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무인항공영상을 이용한 교량 상판의 텍스처 매핑

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Texture Mapping of a Bridge Deck Using UAV Images

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[요 약]

도로의 상태를 관측하는 많은 방법의 하나로 무인항공기 영상이 사용된다. 무인항공기 영상 파일이 너무 크고, 불필요한 정보가 많을 때, 특징적 정보를 압축한 텍스처 추출 기법이 사용된다. 특히 무인항공기 영상을 이용한 3차원 시뮬레이션에서 많은 양의 데이터가 입력되기 때문에 텍스처 추출이 중요하다. 본 논문에서는 교량의 고해상 영상을 얻기 위하여 무인항공기 영상으로부터 텍스처 추출 방법을 제시한다. 제안된 방법은 3단계로 이루어진다. 첫째, 브이월드 데이터베이스에서 3차원 교량 모델을 취득한다. 둘째, 기하보정 정보를 가진 무인항공기 영상에서 텍스처를 추출한다. 셋째, 개별 영상에서 추출된 텍스처를 융합한다. 본 연구 결과는 브이월드 텍스처를 고해상 영상으로 갱신하는 데 사용될 수 있다.

[Abstract]

There are many methods for surveying the status of a road, and the use of unmanned aerial vehicle (UAV) photo is one such method. When the UAV images are too large to be processed and suspected to be redundant, a texture extraction technique is used to transform the data into a reduced set of feature representations. This is an important task in 3D simulation using UAV images because a huge amount of data can be inputted. This paper presents a texture extraction method from UAV images to obtain high-resolution images of bridges. The proposed method is in three steps: firstly, we use the 3D bridge model from the V-World database; secondly, textures are extracted from oriented UAV images; and finally, the extracted textures from each image are blended. The result of our study can be used to update V-World textures to a high-resolution image.

색인어 : 무인항공영상, 텍스처 추출, 3D 모델, 브이월드
Key word : UAV images, Texture extraction, 3D Model, V-World

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Ⅰ. Introduction

To obtain information in surveillance, environmental monitoring and management [1]-[4], an unmanned aerial vehicle (UAV) has been an efficient and effective tool. Although UAV images have a lot of necessary information, there are also unnecessary and redundant information, which increases the costs and computation times. Texture extraction is used to extract the adequate information and remove redundant ones. The regions of user interest can be post-processed after texture extraction and, in addition, the object classes can be identified and quantified by texture analysis.

In recent years, the maintenance of civil structures using UAV images has been widely studied [5]-[6]. [7] investigated the usability of UAV systems for monitoring and maintaining bridges and structures. [8] introduced a UAV-based digital imaging system to derive a three-dimensional (3D) surface model over a road distress area for distress measurement. [9] demonstrated that red-green-blue cameras on UAVs could detect, from varying distances, cracks of sizes comparable to those sought in visual inspections. [10] provide deformation measurements, change detection, and crack pattern identification from a representative infrastructure mockup with several simulated damage scenarios using color images obtained by UAVs. [11] presented and compared the most relevant works in terms of UAV potential to lead to automatic construction monitoring and civil infrastructure condition assessment. [12] developed a prototype web-based tool named BridgeDex. The spatial and temporal information for each image are attributed and then linked with other bridge metadata, including inspection notes, design drawings, and possible destructive and nondestructive test results.

In order to create a realistic 3D model, a study of texture extraction and mapping of terrain and facilities has also been progress in this area. [13] designed and implemented an algorithm for 3D reconstruction of city buildings from multiple images using a single UAV. From the oblique photo, they could derive various types of information, such as the height of every main part and small part, the top texture, and the side texture. [14] presented a flexible texture blending technique for the generation of photorealistic textures from multiple optical sensor resources in creating large-scale (city-size) scene models. [15] exploited UAV for capturing images of a building of interest from multiple different perspectives using a Falcon 8 octocopter from Ascending Technologies, which resulted in a 3D model of the building. [16] presented a method for model-to-image matching and texture extraction with the best texture selection procedure for thermal infrared image sequences and UAV images. [17] tested UAVs in a scientific test bed and earthwork of large infrastructure projects. They used a stepwise processing of the image collection: (1) align photos, (2) build geometry, and (3) build texture. [18] presented a methodology for co-registration of uncertain 3D building models with airborne oblique view images for a high-quality texture extraction.

