Reasoning and Post-Disaster Damage Assessment for the Petrochemical Pipeline Explosion using UAV Techniques

Kuan-Tsung Chang[1*], Min-Cheng Teng[2], Gwo-Chyang Tsuei[3], Cheng-Fang Lo[4], Jin-King Liu [5]

Abstract: In this paper, a case of petro-chemical pipeline explosion was selected as the show case. The causes and the impacts of the case are described. These can be good lessons for managing this type of man-made hazards. In addition, the detail on data acquisition for high resolution aerial orthophotos obtained by the unmanned aerial vehicle (UAV) techniques after the disaster event enables engineers to assess the current site condition and to perform safety evaluation.

Keywords: Disaster, UAV, Pipeline, Emergency

1. Introduction

The International Federation of Red Cross and Red Crescent Societies (IFRC) gave specific definition on technological or man-made hazards in recent years. Events that are caused by humans and occur in or close to human settlements include environmental degradation, pollution and accidents. Typical technological or man-made hazards are complex emergencies, conflicts, famine, displaced populations, industrial accidents and transport accidents. They all interrelated to human habitat and civilization today, especially transport such as highway and airports. Owners and operators of land transport systems exposed to rainfall-induced hazards are rarely aware of risk-related concepts when assessing performance objectives and preventive measures for the sustainability of infrastructure system with regards to flooding events. The majority of devastating disasters occurred as a result of unusually heavy rains. Past events have highlighted the necessity to adjust the required design specification level for the new projects. However, the amendment may not be cost-effective, neither be soon enough. To learn from the past events may help the owners and operators plan ahead regarding not only the exposure, but also the vulnerability and criticality of infrastructures. The design according to a specific return period, e.g. 100 years, may be appropriate for a new single infrastructure element in the past. But, applying variation concerning climate change on aging infrastructure would most likely be inappropriate. Thus, the challenge engineers face today is not to be against the nature but through adaptation to lessen the adverse impacts of climate change through a wide-range of lessons learnt from past incidents to establish a comprehensive approach addressing these security issues having an impact on the availability and quality of transport networks.

Engineers today apply internet technology and remote sensing to provide unique solution beyond what conventional methodology would normally provide. Take an unmanned aerial vehicle (UAV) as an example, UAV is an aircraft without a human pilot aboard to perform scientific observations and investigation tasks. Since the UAV payload and flight stability has increased dramatically in recent years, spatial positioning components, such as Global Positioning System (GPS) and Inertial measurement unit (IMU), are miniaturized to extend the flight time. It also has the advantages of real-time wireless video transmission, low cost, flexibility, and low-level operations under the cloud. These properties can compensate for conventional aerial or space remote sensing subject to the shortcomings of cloud cover, so it becomes one of the important aids for traditional aerial photogrammetry to obtain spatial data. The latest technology enables engineers to learn and improve technique from different perspective. The UAV has been widely used in the world, including maritime search and rescue, forest conservation, soil and water conservation, natural disaster investigation, and so on [1-8].

2. Case Study

During 23 o'clock July 31, 2014 to the wee hours of August 1, the underground petrochemical pipeline exploded in Kaohsiung City. In the initial stage of the accident, as the propylene leak was not detected in time, a great deal of propylene leaked from the pipeline to the outside via the drain boxes, the too high concentration and uncertain ignition source caused multiple explosions, which caused 32 deaths and 321 injuries, multiple vehicles were destroyed, and multiple important roads were damaged seriously, including at least Sanduo 1st Rd., Kaixuan 3rd Rd. and Yixin 1st Rd. It's the most severe pipeline explosion disaster event in Taiwan.

2.1. Preliminary analysis of causes and social impact

The primary cause of the accident was that LCY Chemical Corp. failed to detect the pipeline rupture instantly in the propylene transport process. The pipeline was exposed in the drain box for long, and the thickness of pipeline wall was only 1/7 of the original design. When the pipeline was damaged, the company still conveyed propylene, so that a great deal of propylene leaked from the pipeline via the drain box. When the concentration reached the explosion ratio and the uncertain ignition source occurred, the intense fire and multiple explosions were initiated. According to Kaohsiung gas explosion investigation indictment and Control Yuan investigation report, the major causes of accident include: the pipeline was not constructed as per the design, the pipeline was not inspected thoroughly after completion, the pipeline maintenance was insufficient, the emergency response was improper during gas leak and the responsible units for the underground line did not implement proper management. The aforesaid accident can be learned about to enhance the establishment and amendment of dangerous material pipeline safety prescripts for disaster prevention management in the future, to enhance the facility maintenance and the mastery of operation information, to enhance disaster cognition and common people's risk inform and disaster impact evaluation, so as to reduce the disaster impact and loss.

