Data Collection System for a Rapid Recovery Work: Using a Digital Photogrammetry and a Small UAV (unmanned aerial vehicle)

Tsuyoshi Yamamoto[1], Hiroshi Kusumoto[2], and Katsuhisa Banjo[3]

[1] Director of the Kinki Regional Center, Japan Construction Information Center (JACIC), 2-1-9 Uchihirano-cho, Chuo-ku, Osaka, Japan, PH +81-6-6949-3060; email: yamamoto_t@jacic.or.jp

[2] ASCO CO.,LTD., 1-10-1 Enokojima, Nishi-ku, Osaka, Japan, Technical Development Department, General Manager, PH +81-6-6444-1121, email: hiroshigm7@gmail.com

[3] ASCO CO.,LTD., 1-10-1 Enokojima, Nishi-ku, Osaka, Japan, Geographical Information Department, Deputy General Manager, PH +81-6-6444-1544, email: k-banjo@asco-ce.co.jp

ABSTRACT

Photog-CAD® is software to aid prompt operations from conducting surveys to making designs and estimated expense for recovery in the collapsed area of slopes and river revetments caused by natural disaster. This software is intended to make a design and an estimate based on the 3D models created by processing pictures of the collapsed site from three directions using a close-photogrammetric technique. However, when taking pictures from the ground, there are many restrictions which often make the use of this software difficult. This research paper proves that it is efficient to use an unmanned aerial vehicle (UAV) which can take photographs from the sky above, and reports a case study in which we efficiently conducted a survey using Photog-CAD® with the UAV, and made a design, estimate, and documents for the budget request.

INTRODUCTION

Japan is one of many countries where large natural disasters including landslides and river floods are caused by typhoons and heavy rains every year. Particularly in recent years, extreme weather such as torrential rains often causes extensive damage. The Japanese government is responsible for supporting municipalities affected by disasters in providing a prompt disaster recovery like dispatching experts and providing economic assistance. As the time limit for subvention applications is regulated by the law, the municipalities need to prepare both an outline of the situation of the disaster area and the estimated expense for the recovery immediately. To make the operations easy, a computer system called Photog-CAD® was developed by the Japan Construction Information Center (JACIC) in 2009. This system can automatically conduct surveys, make recovery plans, and obtain estimated expenses and has been provided to not only municipal governments but also private companies. To estimate an expense for a disaster-relief project, we generally survey and map the disaster site for a recovery plan. On the other hand, using

Photog-CAD®, we create CAD figures from the pictures of the site which were taken from three directions as shown in Figure 1. Photog-CAD® only uses the photographic data for showing the condition of the site for a recovery plan. To create 3D data, images of the entirety of the devastated site must be contained in pictures taken from three directions. Moreover, this system cannot function without ensuring the proper three positions for taking pictures from. Photog-cad® and other bundle adjustment calculation software also basically use principle of photogrammetry. Because of this, it is necessary to conduct multiple photo shootings for viewing the object stereoscopically, however it is known that if the locations of the camera are close to each other, it will reduce the accuracy. Also, to stereoscopically view the hidden parts of an object, it is key to take pictures of the object from different angles as much as possible. Moreover, obtaining the images and other data is not available with the conventional methods such as using a digital camera or total station (TS) when there is an obstacle blocking the sight line with the object. The purpose of this study is proposing the use of UAV to solve these issues. Additionally, this paper reports a case study in which we efficiently conducted a survey using a UAV with Photog-CAD®, and then made an actual recovery plan, estimation and materials for the budget request.

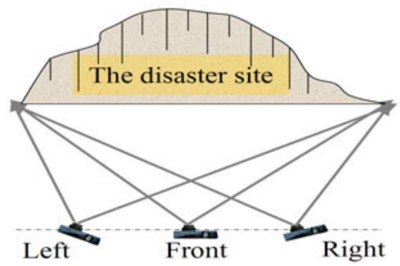


Figure1. The directions for photographic survey

MODULES OF Photog-CAD® AND SYSTEMATIC PROBLEMS

Modules of Photog-CAD®. Photog-CAD® consists of two gradual modules. In the first module, we take three stereo pictures using a digital camera from the ground and create 3D data out of the pictures using close-range photogrammetric techniques. The second module contains two modules; one module for drawing cross-section views and outlining designs for restoration by CAD data and the other which is for making assessment documents by calculating restoration expenses. Figure 2 shows the module structure of this system.