There are also studies to build and utilize spatial information using V-World. [19] proposed a methodology to construct 3D building models and textures to utilize existing resources V-World and a drone. [20] studied an object information database that can be organized with all the information on the BIM and GIS of facilities with V-World for the facility management practice.

In this study, we propose a method to utilize a drone image to extract the texture of a bridge model and compare it with the V-World texture using existing aerial photographs. It is expected that time series analysis will be possible when the use of drone is extended to the maintenance of bridge in the future.

Ⅱ. Texture Composition of a Bridge Deck

2-1 Mathematical fundamentals of Photogrammetry

In photogrammetry, there are multiple coordinate systems in which measurements can be made [21]. These spaces need to be interconnected in order to obtain reliable 3D information. The image coordinate system has a two-dimensional image-based reference system of the Cartesian coordinates *x* and *y*. A camera coordinate system is defined by the perspective center *O'* of the camera. The *x* and *y* axes are parallel to the image sensor and the *z* axis approximately coincides with the optical axis. The model coordinate system is a 3D coordinate system (*x, y, z*) that is used to describe the relative position and orientation of two or more images. The object coordinate system is used for every spatial Cartesian coordinate system (*X, Y, Z*) defined by reference points on the object.

The pixel coordinate system relates to the camera coordinate system by an interior orientation process. The interior orientation is given by Eq. (1):

$$\begin{bmatrix} x' \\ y' \\ z' \end{bmatrix} = \begin{bmatrix} x_p' - x_0' - \Delta x' \\ y_p' - y_0' - \Delta y' \\ -c \end{bmatrix} \tag{1}$$

where x_p', y_p' is the coordinate of image point *P*, x_0', y_0' is the coordinate of the principal image point *H*, $\Delta x', \Delta y'$ are the axis-related correction values for imaging errors, and *c* is the focal length.

The exterior orientation process relates the camera coordinate system and objects coordinate system to each other. The position vector from the origin to the perspective center *O'* defines the spatial position of the image coordinate system. The orthogonal rotation matrix *R* defines the angular orientation in space. It is the resultant of three independent rotations ω, ϕ, κ about the coordinate axes *X, Y, Z*, respectively.

$$R=\begin{bmatrix} r_{11}\, r_{12}\, r_{13} \\ r_{21}\, r_{22}\, r_{23} \\ r_{31}\, r_{32}\, r_{33} \end{bmatrix} \quad (2)$$

$$x' = x_0' + z' \frac{r_{11}(X-X_0)+r_{21}(Y-Y_0)+r_{31}(Z-Z_0)}{r_{13}(X-X_0)+r_{23}(Y-Y_0)+r_{33}(Z-Z_0)} + \Delta x' \quad (3)$$

$$y' = y_0' + z' \frac{r_{12}(X-X_0)+r_{22}(Y-Y_0)+r_{32}(Z-Z_0)}{r_{13}(X-X_0)+r_{23}(Y-Y_0)+r_{33}(Z-Z_0)} + \Delta y'$$

With given parameters of exterior orientation, the direction from the perspective center *O'* of the image point *P'* can be transformed into an absolutely oriented spatial ray from the perspective center to the object point *P*. Once the position and orientation of the perspective center are determined, the object coordinates of image points can be calculated by the collinearity conditions (Eq. 4) using more than one image of the object. The initial position and orientation of images can be optimized using an iterative, alternate process until the optimization converges to a minimum solution.

