Indoor Visualization Experiments at Building Construction Site using High Safety UAV

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Abstract –

Importance has been placed on improving productivity at construction sites in a recent year, reducing bitterness and repetitive work, and improving the efficiency of inspection and management work. Since buildings usually have a unique shape, efficiency improvement methods used in mass production plants had not been able to be applied, however, due to the recent progress in machine learning and robotics technology, complex works have also been becoming possible gradually. Especially at a construction site where the gross floor area is large, it is necessary to spend a lot of time for checking the status of daily situations and inspection work, and then it is often discussed as an object of efficiency improvement. There are also attempts to autonomously run the rover at a construction site, photograph the surroundings with a camera, automatically check a situation with Building Information Model (BIM), and identify the unusual part. However, the floor surface of the construction site is generally complex shape in many cases, for example reinforcing bars are exposed, it is not easy to run around. Accordingly, we focused on Unmanned Aerial Vehicle (UAV) as a means to move freely without concern the shape of the floor. There are many merits because it is possible to move in any structure as long as it is a small UAV, and it is also possible to grasp states of a high altitude that cannot be reached by a rover. Although autonomous flight of UAV is almost established outdoors, the introduction of indoor autonomous flight has not advanced yet because localization technology and object recognition technology are insufficient, and the risk of damage to people and structures due to collision and fall. There are some UAVs equipped with collision avoidance sensors, and safety is not guaranteed completely. Therefore, in this research, we developed a high safety UAV against collision and falling and conducted experiments on verifying the efficiency of inspection work and the possibility of visualization of acquired data. To ensure strong safety, a balloon type fuselage was manufactured, and collision tests and drop tests were carried out to confirm that it is incredibly safe. Besides, we performed a flight test in the indoor construction site using the UAV and demonstrated that it could be used for inspection work. Furthermore, the walkthrough view was generated from the photographed image for making daily progress management easily. As the results, it was confirmed that some works of walking around the construction site for checking would be reduced, and productivity will be improved. In the near future, we aim to collect data by autonomous flight at night when work is stopped and to create a database of daily information.

Keywords –

Construction management; Inspection; UAV

1 Introduction

The productivity of the construction site has not much changed for decades. Improvement of productivity such as reduction of repetitive work, inspection, and management optimization by cooperation with BIM, becomes an urgent issue. Since the shapes of buildings are usually individual, productivity improvement has been not natural so far. However recent drastic advancement in machine learning technology and robotics technology, even complicated works have also been becoming possible. For example, Shimizu Construction has built a Shimizu Smart Site (Fig. 1[1]) which has been running horizontal slide cranes, column welding robots, arm robot, and horizontal/vertical conveying robot autonomously with artificial intelligence (AI) and internet of things (IoT). The operation status and the work results are recorded and accumulated in real time in the management system integrated with BIM and can be confirmed at any time on the tablet screen, which leads dramatic reduction of work.

Regarding inspection work, it is necessary to spend a lot of time for checking the status of each day and detecting abnormality at construction sites where the total floor area is wide in particular. Typically, a worker is occupied by the inspection work for several hours in a day because pictures taken by a camera at each point including high-place is required. Then it is often cited as an object of efficiency improvement. Thus, there are many attempts to autonomously run a rover at a construction site, photograph and check the surroundings with cameras automatically with the building information model (BIM), and identify the abnormal part[2]. The accuracy of detecting concrete cracks and tile damage by camera imagery has been improved by using AI and machine learning techniques.

However, the floor surface of the construction site is generally in a complex shape in many cases. For instance, since the reinforcing bars are exposed, it has risks and dif-