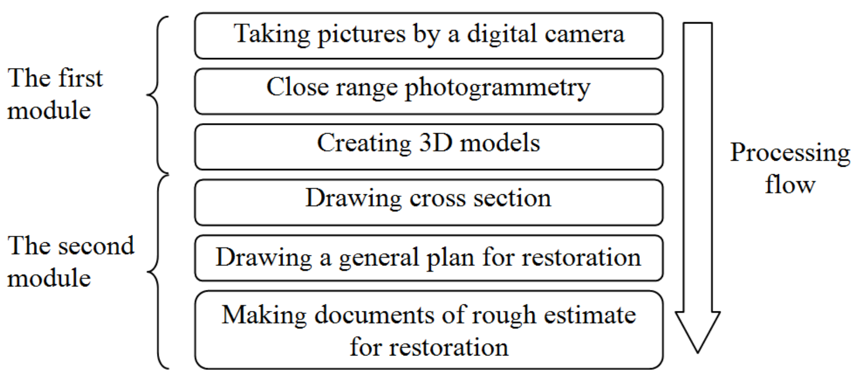


Figure 2. Modules of Photog-CAD®

Systematic Problems. Photog-CAD® creates a 3D model simply from three pictures to save time for the operations. For this reason, the pictures taken from three directions must contain images of the entire target area. However, it is too difficult to take pictures in such cases mentioned below for this system. Also, it is not simple to ensure sufficient accuracy of drawn models for such places shown in Figure 3, because of the difficulty of taking pictures at the target area from the right angle. It may even be impossible to construct a 3D model in an extreme case. Since Photog-CAD® cannot be used in such cases, we would need to take a conventional survey using a TS and poles.

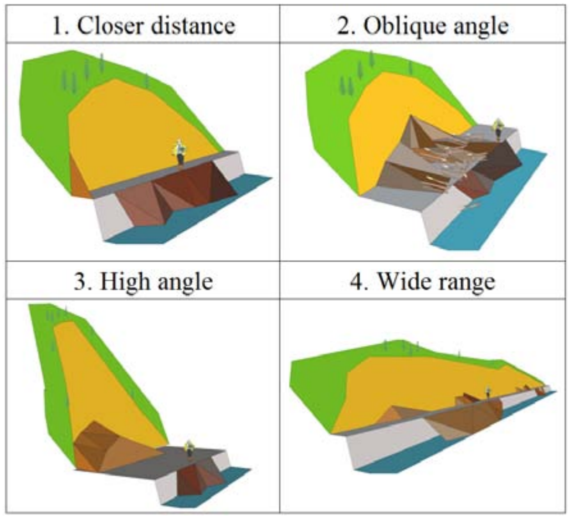


Figure 3. Difficult cases for photographic survey

1. When shooting distance from the subject is too short, such as on a mountain road with a single lane.
2. When the collapsed area is not accessible because of obstacles blocking a road, or when the shape of the target area is too complicated to capture the whole shape in three pictures.
3. When the collapsed area is too high to take pictures from the ground.
4. When the collapsed area is spread out over too long an area along a road or a river. The photogrammetric module of current Photog-CAD® secures accuracy by combining one unit of three pictures with 20 meters wide in the area. Therefore, a time-consuming postprocess to combine the data will be necessary afterwards.

EXPERIMENT AND VERIFICATION

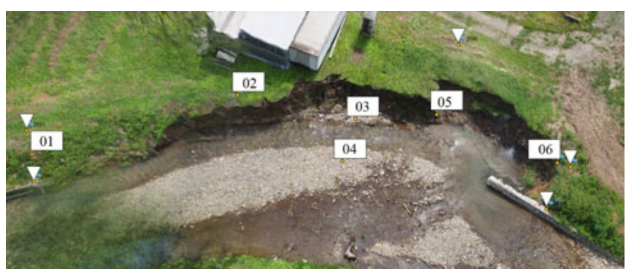
Test case 1. The accuracy of Photog-CAD® has been already verified and reported[1)]. This test case aimed at verifying the effectiveness of the photographic survey method using a UAV in areas in which it is too difficult to make 3D data using the photographic survey method specified for Photog-CAD®. We performed this test in a collapsed area at a river revetment in Iwate Prefecture, caused by a heavy rainfall in August, 2013. Brief specifications for the UAV we used are in Figure 4.

AibotX6

Length/width	1.04m
Housing	CFK (Carbon)
Weight	2.55kgf
Max. Speed	60km/h
Flight height	up to 150m
Flight time	up to 20 minutes (dependent on payload)
Controlling	Remote Control,Tablet-PC (optional) or Autonomous
Power Source	Litium-Polymer 5.000 - 10.000 mA

Figure 4. Performance of the UAV

When pictures were taken from three directions from the ground in this site, it was impossible to capture the flat area on the top of this site and the collapsed area in the back side of a retaining wall block. Therefore, creating 3D data and a cross-section view was impractical. To solve this problem, we took pictures from above using the UAV. The camera which was mounted on the UAV was a digital single-reflex camera with the image stabilizing system with 14mm focal length, which is equivalent to about 28mm for a 35mm full-framed camera. The camera was set to automatically shoot a picture every two seconds to fully utilize the performance of the software which can instantly compute a bundle adjustment from the many pictures. In this test, we used the software, “Agisoft PhotoScan”, which automatically makes exterior orientation, image correlation, and 3D data from the images taken with the UAV. It compared the positional coordinates of inspection points on the 3D model and those of reference points measured using a TS to verify the accuracy. Stereophotogrammetry has been developed by various software companies in recent years. Algorithms which can handle huge amount of bundle adjustment at high speed have been adopted. Figure 5 shows the reference points and the inspection points.