2-2 Texture Mapping

Texture refers to the surface characteristics and appearance of an object, given by the shape, size, density, proportion, and arrangement of its elementary parts. Due to the significance of texture information, realistic texture feature extraction is a key function in various image processing applications such as remote sensing, 3D modeling, and content-based image retrieval.

Texture mapping of terrain and facilities is the process of applying the actual image to the target surface. In this study, the texture is extracted so that the actual drone image can be rendered on the bridge. The texture rendering takes as input a bridge, the recovered camera poses, and their associated images.

The bridge model is decomposed into their corresponding faces. In order to determine the optimal texture map for each face, the face's vertices are projected onto all drone images using the orientation information. When one or more vertices of each face is projected into the image area, the texture of each face is obtained from the region image. If we obtain more than one texture on a face, we combine these textures to get a composite texture. In this study, the composite texture was synthesized after a relative image-to-image registration of each texture. [22] proposed SIFT flow, a method to align an image to its nearest neighbors using matching densely sampled, pixel-wise SIFT features between two images. We used SIFT flow to perform pixel-wise precise registration of two images that are approximately co-registered. Additionally, the RANdom SAmple Consensus (RANSAC) algorithm is used to iteratively estimate parameters for the homography transformation from a set of corresponding match containing outliers [23].

2-3 Blending

Image blending is a final step and an important stage when creating a panoramic image. During texture mapping, the seams between the input images are generated for reasons such as differences in tone or projection, and moving objects. The blending techniques should produce seamless mosaics by compensating for existing exposure differences in component images without introducing blurring or ghosting. A final large image must be such that the transition from one image to another image is invisible [24]. There are several image blending methods that are used for image stitching to reduce the occurrence of unwanted artifacts; for example, Laplacian pyramid, alpha blending, gradient domain blending [25], exposure compensation [26], and path-finding algorithm [27]. We use the alpha blending method to create a composite texture. The alpha blending method was used to make the panorama smooth after the seamline was removed. The blended color can be obtained by combining the translucent foreground color and background color [28]. The value of the resulting blended color is given by the equation:

$$I=\alpha I_1 + (1-\alpha)I_2\,;\ \alpha=\frac{dr}{dl+dr} \quad (4)$$

where *dr* and *dl* are the distances from the pixel to image 1 and image 2, respectively, and I_1 and I_2 are pixel values. The range of α is from 0.0 to 1.0.

Ⅲ. Experiment and Results

3-1 The study areas and datasets

A dataset, containing 19 images as shown in Fig. 3, were tested. The dataset was acquired in 2017/4/20 using drone Phantom 4 Pro at an average altitude of 40 meters with approximately 80% forward overlap and 70% side overlap (Fig. 1 and Table 1). The Phantom 4 Pro with camera CMOS 24 mm focus length was used to acquire the images of size pixels. The images in the dataset cover the MadongIC Bridge from Yeosu city to GwangYang city, Korea. As shown in Fig. 2, the red circle represents the approximate location of the camera.

그림 1. 팬텀 4 프로 드론과 카메라
Fig. 1. Drone Phantom 4 Pro and Camera attached

표 1. 팬텀 4 프로 드론의 사양
Table 1. Drone Phantom 4 Pro specification

Aircraft		Camera	
Weight	1388 g	Sensor	1" CMOS, Effective pixels: 20 M
Max Speed	72 kph	Lens	FOV 84° 8.8/24mm, f/2.8 − f/11
Max Tilt Angle	42°	Image Size	5742×3648
Flight Time	30 mins	Photo	JPEG, DNG
Temperature Range	0° to 40°C	Video	MP4, MOV

그림 2. 팬텀 4 프로의 비행경로 계획
Fig. 2. Setup flight plan of Phantom 4 Pro before obtaining images

