COMPARISON OF PHOTOGRAMMETRIC POINT CLOUDS WITH BIM BUILDING ELEMENTS FOR DAM CONSTRUCTION PROGRESS MONITORING IN INDONESIA

Arliandy P. Arbad(1), Z. N. Arifin(1), N. Martina(1), H. Setiadji(2), E. P. Nindya(2), M. A.Nurfa(3)

[1]Civil Engineering Dept. State Polytechnic of Jakarta, Kampus UI, Depok, Indonesia
[2]Waskita Karya, Indonesian state-owned construction company, Cawang, Jakarta, Indonesia
[3]School of Agriculture, Lampung University, Bandar Lampung, Lampung, Indonesia

Email: arliandy.pratama@sipil.pnj.ac.id

KEYWORDS: Photogrametric, BIM, Construction, Monitoring

ABSTRACT: Image-based object detection provides a valuable basis for site information retrieval and construction progress monitoring. For construction progress monitoring a planned state of the construction at a certain time (as-planed) has to be compared to the actual state (as-built). The as-planed state is derived from a building information model (BIM), which contains the geometry of the building and the construction schedule. In this paper we introduce an approach for the generation of an as-built point cloud by photogrammetry. It is regarded that that images on a construction cannot be taken from everywhere it seems to be necessary. Because of this we use a combination of structure from motion process together with control points to create a scaled point cloud in a consistent coordinate system. Subsequently this point cloud is used for an as-built – as-planed comparison. From these recordings, dense point clouds are generated by the fusion of disparity maps created with semi-global-matching (SGM). These are matched against the target state provided by a 4D Building Information Model (BIM). For matching the point cloud and the BIM, the distances between individual points of the cloud and a component's surface are aggregated using a regular cell grid. This allows to identify not existing building parts. For the verification of the existence of building parts a second test based on the points in front and behind the as-planed model planes is performed. Experimental results from a real case study are presented and discussed.

1. INTRODUCTION

Monitoring the construction progress of large dams has been always facing challenges. Dams are very complicated structures and created from outstanding engineering performance, and excellent civil engineering and technology that has been developed in many years for water supply and irrigation, rainwater in reservoirs, and also to drive a turbine to generate electricity. The actual progress (as-built) of dams may differ from the initial values computed at the origin design (as-planned) for several reasons. Therefore, near real-time monitoring of the overall structure is needed to secure and preserve the progress of the structure. Building Information Models (BIM) and surveying methods have been used in order to support the control of construction progress. In future the usage of BIM will dominate. That means that a model including the information about the building geometry, the construction schedule and attributes of the building parts will be available. For updating the model based on the deviations detected in the plans, the monitoring process shall directly be imposed on BIM. Deviations from the origin planned (as-planed) in the BIM shall be recognized automatically by a surveillance system which records the state of the building at a certain time step (as-built). The detected deviations then cause changes in the construction logistic, e.g. by adapting the schedule so that delays can be handled in a resource efficient way.

This paper examines the comparison of photogrammetric point cloud and BIM for near real-time delivery of information to support progress monitoring and management of the construction at the Margatiga dam in Lampung Province. The reduced accessibility of dams and the large time needed for an inspection by traditional method. Therefore, the use of unmanned aerial vehicle (UAV) is more acceptable (Colomina and Molina 2014; Ellenberg, Branco et al. 2014; Ellenberg et al. 2014; Vetrivel et al. 2015) to derive visual inspection. Recent work related to progress monitoring of data acquisition with photogrametric point clouds and BIM (Rankohi & Waugh 2014; Tuttas, S., et al. 2014) for the monitoring of construction progress. The as-built point clouds acquired by photogrammetric methods (Nevalainen, O., et al. 2017; Torres-Sánchez, J., et al. 2018). Braun, A., et al. (2015) ecplained the concept for automated construction progress monitoring using BIM-based geometric constraints and photogrammetric point clouds.

2. METHODS

2.1. Case Study

In this study an overview of the main construction areas of the Margatiga dam are discussed. The case study includes discussions on:

- Regular construction monitoring of the main dam structure by comparing point clouds photogrammetric (as-built) and BIM (as-planned);
- Earthworks monitoring at the abstraction weir and earth-fill embankment dam; both structures with building information models (BIM) integration for validation

Figure 1. Location of Margatiga dam

The Margatiga Dam is located in Trisinar Village and Jemanten Village, Margatiga District - East Lampung Regency - Lampung Province. Margatiga District is part of the East Lampung Regency. The estimated area for irrigation is 10950 hectares and 65 million m^3 volume. The dam construction is carried out to meet the national food and water security targets.