Figure 1. Shimizu Smart Site

ficulties to walk around. Then we focused on Unmanned Aerial Vehicle (UAV), especially multirotor as a means to survey the site freely without the constraint of the shape of the floor. There are many merits because it is possible to fly any structure as long as it is a sufficiently small UAV, and it also makes possible to grasp the situation of a high altitude that cannot be reached by a rover. Autonomous flight of UAV is generally utilized Global Navigation Satellite System (GNSS), various cameras, Light Detection and Ranging (LIDAR), etc. However, GNSS can only acquire absolute position outdoors, distance accuracy from the camera is low while it is relatively easy to recognize an object, the weight of LIDAR is large while it has high distance accuracy. Although autonomous flight of UAV is usually achieved outdoors, indoor flight has a risk of damage to people and structures due to collision and fall because of the difficulty of localization technology and object recognition technology have not sufficiently developed yet. Carnegie Mellon University[3] and Pennsylvania University[4] are working on research of autonomous flight in GNSS-denied environments, and partially succeed in flying while carrying out localization and obstacle avoidance even in complex shape. Although there are some products equipped with collision avoidance sensors, these are not entirely guaranteed safety. Utilizing UAV for indoor inspection by comparing to BIM is not yet practically sufficient[5] because of the above reasons.

Therefore, in this research, we developed a quite safe multirotor against collisions and falls. Flight experiments were conducted for verifying the efficiency of inspection work and the possibility of visualizing the acquired data. To ensure reliable safety, a balloon-type fuselage was manufactured. Collision and drop tests were carried out to confirm that it was extremely safe. Since it uses injected helium gas, it also has the advantage of increasing the payload weight by buoyancy. Besides, we conducted a flight test in an indoor construction site using the multirotor and demonstrated that it could be used for inspection work. Furthermore, walkthrough view was generated from the photographed imagery which makes daily progress management easy. As a result, it will reduce the amount of walking and checking works, which means productivity considered to be further improved.

Ultimately, we plan to aggregate data by autonomous flight through the night when work is stopped and to create a database of daily information automatically in the future.

2 Method

2.1 Concept

As mentioned in the previous section, general multirotor has the risk of crash and collision, and it is not allowed under current circumstances to use it at the construction site where safety is of utmost importance. Also, if the interior is damaged before completion, time and cost will be wasted. Therefore, in any case, safety must be ensured. As a means to solve this problem, a structure having a spherical frame, a structure hanging from a spherical balloon, a method of mounting an airbag, a structure of extremely lightweight, and a way of making the UAV itself a balloon-type are conceivable. Although the spherical shell structure is lightweight, there is a risk that it may be caught by reinforcing bars or pipes at a construction site, the method of hanging from a spherical balloon is challenging to ensure mobility, the airbag has uncertainty of deployment, lightweight body has a disadvantage that cannot mount a highly accurate sensor.

Therefore we focused on balloon-type multirotor, which can overcome any of the above drawbacks. First, we confirm the flight performance using this balloon-type body. Also, experiment by changing the type of camera installed, and confirm what kind of capturing method is most beneficial to the construction site. The camera to be used is a spherical camera, infrared camera + visible camera, and a high-resolution action camera.

Since the operator must easily check the photographed image, a visualization test is performed by creating a walkthrough view of the work site for validity confirmation. In the future, we will build a system that automatically carries out everything from site photographing by autonomous flight to visualization.

2.2 Balloon-type Multirotor

The figure 2 shows the developed balloon-type multirotor. The position and attitude angles are controlled by the rotational speed of the four propellers attached to the rods. In the center of the body, communication equipment, control equipment, battery, and camera are installed. Depending on the application, the camera can be replaced with a spherical camera, an infrared camera, an action camera, etc., and its orientation can also be changed.

As shown in the table 1, the outside body is covered with polyvinyl chloride so that both collision safety and buoyancy are acquired by injecting helium gas into the inside. Since it is a prototype, the payload that can be installed at present is as small as 0.3 kg and the flight time is as short as 10 minutes, but these can be improved by the design refinement and the advance of battery performance. The propeller noise is the same as a conventional multirotor, and the flight speed is about the same as a person's walk. Also, video transmission by wireless is also enabled. Because it is very safe against a collision, it also has the advantage that it is possible to take close-up shots when examining walls and ceilings.

