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UAV-based automatic generation of high-resolution panorama at a construction site with a focus on preprocessing for image stitching

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ABSTRACT

As construction sites increase in size, it becomes more difficult for a manager to understand the status of the site on time. However, with the development of unmanned aerial vehicles (UAVs), it is possible to collect a large amount of visual data of the construction site in a short time. Using this data, a large-scale construction site can be monitored in a timely and frequent manner with computer vision technologies. This paper proposes a method to generate a panorama of a construction site by using an image stitching technique with a focus on preprocessing. To create high-quality panoramas, blurred frames of videos are filtered out, key frames are selected, and camera lens distortion is corrected. The proposed method produced a high-quality panorama of a construction site, which was evaluated by comparing it with an aerial photograph and the panorama produced by the existing image stitching technique. The proposed method is expected to help managers to easily identify various construction site conditions with the help of high-quality image data.

1. Introduction

Image processing has been widely studied for construction management applications. Examples of such applications include productivity analysis [1,2], safety management [3–5], facility condition assessment [6–9], and progress monitoring [6,10–12]. However, to automatically monitor a large construction site, more often than not, the entire site or a large portion of it needs to be captured in an image. The relative locations of important construction objects, such as materials, heavy equipment, and temporary structures, can only be well understood in the context of the entire site or a large portion of it. This argument is more valid considering equipment movement analysis, progress monitoring, or material tracking for a large-scale construction site. Thus, a methodology is needed to generate a high-resolution panorama that covers a large construction site for various management purposes.

Image stitching has been developed in the computer vision field for the past few decades [9]. There are some off-the-shelf software packages such as Image Composite Editor (ICE) [13], Photostitch [14], and Autostitch [15] that automatically create a panorama of the multiple images inputted by users. Although these software packages make it easy to conduct the image stitching process, they do not always produce high-quality panorama images. The quality of panorama images is dependent on many factors including overlap ratios between images, lens distortion, and the quality level of the input image itself. In general, effective preprocessing is required to turn raw images into a high-quality panorama.

Advancements in unmanned aerial vehicles (UAVs) enable the efficient collection of image information of construction sites [16,17]. UAVs equipped with a camera can collect images from various perspectives, unlike closed-circuit television (CCTV) cameras. However, using UAVs for construction monitoring is challenging. First, the enormous number of images taken on construction sites must be processed promptly to be meaningful for project management. Second, vibrations in UAVs caused by wind and unstable control of the aircraft are likely to result in the acquisition of low-quality images. Third, the continuous position changes of UAVs makes camera pose estimation difficult.

To address these issues, this paper suggests an automatic method of high-resolution image generation using UAV videos, with a focus on preprocessing, which consists of three modules: blur filtering, key frame selection, and camera correction. The blur filtering module filters out blurred images caused by the vibration of the UAV. The module for key frame selection chooses frames that contain important information from UAV videos by maintaining a constant overlap ratio. Third, the camera correction module corrects camera lens distortion for accurate matching between images. The preprocessed images go through an image stitching algorithm. An experiment involving a real subway construction site in Korea was conducted to evaluate the proposed method. The resultant panorama image of the construction site covered a large portion of the site with high-quality detail. The remaining part

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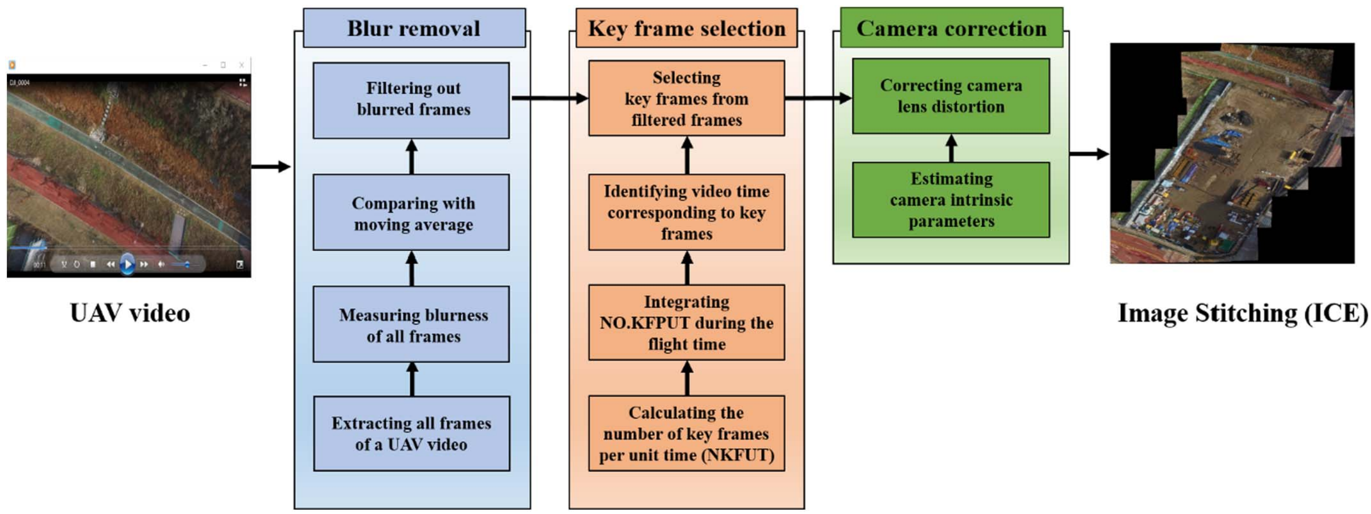

Fig. 1. Overview of proposed method.

of the paper includes literature review, methodology, and experiment. Finally, conclusions and recommendations are provided.