2.2. Image Triangulation

Camera calibration and image orientation are two fundamental prerequisites for any metric reconstruction from images. For image orientation a concept is presented which shall fit for the situation on a construction site with consecutive and overlapping images which derived from small UAV. Automation is nowadays necessary and feasible at the image orientation, DSM generation, and orthophoto production stages, while accurate feature extraction is still an interactive procedure. A typical image-based field surveying with UAV systems require a flight or mission planning, GCPs measurement (if not available and required for geo-referencing), image acquisition, camera calibration and image orientation, image processing for 3D information extraction. The mission (flight and data acquisition) is planned with dedicated software, starting from the area of interest (AOI), the required ground sample distance (GSD) or footprint, and knowing the intrinsic parameters of the mounted digital camera.

Camera calibration and image orientation tasks require the extraction of common features visible in as many images as possible. In aerial photogrammetry this task is accomplished today by exploiting aerial triangulation (AT). The multiple aerial photos of the area were collected by UAV was flown at 150 meters height at a mean scale of 1:5000 and oriented to a GPS network of 8 ground control points (GCPs), and 80% overlap and 70% sidelap. Residual of bundle block adjustment on GCPs and tie points for outer orientation were on the order of few centimeter (Mora, et al.,2003). Digital photogrammetric techniques are currently the most interesting solution for the automatic generation of terrain models and orthophotos (Bitelli, G., et al. 2004), which are highly important for the monitoring study of construction progress. We used Agisoft metashape software for the image processing (alignment process, gradual selection, and build dense cloud) (Uysal, M. et al. 2015 and Javernick, L. et al. 2014). In order to evaluate the accuracy's dependency on the number of GCPs used during indirect sensor orientation, six images of different acquisition altitudes were chosen to perform Aero-triangulation processing. During that test, the number of GCPs used during aerotriangulation varied from 2 to the maximum of GCPs that were visible in the image. For every number of control points the sensor orientation has been executed and the RMSE as well as the accuracy of the calculated orientation parameters were registered.

2.3. Dense Point Clouds

Camera calibration and image orientation are two fundamental prerequisites for any metric reconstruction from images. For image orientation a concept is presented which shall fit for the situation on a construction site with consecutive and overlapping images which derived from small UAV. Automation is nowadays necessary and feasible at the image orientation, DSM generation

Once a set of images has been oriented, the following steps in the 3D reconstruction and modeling process are surface measurement and feature extraction. Starting from the known exterior orientation and camera calibration parameters, a scene can be digitally reconstructed by means of automated dense image matching techniques or interactive methods for manmade features and vector information extraction. Interactive approaches deliver sparse point clouds which need structuringand editing in order to create accurate 3D data (e.g. dam models). Automated methods produce a dense point cloud describing the surface of the surveyed scene (DSM), which has to be interpolated, maybe simplified and finally textured for photo-realistic visualization. A powerful image matching algorithm should be able to extract dense 3D point clouds with a sufficient resolution to describe the object's surface and its discontinuitie (Remondino, F., et al. 2011).

Figure 2. Automated image triangulation results for the UAV block over the dam area

For every time step a dense point cloud is generated from the oriented images for the as-built as-planed comparison.