Figure 2. Balloon-type Multirotor

Table 1. Specification

Size	$\phi 1.2x0.6$ m
Weight	1.6 kg
Buoyancy of helium gas	−0.3 kg
Endurance	10 min
Speed	1.0 m/s
Membrane	PVC

2.3 Time-Series Spherical Viewer

There are various ways to visualize the acquired data, such as three dimensional model generation by Simultaneous Localization and Mapping (SLAM)[6, 7], Structure from Motion (SfM)[8], a database of images by cooperation with indoor positioning system by Bluetooth beacon or ultra-wideband (UWB), fixed camera images, immersive viewing system with virtual reality (VR) headset using spherical imagery, and so on. However, as the result of our examination and hearing, we found that the walkthrough view of spherical images can be most intuitively operated and the inspection is easy. Therefore, by using commercially available Holobuilder[9], it is possible to browse by moving to the target place simply by clicking the points on the screen or clicking the position on the drawing. Additionally, since images can be saved in chronological order, it is also possible to confirm daily changes, progress, and the cause when an abnormality occurs.

3 Results

The size of the multirotor body is 1.2 m in diameter that is rather large in the present situation, and then the flight experiment was carried out at the site under construction of sufficiently large space (Fig. 3). As a component where inspection is difficult with a general rover, the diagonally below the catwalk near the ceiling was selected as the experimental location.

According to preliminary verification experiments, it was found that the body is very safe against collision and fall, and not damage the object. Additionally, depending on the environment it turned out that the multirotor was liable to disturb the attitude angle by the wind. This is thought to be due to the fact that the shape of the body is ellipsoidal, vortices are likely to occur around the periphery, and the drag coefficient is relatively large. Also, since the inertial efficiency is larger than that of general multirotor, it requires more energy to restore the attitude. The airflow due to convection was confirmed although the influx of wind was also shut out at the experimental site, it was able to stably fly by adequately tuning the attitude control parameter of the multirotor. Typically, when the aircraft is too close to a wall or object, it is likely to be sucked in because the air current is disturbed and the posture is not stable. Nevertheless, such a phenomenon did not occur in this experiment. However, due to the shape of the fuselage and the lack of performance of the propeller, the robustness of attitude stability against a wind more than 1 m/s is not enough at the moment. In the future, it is necessary to improve so that it can maintain stable attitude and position in any wind environment.

Figure 3. Inspection of Catwalk

The figure 4 is an image of a spherical camera (Ricoh Theta V). Because interval shooting is possible, we shot every 4 seconds this time. The resolution of the photo is 5376 x 2688 pix, and the weight of the body is 121 g. As shown in the figure, since the camera is attached to the upper part of the UAV, the lower one third is hidden by the balloon film surface. However, there was no problem

