Development of a Monitoring System with Adjusted Multiple Images of Construction Site

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ABSTRACT

To improve the efficiency of construction site management, we developed a system that provides a three-dimensional model (3D model) textured with images of the status of working areas where construction work is under way. The system has already been applied to a construction site for evaluating its practical performance. The evaluation results confirm that the system is effective for assessing the status of working areas and reducing the manpower required for managing construction work.

1 Introduction

With the continuous development of information and communication technology (ICT), construction sites typically have many cameras of different types including network cameras, mobile cameras and action cameras, used for monitoring construction work and collecting information at building construction sites.

Also, cameras are now frequently used at construction sites to reduce the manpower required for managing construction work, as well as surveillance cameras to tighten the security. The increased use of video/voice application software for mobile communication terminals is also seen in the construction industry. Furthermore, high-level applications for image processing technology are continually being developed.

Accordingly, those involved in construction work have the following requirements for camera images:
a) Make it easier to grasp the geometrical relationship between images taken by multiple cameras installed throughout a large construction site.
b) Use the images to capture the path of workers and machines moving around the entire working area.
c) Measure the size of the subject captured by camera while removing the distortion caused by the geometrical relationship between the camera and subject.

To improve the efficiency of construction work management while responding to the above requirements, we developed a monitoring system (SSV) that uses multiple transformed images of working areas. This paper outlines the SSV and explains how it is effective for managing construction work based on the results of applying it to an actual working construction site.

2 Monitoring System

2.1 System Overview

The SSV, which creates orthographic projection images and provides construction work managers with a 3D model textured with the images, has three image processing functions: collection, reconstruction and viewing of images (see Fig. 1).

a) Collection
This function includes collecting images taken by cameras placed throughout the construction work site and transmitting the images through LAN (Local Area Network) and public Wi-Fi. The camera server in the system controls access to the cameras, browsing on the Web pages and transmission of images. The network, wired or wireless, for image transmission connects the camera server and image server.
b) Reconstruction
All images originally taken by each camera are stored in the image server and are converted automatically to transformed images based on a transformation matrix calculated by the image processing program.
c) Viewing
This function provides a 3D model textured with the transformed images, thereby simplifying the work for monitoring the entire working area. Construction work managers can manipulate the 3D model on any device to arbitrarily access selected areas.

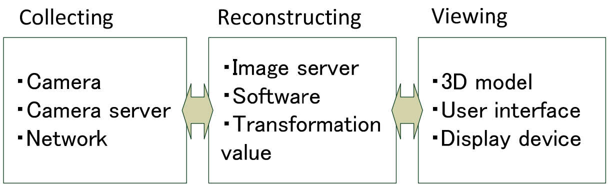

Figure 1: System components of the SSV

2.2 Image Collection

To collect images at a work site, the target subject is determined and then the camera stations and network wiring route are specified.

In planning the above, it is important to minimize the frequency of relocating the cameras during the construction period, since changing the camera stations takes considerable time and requires rerouting of the network cable if relocated scaffolds, formworks or other materials for temporary facilities are blocking the field of vision of the cameras.

Ideally, cameras should be set at the following four points: at the top of tower cranes, on external walls or scaffolds, inside the building and on temporary enclosures (see Fig. 2).

The camera on a temporary enclosure (Camera C1) captures images of the external walls together with the building structure, curtain walls and scaffolds, to monitor the progress of the construction work in the vertical direction. As it is difficult to lay cables across the construction site, public Wi-Fi should be used to transmit the images taken by Camera C1.

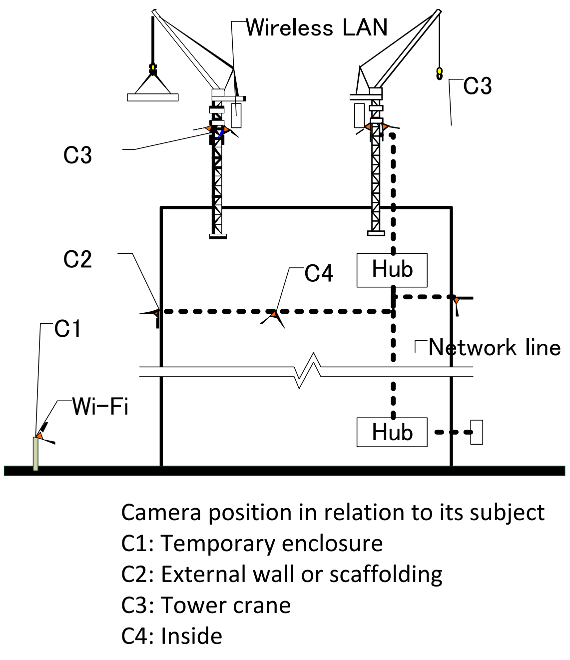

Figure 2: Typical camera positions and subjects

To monitor objects moving within the site, the camera on an external wall (Camera C2) takes images in and around the building including the entrance/exit gates, unloading yards, material storage areas and construction machines. Images taken by Camera C2 are transmitted through branch cables from the vertical main network route.