3. RESULT AND DISCUSSION

3.1 As-Built – As-Planned

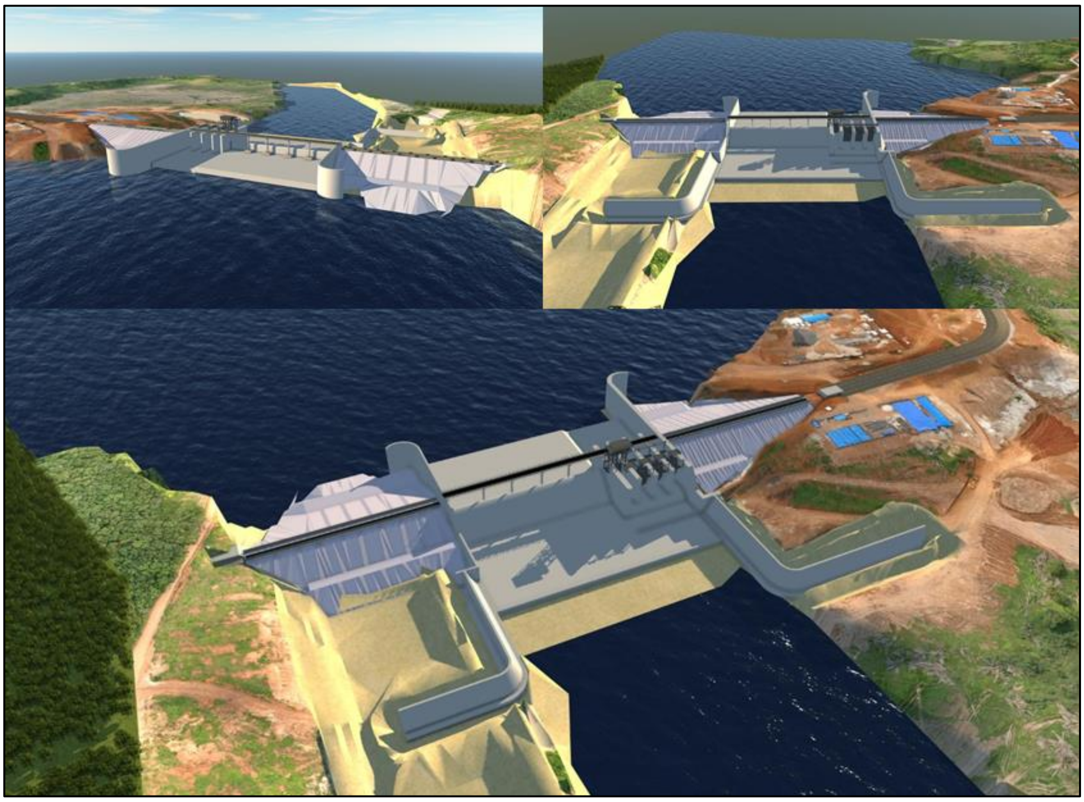

Figure 3. The Margatiga dam design based on 4D Building Information Models

The comparison of the actual state requires the automatic comparison of the as-planned information that is present in BIM with the actual as-built state of the building. For structure progress monitoring with the consistent integration of (as-planned) 4D BIM information into the as-built inspection process is presented.

3.2 Point Clouds

Point Cloud Generation from Aerial Image Data Acquired by a small Unmanned Aerial Vehicle and a Digital Still Camera. The point cloud generated by UAV is generally in an arbitrary reference frame and needs to be registered to the coordinate system (GCPs). The point cloud below is sparse in areas of complex vegetation and where surfaces have a homogeneous texture. The flight area at the Margatiga dam site contains fields, trees, buildings, and roads with gravel and asphalt coatings. Clearly, that the point clouds below is accurate for many targets, such as buildings, roads and test site. Field surface and other areas covered by vegetation (trees, bushes, grass) are less stable targets.

Figure 4. Point clouds generated from UAV images

3.3 Comparison As-Built – As-Planned

We registered the point clouds photogrammetric (as-built) with the underlying 4D BIM model (as-planned). This means the discovery of the pose of each image of a sequence according to the coordinate system of the building model. Being aware of the image origin, it allows for the advanced interpretation of the content in consecutive processing. The relevant tasks of the expected state of the 4D BIM model are projected onto the image space. The resulting image regions of interest are then taken as input for the determination progress of construction. In order for the point clouds to be useful, several steps should be taken, such as cleaning, and filtering. Moreover, the processed point clouds could be incorporated into Building Information Modeling

(BIM) platforms, which have emerged as a means to integrate building design. The Point clouds is analyzed and organized for feeding into the BIM environment. In particular, the point clouds obtained from a number of positions of the scanning device have to be registered and merged. To do this, a certain overlapping between adjacent point clouds is required. Of course, the set of point clouds should cover the entire study area.

