Creative Construction Conference 2016

Application of UAS for Nuclear Plant Containment Building Inspection: Lessons Learned from Testing the First Application

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Abstract

Inspection of cracks on the surface of tall concrete structures, including nuclear power plant containment buildings, often starts with visual monitoring, for which field crews need to climb up those cylindrical structures. In many cases, this practice takes time, cost significantly, and is dangerous. Korean Electric Power Corporation (KEPCO) has experienced this challenge for years while maintaining their nuclear power plants. Seeing how small Unmanned Aerial Systems (sUAS) are used for crop and livestock monitoring, one may be wondering if sUAS could be used to take pictures of cracks on the surface of the containment building. However, assuming that pictures need to be taken at a very close distance from the surface of the containment building, and also knowing that the line of sight has to be maintained all the time between sUAS and radio controller, one can reasonably figure out some challenges in terms of controlling sUAS manually. As a first step to handle this challenge, a research team at Texas A&M University developed a computer application that controls sUAS to fly around a simple circular building autonomously while changing its elevations. This paper presents how this application works, and what we learned from our field test.

Keywords: concrete crack monitoring, unmanned aerial system, waypoint flight control.

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1. Introduction

Korea Electric Power Corporation (KEPCO) is a company that was founded in 1898 with an objective to generate electric power in South Korea. It runs several units of power plants including 23 nuclear power plant units in operation, 5 units under construction, and another 10 units in the planning stage [1]. Learning from previous accidents in Three Mile Island in 1979, Chernobyl in 1986 and Fukushima in 2011 [2], no one can emphasize enough the importance of safety in operating and maintaining the nuclear power plant. Among many facilities in the nuclear power plants, the containment building is one of the critical buildings, as it should prevent radioactive substances from leaking even in the worst-case scenario. Therefore, the Korean Government Ministry of Science and Technology [3] mandates that the containment buildings need to be inspected periodically.

The visual inspection of the containment building often requires field crews to climb up to a higher elevation or employ special cranes to detect any cracks that would endanger the stability of the structure, which prevents them from inspecting the structure surface more frequently. In case of using telescope lens to monitor any crack developments, they even need to deal with distortion problems.

2. Small Unmanned Aerial Systems (sUAS)

Unmanned Aerial Systems (UAS), which is also known as Unmanned Aerial Vehicles (UAV) or simply drones, have been originally used for military operations. Recently, various small Unmanned Aerial Systems (sUAS) were introduced for commercial use and they have been used to take aerial photos or video footages of construction sites. They are also used for emergency and disaster management, traffic surveillance and management [4]. Metni and Hamel [5] proposed sUAS for periodical visual inspections of bridges without interrupting traffic flows, and

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obtained images of cracks on concrete surface with good resolution. Morgenthal and Hallermann [6] discussed the potential use of sUAS for visual inspection of vertical structures including chimneys, towers and other structures, where cracks can be developed in higher elevations. In a study reported by Niethammer et al. [7], a drone equipped with a digital compact camera was used to track a landslide, soil moisture changes, and landslide displacement. Ruzgiene et al. [8] demonstrated the advantages of UAV with respect to collecting aerial photos and converting them into a 3D model.

There are different models of sUAS, and some of the most important ones are Fixed Wing and Multirotors. The first ones are mainly used for aerial mapping covering large areas including mines sites and stockpiles. The second ones are used for detail inspection of hard-to-reach structures such as towers, bridges, and other structures [9].

3. Automatic control of sUAS

Some sUAS can be controlled with pre-defined waypoints or points of interests. For example, the 3DRobotics, one of the leading sUAS vendors in the U.S., offers various applications including Mission Planner, MAVProxy, DroidPlanner, Tower, AndroPilot, MAVPilot, iDroneCtrl and QGroundControl [10] for automating the flight of sUAS using pre-defined waypoints or points of interests. These applications use various sensors including gyroscope, barometer, accelerometer, and Global Positioning System (GPS) to determine the location, elevation, and directional angle of the sUAS in operation. Most automatic flight control applications are used in an open space to pick up a series of aerial photos or video footages of a site, which can be used later for producing a digital map or a 3D topography model. One may speculate then if the visual inspection of nuclear power plant containment buildings can be executed automatically by utilizing these automatic flight control applications.

To test if it is possible to inspect the surface of the nuclear power plant containment building automatically using sUAS, a research team at Texas A&M University developed two computer applications enabling sUAS to fly autonomously around cylindrical objects. These applications were developed for a specific sUAS called IRIS from 3D Robotics. This particular sUAS was chosen for this test because of its flight controller called PixHawk, which can be controlled through a computer application that one can develop based on the open-source led by Dronecode Project. The Dronecode Project is an open source project led by the Linux Foundation, and it facilitates to develop a collaborative computer application for the automatic flight of the sUAS.