To monitor construction workers and materials, Camera C3 at the top of a tower crane captures the entire work area on the top floor. Images taken by Camera C3 are transmitted through cables connected to the vertical network line. If there are two or more tower cranes on the site, a wireless LAN should be used to improve the efficiency of cable laying work.

Camera C4 set inside the building captures images of hazardous areas, elevator halls and (cable) branching points, and transmits the images through an existing cable network, which is a simpler transmission method than that used by the other cameras.

In principle, the greater the number of cameras installed, the greater the number of images collected. However, it is important to limit the number of cameras to within the capacity of the transmission network.

2.3 Image Reconstruction

The images originally taken by camera are transformed by software into orthographically projected images.

However, the images are affected by projection distortion, for example, a square drawn on a slab looks like a trapezoid when captured at an angle (see Fig. 3). Planar projection transformation (hereinafter “homography”) transforms the apparently trapezoidal image into a square image. The transformed image (b) is a reproduction having the actual aspect ratio of the square object on the slab. However, it is important to note that projection distortion is not corrected for columns or walls above/below the slab surface that have been subjected to homography.

Homography applies 3×3 matrix transformation to all pixels in the original image. [1] As it consists of eight unknowns, the transformation matrix is obtained from the coordinates of four pairs of correlated points, with one party in each pair being one of the four corners of the pseudo-trapezoid in the original image, while the other party in the same pair is one of the four corners of the authentic square in the transformed image.

In the case of multiple transformed images for a working area, they can be jointed while overlapping in part to make a composite transformed image to cover the entire working area by means of parallel translation alone, as each component image has been subjected to homography for transformation that excludes rotational/in-scale distortion, thereby making it possible to determine the direction/distance of parallel translation based on two points shared in common (see Fig. 4).

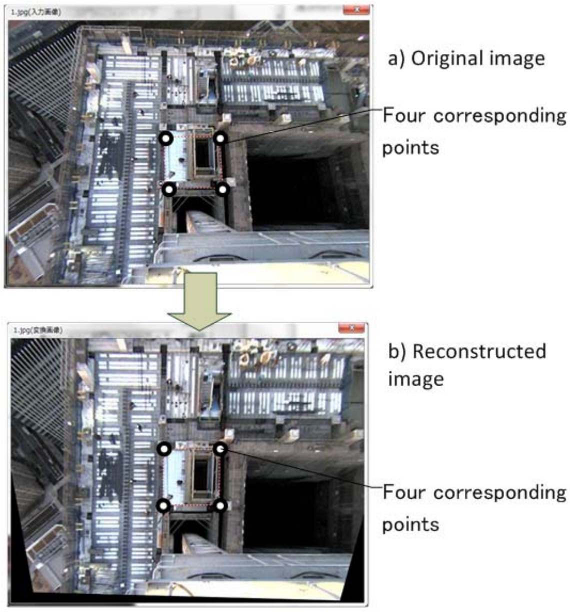

Figure 3: Typical camera positions and subjects

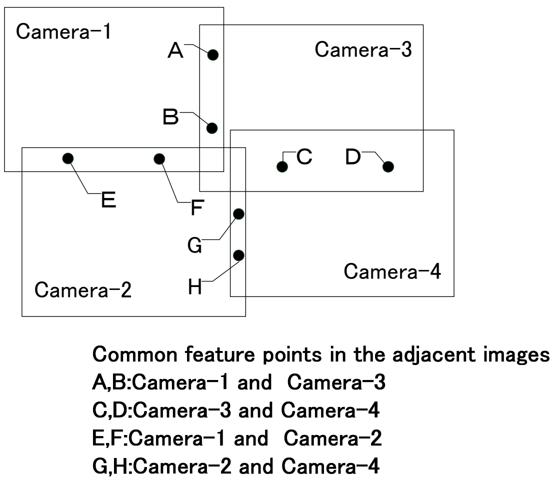

Figure 4: Typical camera positions and subjects

2.4 Image Viewing

To simultaneously monitor the status of multiple work areas, all the images are normally displayed in line on a computer screen, and the construction work manager is required to assess the status of the construction site while envisaging the geometrical relationship between the images. However, if too many cameras are deployed, it will be difficult to unmistakably identify the spot currently being captured by each camera. Therefore, to help construction work managers intuitively recognize the geometrical relationship between the different images, we developed a 3D model to display the transformed images in a virtual space.