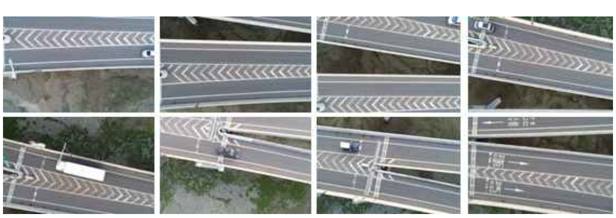


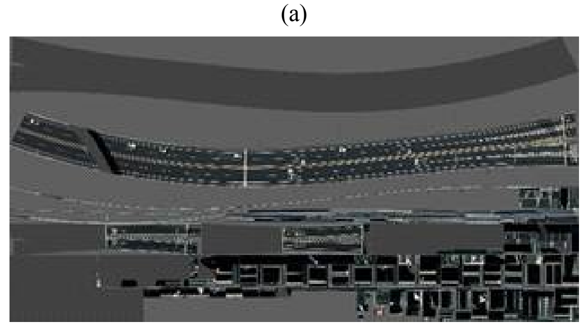
그림 3. 팬텀 4 프로 드론에 의하여 취득된 일부 영상
Fig. 3. Some images obtained by the Phantom 4 Pro drone

3-2 V-World Bridge Model

V-World map service (https://map.vworld.kr), an open platform for spatial information disclosure of the Spatial Information Industry Promotion Institute (https://www.spacen.or.kr), provides 3D models for buildings, bridges, and so on. Additionally, it provides the texture of the models using digital aerial images through Pictometry. Since it uses aerial photogrammetry, it is difficult to reflect changes in small scale units quickly, and there is the disadvantage of longer duration and high cost of updating the database.

We used the V-World's bridge model and texture to extract the drone image texture of the bridge. The V-World model and texture of the MadongIC bridge to be tested is shown in Fig. 4. The vertices of the bridge model have coordinate values in the TM Cartesian coordinate system, thus they can be used with existing spatial information. We selected the ground control points (GCP) from the bridge model to co-register the drone images.

(a)



(b)

그림 4. 마동IC교의 (a) 브이월드 텍스처 모델 (b) 텍스처 영상
Fig. 4. (a) V-World textured model and (b) texture image of MadongIC bridge

3-3 Texture Extraction Result

Prior to obtaining the texture of the images, the internal and external camera parameters need to be obtained. In this study, the Pix4D software was used to obtain the camera parameters of the

UAV images. Thereafter, we determined the test subdivision of the bridge model. As shown in Fig. 2, the test area for texture extraction is the top road surface of bridge junction.

Fig. 5 shows all of the images after the texture of each drone image was extracted. A total of 19 images, named Oimage 1 through Oimage 19, were used for the extraction. As can be seen in Fig. 5, some images are just black images, which are so because there is no bridge surface belonging to the face in the original drone image. Fig. 6 shows the face area projected onto Oimage 3 and Oimage 4 and the extracted textures.