2.2.Procedures of Data Acquisition and Processing with an UAV

First of all, a flight plan can be made based on the requirements of the emergency mission and the sensor system used, including items such as the specifications of the camera used, overlap ratio of photos, and the condition of the disturbed ground surface. UAVs come in many shapes and sizes. The characteristics or specifications of the UAV ultimately lead to the operator's decision as to which platform will best fit the survey application. These key attributes and acting on them will ensure that that the mapping mission is a success. There are two main types of UAV available that are suitable for surveying work. The first type is a fixed wing model. In general, the stability of a fixed-wing UAV is good for precision mapping for topography, but it does have certain restrictions in taking-off field and operation conditions. The second type of UAV is a rotary blade, or propeller-based model. Unlike the fixed wing models, these mini-copters are able to fly in every direction, horizontally and vertically, as well as hover in a fixed position. This makes them the perfect instrument for detailed inspection work or surveying hard-to-reach areas such as pipelines, bridges, power lines and rail tracks. A fixed-wing UAV can be suitable for a wide area survey, whereas a rotary UAV can be better adopted for complicated terrain and restricted open space.

Secondly, control points and check points should be properly selected to cover the survey areas. The quantity of the points required depends on the quality of the final outputs required. If they are digital terrain models and orthophotos of high quality, this will require high quality of the control points. Otherwise, a few points (such as 3 points) can be enough for a reconnaissance. Subsequently, the geodetic coordinates of the control points can be measured by Real Time Kinematic (RTK) satellite navigation or measured with a Control Entity Database using control entities of aerial images. In addition, weather conditions are critical for image quality due to the illumination and vibration due to wind speed. Before an aerial sortie, all functions of the platform and sensor should be carefully checked.

After imaging, all taken images are imported into a post-processing software such as Pix4D, Agisoft PhotoScan, or Postflight Terra 3Dsoftware to perform photogrammetric processing of digital images and to generate 3-D spatial data. For example, it is possible to apply Agisoft PhotoScan for a fully automation of the post-processing including image registration for orientations and digital elevation modeling, with either traditional aerial photographs or digital images [9]. A SfM (Structure From Motion) algorithm is adopted in the software to accommodate the situation when there are no control points and/or inner parameters of the camera. SfM will retrieve the spatial coordinates of objects in the stereo-pairs by reconstructing the location and orientations of all the images taken in the air. The procedures of SfM approach include:

1. Reconstruction of the locations and orientations of each stereo-pair;
2. Construction of the trajectories of the camera; and
3. Construction of the 3-D landscape.

Generally speaking, the payload capability of UAV is very limited. Consumer digital cameras are used to replace the conventional metric camera. Thus, it is a pre-requisite to calibrate the digital camera to obtain its parameters, including inner orientation parameters and distortions. These parameters are entered into the post-processing software. Feature points and conjugate points can be retrieved in the software with a function such as Align Photos. Subsequently, photos’ center and orientations of each exposure can be derived. The second stage of the procedure is to use the function of Build Sense Cloud to generate point clouds on the basis of a bundle adjustment and ray tracing approach. This is optimized with filtering out of outliers. The third stage of the procedure utilizes the function of Build Mesh to construct a TIN (Triangular Irregular Network) for the point clouds generated in the previous stage. DSMs (Digital Surface Models) can be generated. The fourth stage of the procedure is applying the function of Build Texture to construct the texture of the 3D models by draping corresponding textures expressed on aerial photographs. It is noteworthy that this involves the reconstruction of the camera parameters of location and orientations. These parameters are better entered as extra parameters for compensating the automatic reconstruction of the adjustment of aerial triangulations and inner orientations.Accurate stereo-models can thus be established with the exterior orientation of each camera exposure stations. Digital Terrain Modes and ortho-photographs can be automatically generated subsequently. Finally, animated videos of the geo-hazards, the 3D models and other useful thematic maps such as slope gradient, slope aspect, and contour lines can be derived as well for other geospatial analyses such as earth volume analysis with Difference of DTMs (DoD) and for assisting in damage assessment and planning mitigation measures.

3. Results and Discussion

After the explosion event of Kaohsiung petro-chemical pipeline, the National Science and Technology Center for Disaster Reduction (NCDR) entrusted the National Land Surveying and Mapping Center(NLSC), Ministry of Interior to collect post-disaster information of $6km^2$ explosion area during 24 hours. An aerial survey was performed by the Geosat Aerospace & Technology Inc. on August 1, 2014. The preparation for aerial survey is shown as Figure 1. A four-axes drone with a Canon EOS 5D Mark II camera had been used in this flight mission. A photograph taken at beside of road section in the explosion area is shown as Figure 2. And a quick overlook came from the Drone is also shown as Figure 3. A total of 502 images were taken at a flight altitude of 200 meters. The dimension of each image is 4384x3288 pixels, the frame size of sensor is 36x24 mm, and average ground sample distance (GSD) of images is 4.8 cm.

After imaging, all taken images were imported into the Pix4Dmapper 1.2.62 version software to perform photogrammetric processing of digital images and generates 3D spatial data. The computation results indicate that number of 2D keypoint observations for Bundle Block Adjustment is 7688561, number of 3D observations is 2160240, and mean projection error is 0.117m. Finally, an orthophoto for post-disaster assessment is shown in Figure 4. The corresponding sparse Digital Surface Model (DSM) is shown as Figure 5.