As this method uses homographically transformed images, texturing the 3D model by pasting the images can be performed simply by specifying the pasting point. Figure 5 shows the relationship between the camera observation point on the 3D model and that for the transformed image. Whereas the camera for the transformed image is fixed in front of the 3D model image pasting surface, the camera in the 3D model space can observe the model at an arbitrary position from an arbitrary observation point. Construction work managers can view the 3D model as a whole from a remote observation point in the same way as for typical 3D models and assess the status of different spots on the 3D model in detail from the points nearby.

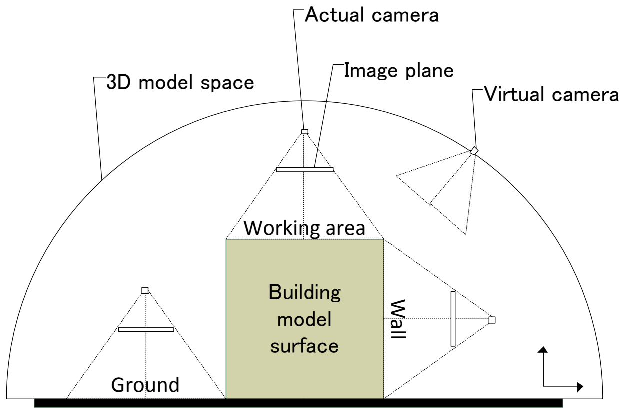

Figure 5: Components of 3D model viewing

3 Implementation Evaluation

To perform an implementation evaluation test, we applied the SSV to the construction work of a high-rise building in Tokyo, having a standard floor area of approx. 1,800 m^2 and an eaves height of approx. 180 m. At the construction site where two self-climbing tower cranes were installed, we used the SSV to capture images of the work areas at the upper portion of the building.

To capture the working areas and create the transformed images, we used four cameras for the SSV, with two installed on one tower crane and the other two on the other crane, in the direction of the slabs (see Fig. 6). The images were transmitted mainly through a wired network. A wireless network was used between the tower cranes and also between the building and a temporarily installed office where wiring was difficult. Figure 7 presents the original images, differing in distortion, taken by four cameras from different observation points, in JPEG format, 640×640 pixels (approx. 53 KB) in size.

Since the cameras and network components for this test were installed after the tower cranes were erected, the work had to be done under unstable conditions at elevated spots. If it had been possible to install the cameras and other components on the ground before the tower cranes were installed, work safety and efficiency would have been substantially improved.

Despite its ease of installation, a wireless LAN is often subjected to an unstable transmission environment at the construction site of a high-rise building, so we basically adopted a wired LAN at the test site and relied on wireless transmission where wiring was difficult.

Given their installation at elevated spots, the cameras used in the test were required to have specifications featuring high-level durability. Therefore, we used waterproof cameras supplied with power through network cables and not equipped with a driving mechanism for zooming or rotating operation. As a result, not a single failure occurred during the test period of approx. one and a half years.

Management of network equipment is also important. As cables are prone to breakage and other components are prone to failure in the environment at a construction site, we installed a control hub to immediately locate the trouble spot if a cable or component failed.

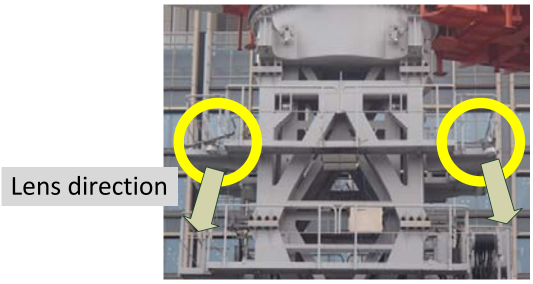

Figure 6: Camera installed on the tower crane

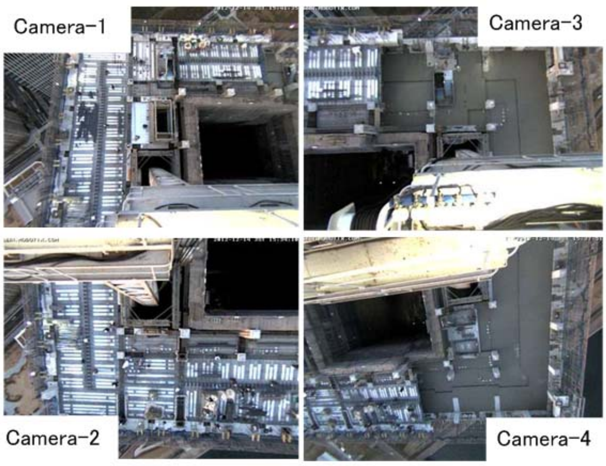

Figure 7: Original images from four cameras

Original images taken by the four cameras were transmitted at one-second intervals to an image server in the temporary office at the site. The transmission interval was set as above to cope with the network load and the speed of workers and materials moving in the work area. The original images were automatically converted to transformed images at five-second intervals through a transformation matrix predetermined for each of the four original images and input into the program used for transformation. The interval for image transformation was set to match the computer load and ensure monitoring precision.