▽ Reference points measured by TS
▭ Inspection points measured by photogrammetry

Figure 5. Reference points and inspection

Five reference points, of which positional coordinates were already known, and six inspection points were prepared. Actually, only three reference points would be enough to make a verification, however, because we use the method of least square for adjustment calculations, distributing more points into the photographic survey range in a well-balanced pattern makes the accuracy improve. This test was intended to verify the effectiveness and the accuracy of the photographic survey using a UAV, but not to make an official document for assessment of the disaster. Also, reference points and inspection points were made of simple cardboards. Figure 6 shows an image of TIN (triangulated irregular network) data, and Figure 7 shows a cross-section view from the TIN data. TIN is something which the surfaces of the triangles were connected by the vertices which have three-dimensional coordinates (x, y, and z) to present topography as a digital data structure. These figures show that a cross-section view can be drawn at an arbitrary positioning from the data of dense TIN. Moreover, we were able to achieve our goal for this experiment, which was to create cross-section views of both the flat area and the collapsed area in the back side of a retaining wall block.

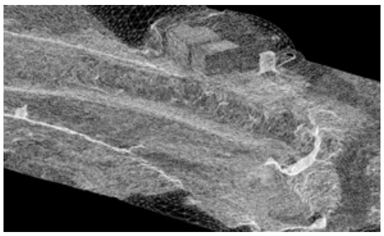


Figure 6. TIN data of the collapsed site in Iwate Prefecture

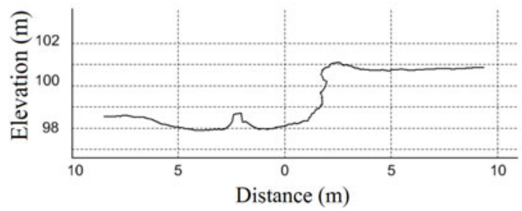


Figure 7. A cross-section view made from the TIN data

Table 1 shows the accuracy verification result. The error margin of photogrammetry was 10mm to 34mm. Less than 100mm of error is empirically acceptable because there is no requirement for accuracy in surveys taken in disaster areas[2)], and the government has conducted basic surveys to roughly assess a subvention for the municipalities of the devastated area. Considering them, we can say that we obtained the sufficient accuracy in this test.

Table1. The difference in the measurements of coordinates from the actual measurement using a TS

Inspection point numbers	Differences from TS surveyed coordinates			Dfferences on an X-Y plane (m)
	X-error(m)	Y-error(m)	Z-error(m)	
01	-0.034	-0.002	0.075	0.034
02	0.006	-0.022	0.016	0.023
03	0.013	-0.027	0.011	0.030
04	0.012	-0.026	0.020	0.029
05	0.026	0.004	-0.008	0.026
06	-0.010	0.002	-0.002	0.010

Figure 8 is the PDF of a 3D drawing made from the 3D data, which can be viewed using a PDF viewer provided by Adobe Systems, Inc. We can take a quick measurement and view the sites from any angle shown on the viewer. Therefore, the conditions of the back side of a retaining wall block and scoured lands can be viewed as shown in Figure 9. This brings great benefits to officers in charge of assessment of the disaster because they can easily check the condition and the extent of the disaster on a computer.

Figure 8. 3D-PDF of the damaged site wall

Figure 9. The back side of a retaining wall block

Test case 2. The typhoon No. 18 formed in October, 2013, severely damaged various regions in Japan. We had a test at a river area damaged by the typhoon, shown in Figure 10, in Kyoto Prefecture. We took pictures with the UAV, and developed a plan and calculated approximate construction cost from the CAD drawing of Photog-CAD®.