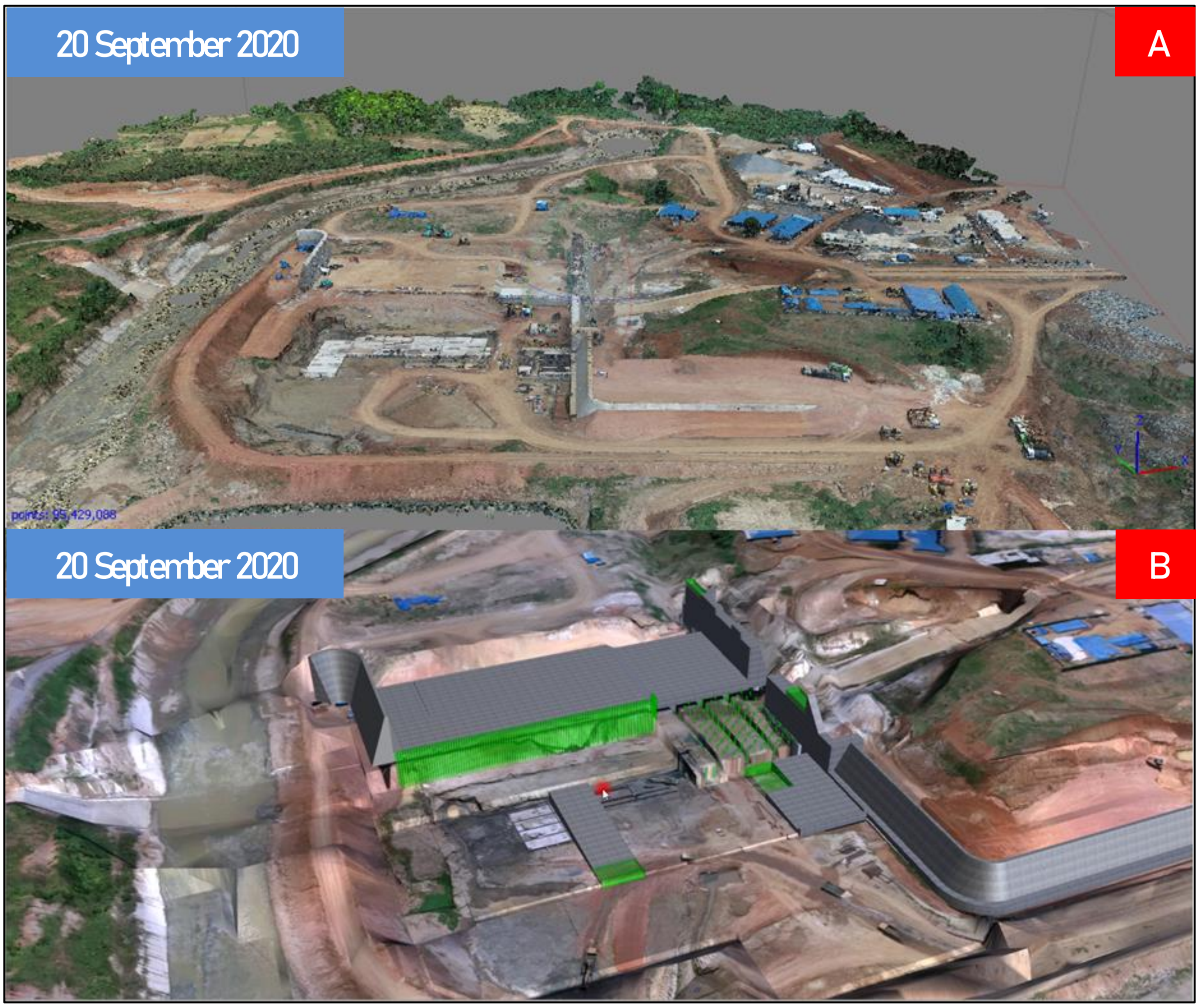

Figure 5. Comparison between point clouds as-built (A) and superimposed to 4 BIM (B)

In Figure 5A you can see the extracted point cloud corresponding to the model part shown in Figure 5B. In Figure 5B, the green area on the building/dam site background indicate parts which are not existing (shown in figure 5A), grey background indicates existing parts in schedule time. Regarding the uncertainties of the point cloud, to decide if a model plane can be verified. The results show percentages for the confirmed areas rates closely to 95% is expected.

3.4 Validation

The use of a Total Station survey to accurately map a set of reference points around the study area is an accepted method of obtaining "ground truth". The accuracy of Total Station data using error propagation theory and found that uncertainty in position is ~1 cm and uncertainty in elevation is ~2 cm. To estimate the accuracy of the georeferenced point clouds and to evaluate the effect on the accuracy of GCP, we compared with reference cross-section of the Total Station dataset. Validation on cut and fill work between photogrammetry and the total station is relatively similar.

