$ in the second experiment.



(a) Original texture

(b) Completed texture
without reflectance image

(c) Completed texture
with reflectance image

Texture mapping (Scene 1)


(d) Original texture


(e) Completed texture
without reflectance image


(f) Completed texture
with reflectance image

Texture mapping (Scene 2)

**Fig. 5**. Texture mapping results

At first, we carried out the preliminary experiment in a simple situation shown in Fig.3(a). In this experiment, we cut out a part of the input texture image and attempted to restore the missing region. Fig.4(a)(b) show a reflectance image and a priority map. Fig.4(c)(d) show the completion results without and with the reflectance image. By taking into account a property of the reflectance image, our proposed technique successfully filled in the missing region compared with the conventional technique. Textured 3D models of Scene 1 are shown in Fig.5(a)-(c).

Next, we addressed the experiment in a more complex scene shown in Fig.3(b) where an obstacle occludes the wall and the texture behind it cannot be seen. Fig.4(e) shows the reflectance image from the same viewpoint of the texture image, and the completion order is determined by considering the structures of the reflectance image as shown in Fig.4(f). The completion results after applying the conventional technique and the proposed technique are shown in Fig.4(g)(h) respectively. 3D geometric models of Scene 2 after applying texture mapping are shown in Fig.5(d)-(f). As shown these figures, our proposed technique outperformed the conventional technique which caused some artifacts. However, the proposed technique also produced partial discontinuous textures, especially in a vertical direction. The reason why these artifacts occurred was that sufficient appearance information in the reflectance image could not be acquired due to the low resolution of the laser scanner.

### 4. CONCLUSION

In this paper, we proposed a new texture completion technique for texture mapping utilizing laser reflectivity. The proposed technique is able to generate the texture image in an occluded region of the 3D geometric model accurately by prioritizing the completion order.

In the future, we will improve the proposed technique so that it works well even with a low resolution reflectance image. Furthermore, we will extend our proposed method and generate the entire texture of a 3D geometric model from a single picture.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