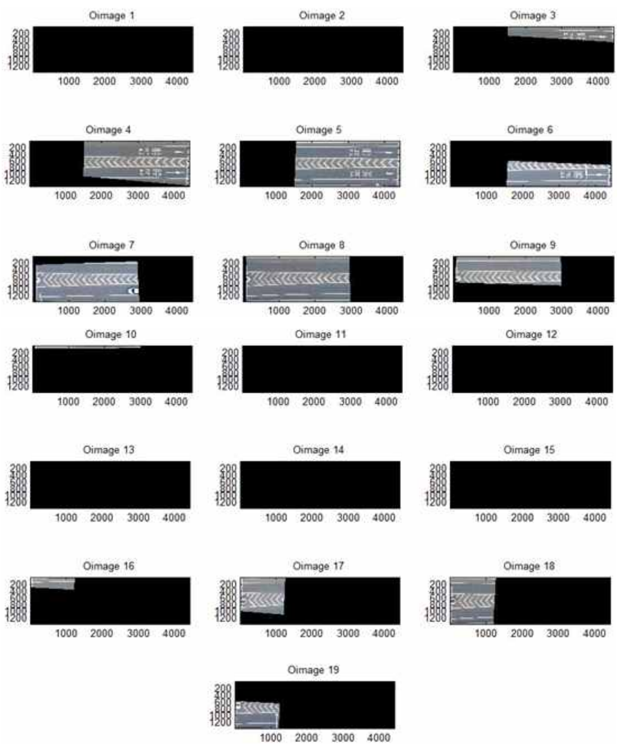


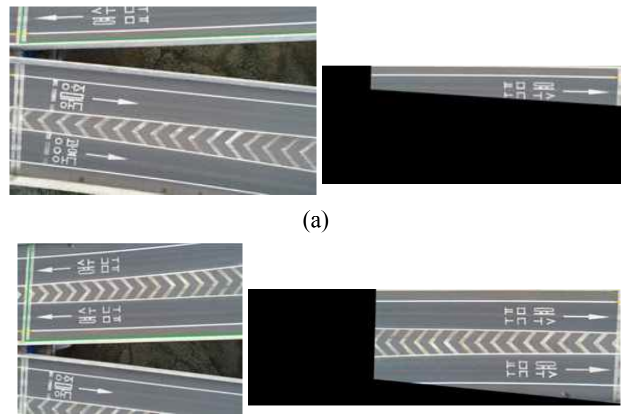
그림 **5.** 추출된 모든 텍스처

Fig. 5. All extracted textures

After the texture of each drone image was extracted, they were registered to obtain the single large image with a high-resolution. As can be seen in Fig. 7, with the composite image, we can obtain maintenance information of the road surface, such as a crack or concave area, which is difficult to obtain with original single UAV images.

Ⅳ. Conclusion

In this study, we presented texture contents for the road surface of MadongIC bridge. 3D models of V-World, which is built with open spatial data, were used to obtain the textures from drone images. We obtained high-resolution images, which were interpreted to suggest safety maintenance mechanisms for bridge surfaces. The result of our study can be extended to monitoring various infrastructure.

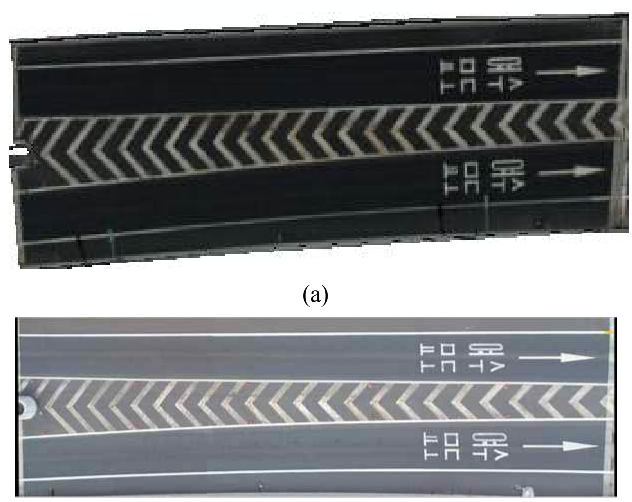


(a)

(b)

그림 **6.** Oimage 3과 (b) Oimage 4의 투영 영역(녹색)과 추출된 텍스처

Fig. 6. Projected area (in green) and extracted texture of (a) Oimage 3 and (b) Oimage 4



(a)

(b)

그림 **7.** 텍스처 비교; (a) 브이월드 텍스처, (b) 영상 보정 및 융합 후 합성 영상

Fig. 7. Comparison of textures; (a) V-World texture, (b) Composite image after registration and blending

In order to obtain the pose information of the drone images, the GCP is manually acquired. This limits the amount of image data for processing. In the future, it will be necessary to automatically match and register the new added images for the change detection and time series analysis of a bridge. It will be necessary not only to detect damages to bridges such as a crack, delamination, concave area, but also to utilize the drone images in a virtual environment [29]-[30].

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