Figure 1. The preparation for aerial survey

Figure 2. A road section in the explosion area

Figure 3. A quick overlook came from the Drone

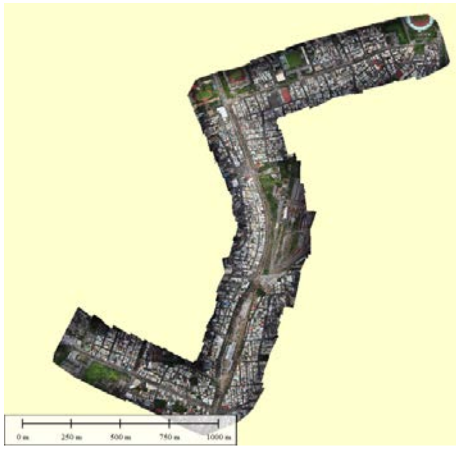

Figure 4. An orthophoto result for post-disaster assessment

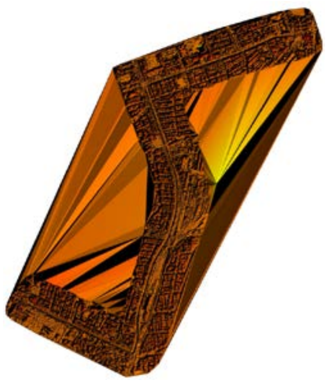

Figure 5. The corresponding DSM before densification

Although there are no ground control points used in the processing, but the fast mapping results still provide overall and real-time important information for post-disaster rescue and restoration work.

3. Conclusions and Suggestions

After the biggest explosion event of the petro-chemical pipeline, we learned the establishment and amendment of dangerous material pipeline safety prescripts for disaster prevention management should be strengthened, and the facility maintenance and the mastery of operation information should be enhanced in the future. Moreover, fast mapping results using UAV techniques for post-disaster information collection had also been introduced in this work. An aerial surveying using a drone, a total of 502 images were taken, mean projection error of 0.117m after aerial triangulation can be derived. The fast mapping results can provide overall and real-time important information for post-disaster rescue and restoration work.

Acknowledgement

The authors would like to thank the National Land Surveying and Mapping Center(NLSC), Ministry of Interior, and Geosat Aerospace & Technology Inc. permitted authors to use their UAV images.

References

[1] Zhou G., Wu J. 2006. Unmanned aerial vehicle (UAV) data flow processing for natural disaster response. In: American Society of Photogrammetry and Remote Sensing; May 1-5; Reno, Nevada. ASPRS .

[2] Bendea H. F., Chiabrando F., Tonolo F. G., Marenchino D. 2007. Mapping of archaeological areas using a low-cost UAV - the Augusta Bagiennorum Test site. In: XXI International CIPA Symposium; Athens, Greece. p. 01-06.

[3] Eisenbeiss H., Lambers K., Sauerbier M., Zhang L. 2005. Photogrammetric documentation of an archaeological site (Palpa, Peru) using an autonomous model helicopter. In: Proceedings of the XXth CIPA International Symposium; Sep. 26-Oct. 1; Torino, Italy. International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, p. 238-243.

[4] Eisenbeiss H., Zhang L. 2006. Comparison of DSMs generated from mini UAV imagery and terrestrial laser scanner in a cultural heritage application. In: ISPRS Commission V Symposium; Sep. 25-27; Dresden, Germany. International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, p. 90-96.

[5] Horcher A., VisserR. J. M. 2004. Unmanned Aerial Vehicles: Applications for Natural Resource Management and Monitoring. In: Council on Forest Engineering Annual Meeting;April 28-30; HotSprings (AR), USA.

[6] Li S. 2011. The use of Low-altitude Unmanned Aerial Vehicle System in the Measurement of Large-scale Topographic Maps —Take the 1:2000 mapping of PuWen as an example. In: 11th South EastAsian Survey Congress and 13th International Surveyors' Congress Innovation towards Sustainability;June 22-24;Malaysia.

[7] Lin Z. J.. UAV for Mapping Low-altitude Photogrammetric Survey. In: International Archives ofthe Photogrammetry, Remote Sensing and Spatial Information Sciences; 37(B1), p. 1183-1186.2008.

[8] Tahar K. N., Ahmad A., Wan M., AkibW. A. A., Udin W. S. 2011. Unmanned Aerial Vehicle Technology for Large Scale Mapping. In: ISG (International Symposium and Exhibition on Geoinformation) & ISPRS(International Society for Photogrammetry and Remote Sensing); ShahAlam, Malaysia.

[9] Chang K. T., Liou Y. A., Hwang J. T., Lee G. W., and Liu J. K. 2014. Using a UAV for Collecting High Resolution Geospatial Data for Golf Course Maintenance. In: International Symposium of Remote Sensing (ISRS 2014); Korea.