Transformed images were simultaneously displayed on the computer screen and stored. We made arrangements so that anyone involved with the construction work would be able to view the transformed images through a Web browser from their computer while relying on the Web server function.

To determine the transformation matrix, we used the coordinates of four points in the original image (manually specified four corners of the object square in the work area) and those of the corresponding four points in the transformed image (to make the target object in the original image a square). We prepared multiple sets of the transformation matrix to cope with changes in the object points caused by changes in camera stations according to the progress of construction work and/or climbing of tower cranes.

Based on the results of the implementation evaluation test, we confirmed that construction work managers can sufficiently assess the work process at the working area by viewing the transformed images and measure the working time by analyzing consecutive transformed images (see Fig. 8).

Although we did not implement monitoring with a 3D model in this test, we created a 3D model for evaluation by using commercially available software. As a result, we were able to confirm that mapping a 3D model and viewing transformed images were possible simply by using the basic functions of the software alone (see Fig. 9).

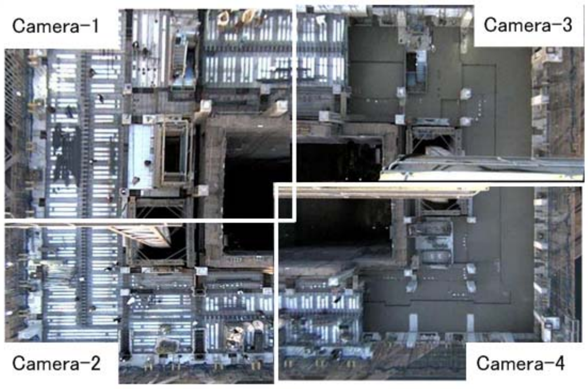

Figure 8: Reconstructed images

Figure 9: 3D model textured with images

4 Conclusion

To improve the efficiency of construction work management, we developed a system that uses camera images for monitoring floors where construction work is in progress and we performed an application test to evaluate its performance for practical purposes. Images of working areas taken by four cameras installed on two tower cranes were successfully displayed on a computer screen, confirming that the proposed system functions perfectly as intended at an actual construction site.

Implementation of the system at the test site proved that it was possible to obtain images and assess productivity and the status of work progress for the entire working area, which had previously been impossible through visual observation or with images taken by unit cameras. Based on the above findings, application of this system could significantly improve the management quality at construction work sites.

Construction work managers gave the following opinions regarding using transformed images for their work.

(a) Control of work progress

Whereas planning is often implemented using ground plans for the distribution of materials carried in beforehand, members for temporary facilities, and installation of machines and equipment, they can now grasp the geometrical relationship between different articles by viewing images similar to actual ones on ground plans, and more easily identify differences from the plans. Furthermore, as images are drawn to the same scale as actual articles on ground plans, they can judge the rates of work progress of floor slab placement, reinforcing bar arrangement and concrete casting in real time.

(b) Improvement of safety in load-lifting operation

If operators at the site can issue instructions from an unloading yard while viewing the status of the entire working area through a monitor during load-lifting operation, safety and workability at the working area can be significantly improved. Simultaneous confirmation of the status of two tower cranes through a monitor enables those in charge to judge the safety and danger of the geometrical relationship between lifted loads and nearby surroundings.

(c) Response in an emergency

Abnormalities of the floor where construction work is under way can immediately be grasped from the office even when an earthquake or a typhoon hits. Therefore, the time taken to respond can be reduced, even though it takes some time to reach the working area on an elevated floor.

(d) Evaluation of the productivity of construction work

Storage and analysis of images at certain intervals make it easier to determine and calculate operation sequences, members for fabrication fixing time, locations of workers and workloads to improve the quality of construction work through detailed assessment of productivity. Although it has been difficult to grasp the traffic lines of workers and routes of materials/members due to dead angles caused by unit cameras in particular, it is now possible to record and assess such factors by using this system. Management of construction work at the working area, which has previously been made visually, can now be implemented directly from the field office, thus reducing the time for workers and materials to move around the working area.

References

[1] Richard Hartley and Andrew Zisserman. *Multiple View Geometry*, Cambridge university press, 2000.