The first application developed for this test is about having the sUAS to fly around a point of interest, starting with an initial height and elevating to higher altitudes with constant intervals for a number times pre-defined. Figure 1.a. has the snapshot image of the tablet or mobile application waiting for user data input for the longitude and latitude coordinate of the point of interest, radius, initial height, height step, and the number of iterations. With this inputs, the application is supposed to have the sUAS fly autonomously around the point of interest multiple times while elevating its altitude each time as shown in Figure 1.b.

The second application developed for this test is slightly different from the first application, as it is designed to change the radius of the flight once the sUAS reaches at a certain altitude. The sUAS keeps flying about the target point until it reaches the maximum height pre-identified by the user. Figure 2.a. shows the snapshot image of the second application, waiting for the user input, and Figure 2.b shows the flight pattern of the sUAS suggested by the application.

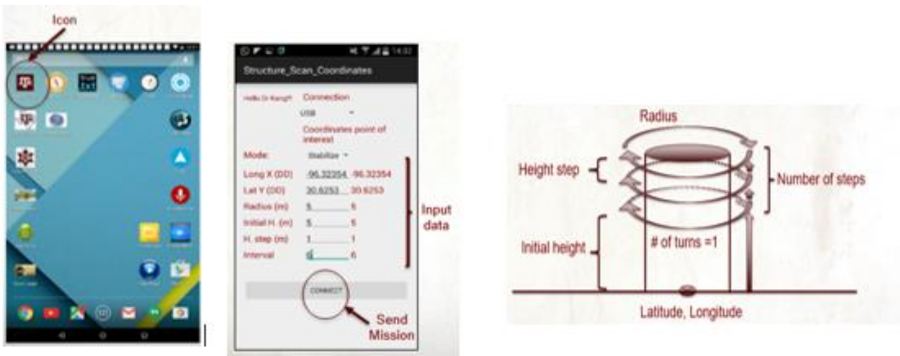

Figure 1: a. Snapshot of a tablet or mobile application 1 which controls automatically the flight of the sUAS (left and center), and b. flight path of the sUAS (right)

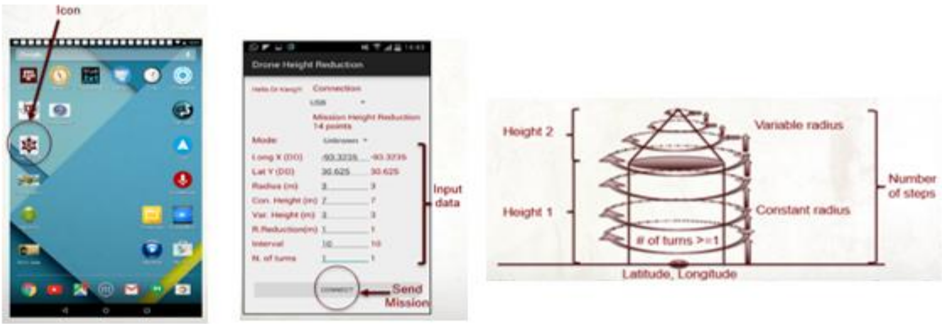

Figure 2: a. Snapshot of a tablet or mobile application 2 which controls automatically the flight of the sUAS (left and center), and b. flight path of the sUAS (right)

4. Field Tests

A field test was implemented in an open space, where a 6-meter pole was placed in the middle. The pole was wrapped with a masking tape in different colors for each an every 1 meter, so that it could be used later to measure the distance between the pole and sUAS flying around it through photos taken from the sUAS. An IRIS from 3D Robotics was used for this test, and a GoPro camera was mounted on the IRIS, which was setup to take time-lapsed photos every second.

The test started by having the IRIS fly autonomously as defined by the user inputs in the application 1 defining the initial height, interval between heights and radius of the circle that the IRIS would fly through. The GoPro mounted on the head of the IRIS kept taking photos every second. Theoretically, one can expect that these pictures would have the pole in the middle if the IRIS flew according to all setups.

A total of 385 pictures were taken from the test, and these pictures were examined to calculate 1) the distance between the pole and the IRIS, and 2) the offset distance of the pole from the center of the photo. These two data were used to determine the longitudinal and latitudinal position of the IRIS. The position of the IRIS could also be identified by collecting the GPS location information from the IRIS, however this test decided not to depend on it knowing that GPS location information carries a certain amount of errors. Figure 3 shows a sample photo taken from the IRIS. These basic dimensions are then brought to a CAD application, and used to determine that locations of IRIS when a specific photo was taken, as shown in Figure 4.

Figure 3: Photo G0024883 taken in a height of 3 m.