2. Literature review

Image stitching has been used in the construction industry mainly to visualize a structure for detecting specific anomalies (e.g., cracks, delamination, and fractures) or to visualize an entire presentation. Some of the studies used existing image stitching techniques as part of their research [7,18–21]. Adhikari et al. [7] stitched together images of cracked segments of bridges as preprocessing for detecting variations in the crack length and width. Klein et al. [18] stitched feature points for image-based 3D reconstruction to automate the updating of as-built documents. Li et al. [19] proposed a methodology to inspect the cracks of bridges using multiple image processing techniques. The detected crack images were stitched and presented as a surface panorama of the bridge substructure, and the locations of all cracks were represented in a panorama. Zhu et al. [20] also proposed a new method that used image stitching techniques to detect bridge columns in a bridge condition evaluation system. Jahanshahi et al. [21] used database technology and image stitching techniques to improve the inspection of structure quality.

On the other hand, some of the studies contributed to the further development of image stitching technologies for the construction industry [8,9,22,23]. Chaiyasarn et al. [8], Zhu et al. [9], and Lee et al. [23] improved image stitching technologies for the panoramic image of a tunnel by assuming the tunnel shape or rectifying the acquired images. Image rectification, which was a geometric correction to be represented in a plane image, was performed using the 3D surface geometry of the tunnel. Hsu [22] used a wavelet analysis to suggest an image registration algorithm for indoor and built environments.

UAVs with cameras have received attention as monitoring tools in the construction industry [10,24–28]. UAVs with high mobility and low cost are suitable for the regular monitoring of a large-scale construction project. Han et al. [10] presented a process using a UAV and 4D building information modeling (BIM) to automate construction progress monitoring. Construction site information saved in the BIM was used as a tool for path planning and navigation; thus, the UAV could autonomously collect and update the visual data. Gheisari et al. [24] evaluated and suggested potential applications of an unmanned aerial system (UAS) for the safety management of construction sites, based on real-time visual access to the job site environment. González-Jorge et al. [25] built a 3D model based on images captured by a UAV to monitor a breakwater. Siebert and Teizer [26] used a UAV to monitor an earthwork process by calculating the volume of the cut and fill area. Wen and Kang [27] implemented an augmented reality (AR) technology that integrates a virtual construction scene with an actual construction site scene captured by a UAV. Yeum and Dyke [28] used a UAV as a tool to automatically detect cracks for bridge inspection. As can be seen from the aforementioned studies, the utilization of UAVs with cameras has contributed to vision-based monitoring for the construction industry.

There have been some attempts to use both UAVs and image stitching techniques for facility monitoring. Ellenberg et al. [29] stitched red, green, and blue (RGB) and infrared (IR) images acquired from a UAV to identify bridge deck peeling. Eschmann et al. [30] used a UAV to acquire images and stitch them in order to observe the damage and cracks of the building. Although the approaches of Ellenberg et al. [29] and Eschmann et al. [30] advanced the body of knowledge because they combined image stitching techniques and UAVs. Luckily, they did not encounter problems in image stitching. However, in general, image stitching can cause many problems in its application to construction sites owing to unstable or uncontrollable operation of the UAV. Moreover, the use of video data acquired from UAVs can also be more difficult than still images. It is common to see failures in the stitching of video images obtained from UAVs during monitoring. Thus, this paper aims to contribute to vision-based construction site monitoring by proposing a UAV-based video image stitching method with a focus on preprocessing.

3. Methodology

3.1. Overview of the method

Fig. 1 describes the method for automatically changing a video of a construction site acquired with a UAV into a high-quality panorama that allows the entire construction site to be viewed at a glance. The first module identifies and removes frames that are blurrier than the surrounding frames. Based on the research of Crete et al. [31], to filter out frames over a certain threshold, we compared the blurriness of all frames with the moving average. The second module selects key frames to have a certain overlap ratio with the adjacent frames. By understanding the altitude and speed of the UAV, the module helps to uniformly express the entire area without assigning too many frames to a specific scene. The third module corrects the camera lens distortion of the key frames selected in the second module. The lens distortion of the key frames is corrected using the camera's intrinsic parameters estimated through the calibration of the camera attached to the UAV. The preprocessed images are used to create a high-quality construction site panorama using an off-the-shelf image stitching program. Details of the proposed method are described in Sections 3.2 to 3.5.