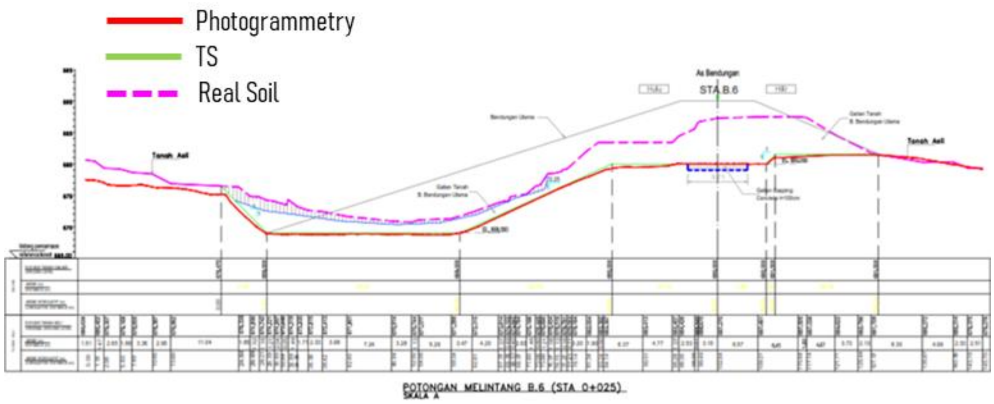

Figure 6. Cross section comparison between photogrammetry and total station

4. CONCLUSION

For the generation of the as-built data we use photogrammetry to create the point cloud since in our opinion it is more flexible than a laser scanner with respect to the accessible acquisition positions and low cost. Monitoring construction progress can overcome material overload, risk of construction failure, and redundancy of work. The point clouds percentages for the confirmed areas rates closely to 95% over the study area. Future work, we have to consider about UAV altitude, image overlap, GCPs ditribution, and optical sensor resolution,

Acknowledgements

Thank you for PT. Waskita Karya to provide UAV images of Margatiga dam project. Remote Sensing of Environment and Disaster Laboratory, Industrial Institute of Technology University of Tokyo and Civil Engineering, State Polytechnic of Jakarta.

References

Tuttas, S., Braun, A., Borrmann, A. and Stilla, U., 2014. COMPARISION OF PHOTOGRAMMETRIC POINT CLOUDS WITH BIM BUILDING ELEMENTS FOR CONSTRUCTION PROGRESS MONITORING. International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences.

Nevalainen, O., Honkavaara, E., Tuominen, S., Viljanen, N., Hakala, T., Yu, X., Hyyppä, J., Saari, H., Pölönen, I., Imai, N.N. and Tommaselli, A.M., 2017. Individual tree detection and classification with UAV-based photogrammetric point clouds and hyperspectral imaging. Remote Sensing, 9(3), p.185.

Torres-Sánchez, J., de Castro, A.I., Pena, J.M., Jiménez-Brenes, F.M., Arquero, O., Lovera, M. and López-Granados, F., 2018. Mapping the 3D structure of almond trees using UAV acquired photogrammetric point clouds and object-based image analysis. Biosystems engineering, 176, pp.172-184.

Braun, A., Tuttas, S., Borrmann, A. and Stilla, U., 2015. A concept for automated construction progress monitoring using BIM-based geometric constraints and photogrammetric point clouds. ITcon, 20(8), pp.68-79.

Colomina, I. and Molina, P., 2014. Unmanned aerial systems for photogrammetry and remote sensing: A review. ISPRS Journal of photogrammetry and remote sensing, 92, pp.79-97.

Ellenberg, A., Branco, L., Krick, A., Bartoli, I. and Kontsos, A., 2015. Use of unmanned aerial vehicle for quantitative infrastructure evaluation. Journal of Infrastructure Systems, 21(3), p.04014054.

Ellenberg, A., Kontsos, A., Bartoli, I. and Pradhan, A., 2014. Masonry crack detection application of an unmanned aerial vehicle. In Computing in Civil and Building Engineering (2014) (pp. 1788-1795).

Vetrivel, A., Gerke, M., Kerle, N. and Vosselman, G., 2015. Identification of damage in buildings based on gaps in 3D point clouds from very high resolution oblique airborne images. ISPRS journal of photogrammetry and remote sensing, 105, pp.61-78.

Rankohi, S. and Waugh, L., 2014. Image-based modeling approaches for projects status comparison. GEN, 30, p.1.

Remondino, F., Barazzetti, L., Nex, F., Scaioni, M. and Sarazzi, D., 2011. UAV photogrammetry for mapping and 3d modeling–current status and future perspectives. International archives of the photogrammetry, remote sensing and spatial information sciences, 38(1), p.C22.

Bitelli, G., Dubbini, M. and Zanutta, A., 2004. Terrestrial laser scanning and digital photogrammetry techniques to monitor landslide bodies. International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 35(B5), pp.246-251.

Mora, P., Baldi, P., Casula, G., Fabris, M., Ghirotti, M., Mazzini, E. and Pesci, A., 2003. Global Positioning Systems and digital photogrammetry for the monitoring of mass movements: application to the Ca'di Malta landslide (northern Apennines, Italy). Engineering geology, 68(1-2), pp.103-121.

Javernick, L., Brasington, J. and Caruso, B., 2014. Modeling the topography of shallow braided rivers using Structure-from-Motion photogrammetry. Geomorphology, 213, pp.166-182.

Uysal, M., Toprak, A.S. and Polat, N., 2015. DEM generation with UAV Photogrammetry and accuracy analysis in Sahitler hill. Measurement, 73, pp.539-543