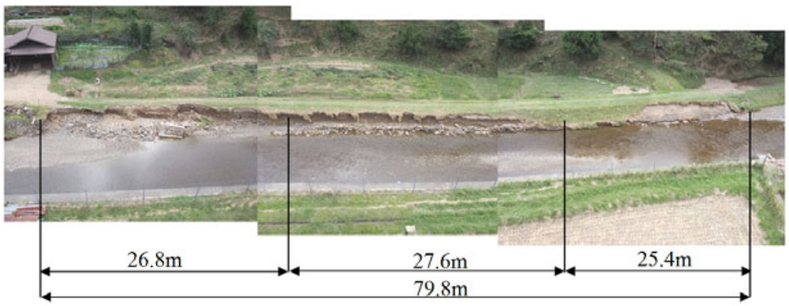


Figure 10. The damaged river bank in Kyoto Prefecture

Figure 11. Conventional surveying

It was difficult to ensure sufficient shooting distance in this site because the collapsed area was too long at 79.8 meters, and the river was about ten meters wide and had a fence on the opposite shore. We used the same UAV and the camera with the same specification as the test case 1. The pictures were taken using the UAV in the site where targets were placed and a vertical pole was driven on a starting point at the upstream. We first took pictures using the UAV from the altitude of about 30 meters so that whole area would be contained in one picture. However, it was too difficult to recognize the targets and the photograph three-dimensionally. Therefore, we took pictures from a lower altitude to capture the disaster site divided into three pictures. It required three vertical poles to split the site into three sections, and to measure the distance between poles, and also to take three pictures of each section. However, taking the pictures took only about ten minutes, and the whole operation took just about 60 minutes, even though it usually takes much more time and work to combine the CAD drawings when a site is split into several sections. Also, this particular site has to be split into more than eight sections using the conventional method of photographic survey from the ground, because the photographing distance is too close. However, the use of the UAV made division into only three sections sufficient this time, and considerably reduced the whole operation quantity including the operation using a computer. Using the conventional method, sites like this required many surveyors to conduct cross-section surveying using poles as shown in Figure 11. Moreover it would take about five days to finish the whole process, from conducting field operations to making documents for assessment. However, the method using a UAV took just two days and two operators to complete the field operation part. Working in collapsed area is dangerous, therefore this test case achieved quite valuable results considering the setback of terminating field operation for a short amount of time. This post process procedure took 2 hours and 45 minutes, in comparison with the conventional method, which requires about 6 hours and 30 minutes. Moreover, this method enables inspectors to conduct a survey in more disaster sites over one day, which is more efficient. Figure 12 shows the TIN data of the section of the starting point side.

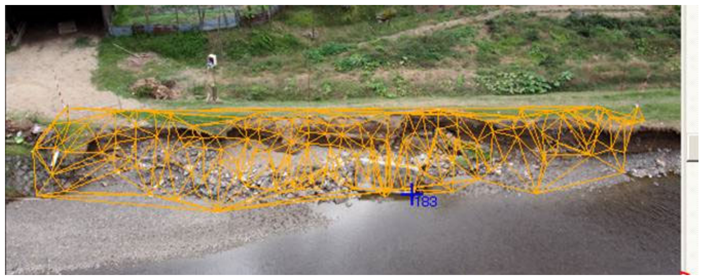


Figure12. TIN data of the damaged site in Kyoto Prefecture

Figure 13 shows a structural drawing of a retaining wall block to be reconstructed, made from the 3D data in the CAD module of Photog-CAD®.

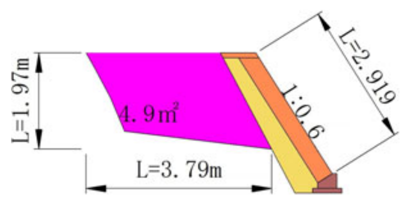


Figure 13. Drawing of a retaining wall block from the CAD module of Photog-CAD®

SUMMARY AND FUTURE

Summary. Since Stuart M. Adams and his colleges published data about the superiority of use of UAV for examining the disaster site, acquisition method for high resolution images, and the software for a flight plans and flying in 2010[3)] and 2012[4)], the valuable information for the methods of acquiring images by a UAV has been made available. On the other hand, to expand the range of applications for Photog-cad®, which can conduct series of operations from conducting survey to creating the assessed documents, we focused on the effectiveness of using a UAV, and we proved it. Photog-CAD® is easily available in many disaster sites when the use of a computer and digital camera and shooting points can be secured. This system can be operated without high skill, and in addition to this, it costs only about 1,500 USD, therefore it could be efficient method for use in developing countries in the near future. Moreover, it is possible to expand the application range of circumstances for Photog-CAD® by using it in combination with a small UAV.

Future. We are planning to present some case studies within the coming few years.

- This time, the flights were randomly conducted at the site and the photos we used for were chosen from many photos later. However, we will verify the most efficient flight plan which is suitable for disaster topography for use in future case studies.
- In this case study, the reference points were placed on the empirical basis. However, testing the number of placing reference points and layout shapes in the case for wide disaster area will be taken.
- Differences in the performance of analysis software have great influence over final accuracy. Therefore, we are going to study the characteristics of effective software for analyzing images shot by UAV equipment.

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