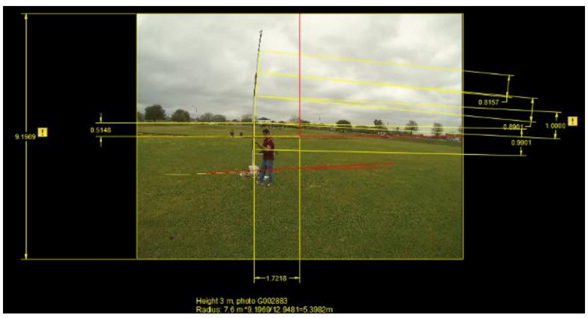

Figure 4: Photo G0024883 analyzed in a CAD application

5. Discussion

The test revealed that sUAS did not fly exactly as programmed. For example, as shown in Figure 5, the x components of the sUAS's location were offset somewhere between 1.5 meters and 3 meters. Currently, additional investigation is still going on to figure out what caused these tolerances. However, one can easily speculate that this might be caused by the native errors carried originally from the GPS. If these errors were caused by the GPS, then sUAS may not be engaged in automatic flight in a congested area such as nuclear power plant sites. Proximity sensors may need to be used in order to increase the accuracy level.

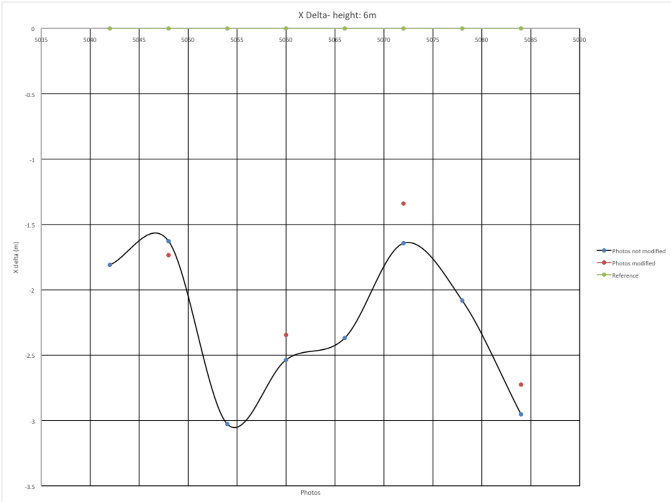

Figure 5: Horizontal distance in meters between the center of the picture and the pole's position per photo in a height of 6 meters

6. Conclusion

Two computer applications were developed to see if it is possible to control the flight of the sUAS for taking aerial photos in a congested area such as nuclear power plants. The application 1 was tested using IRIS from 3D Robotics, and it reveals the gap between the target position and actual position of the sUAS, which ranges somewhere between 1.5 meters and 3 meters. This tolerance level may not be good enough to get sUAS engaged in automatic flight for photo taking. It appears that additional devices such as proximity sensors need to be attached to the sUAS to increase the level of accuracy.

References

[1] KEPCO. (2013). Nuclear power. Available at: http://home.kepco.co.kr/kepco/EN/B/htmlView/ENBBHP001.do?menuCd=EN020201 (Retrieved November 18, 2015).

[2] World Nuclear Association. (2015). Safety of Nuclear Power Reactors. Available at: http://www.world-nuclear.org/info/safety-and-security/safety-of-plants/safety-of-nuclear-power-reactors/ (Retrieved November 18, 2015) [3] G.R. Mettam, L.B. Adams, How to prepare an electronic version of your article, in: B.S. Jones, R.Z. Smith (Eds.), Introduction to the Electronic Age, E-Publishing Inc., New York, 1999, pp. 281–304.

[3] Park, J. & Hong, J. (2009). Present status of nuclear containments and ISI in Korea. Progress in Nuclear Energy 51, 761-768.

[4] Siebert, S. & Teizer, J. (2014). Mobile 3D mapping for surveying earthwork projects using an Unmanned Aerial Vehicle (UAV) system. Automation in Construction, 41, 1-14.

[5] Metni, N. & Hamel, T. (2007). A UAV for bridge inspection: Visual servoing control law with orientation limits. Automation in Construction, 17, 3–10.

[6] Morgenthal, G. & Hallermann, N. (2014). Quality Assessment of Unmanned Aerial Vehicle (UAV) Based Visual Inspections of Structures. Advances in Structural Engineering, Vol. 17, No. 3.

[7] Niethammer, U., James, M., Rothmund, S., Travelletti, J., Joswig, M. (2012). UAV-based remote sensing of the Super-Sauze landslide: Evaluation and results. Engineering Geology 128, 2-11.

[8] Ruzgiene, B., Aksamitauskas, C., Daugela, I., Prokopimas, S., Puodziukas, V., Rekus, D. (2015). UAV Photogrammetry for Road Surface Modelling. The Baltic Journal of Road and Bridge Engineering, 10(2), 151-158.

[9] sUAS News. (2013). UAV: fixed wing or rotary?. Available at: http://www.suasnews.com/2013/09/uav-fixed-wing-or-rotary/ (Retrieved March 30, 2016)

[10] Ardupilot. (2015). Choosing a Ground Station. Available at: http://planner.ardupilot.com/wiki/common-choosing-a-ground-station/ (Retrieved December 3, 2015)