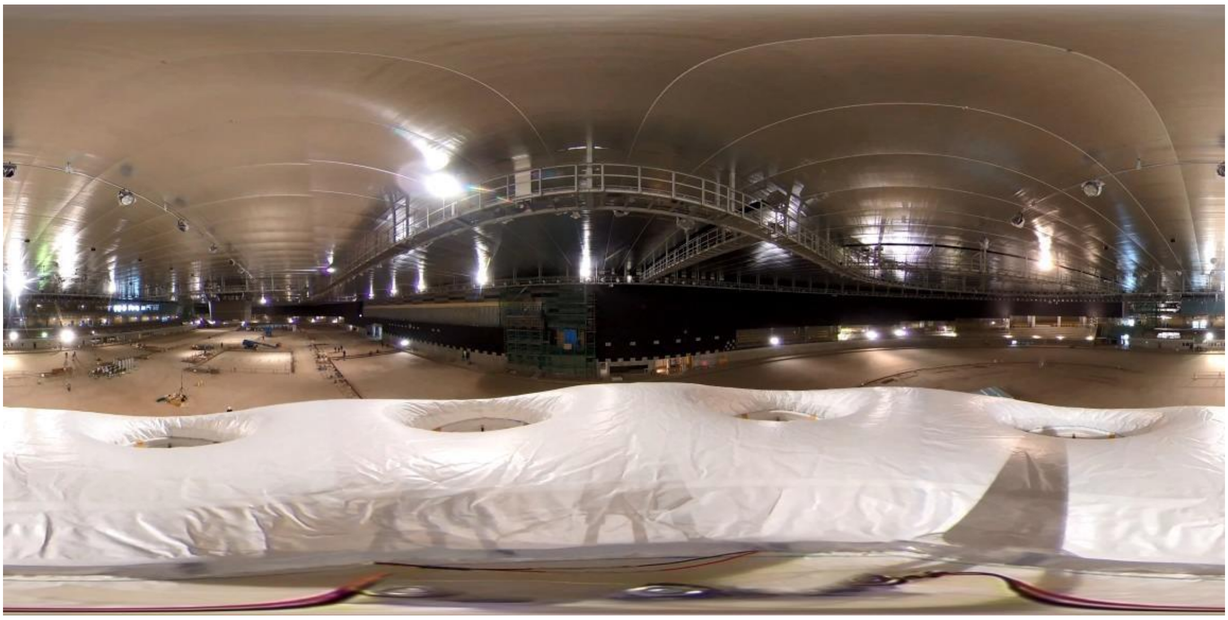

Figure 4. Onboard Spherical Camera

because this purpose is photographing in the upward direction, and further the camera can be attached to the lower part, and then it can be changed according to the purpose.

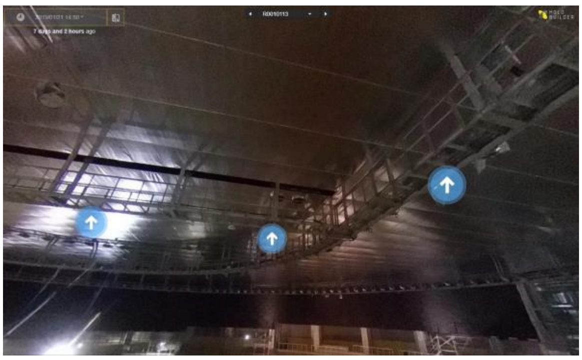

Figure 5. Walkthrough View

The figure 5 shows an example of created walkthrough view from the above spherical camera image using Holobuilder which is on-site image management software. The image can be rotated and scaled quickly, and by clicking the arrow arranged on the picture, it is possible to move to the viewpoint image from the place. By registering the position of the image on the drawing, it becomes possible to view the whole sky ball image at the viewpoint of the desired place. Furthermore, since images can be managed in time series, it is possible to manage daily progress. Also, data is managed on the cloud, and then it can be shared and edited by multiple people. It also has functions such as adding annotations, browsing from mobile devices, and distance measurement. Although it is useful software in visualization, it has a disadvantage that it requires human work such as registration of a position of an image. Recently, the software that can automatically performs localization from a movie and image extraction also appears.

Figure 6. Onboard Action Camera

The figure 6 is a captured image of a motion picture taken by action camera (GoPro Hero 6, 120 g weight). It is possible to take a picture at 4K (3840 x 2160 pix), but this time for the purpose of image processing, we shot at 2.7K (2704 x 1520 pix) using Linear View function with lens distortion removed. The image was very clear, and it was possible to grasp the state of the bolt finely and so on. It was also found out that it was possible to reconstruct the 3D model by SfM from Linear View images. However, position information such as a marker is indispensable for high-precision 3D reconstruction, however, it is not desirable to increase the amount of people's work at the construction site where the environment changes every day. It is a future subject to realize everything automatically and unattended.

The figure 7 is an image by FLIR Duo R (84 g weight) which is a combination of an infrared camera and a visible

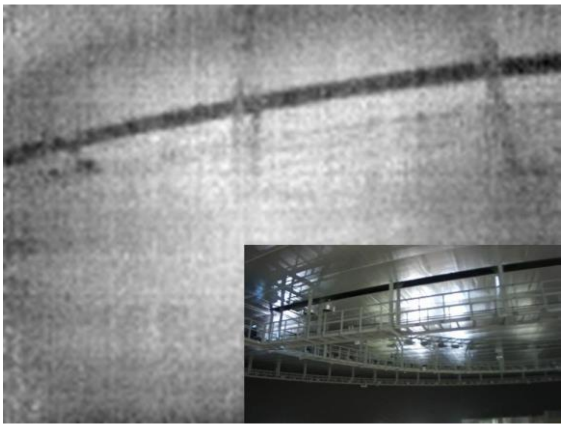

Figure 7. FLIR Infrared & Visible

light camera. As for the resolution, the infrared image is 160 x 120 pix, and the visible light image is 1980 x 1080 pix. Using SfM software such as Pix4D[10], it is possible to paste an infrared image as a texture to a three-dimensional model reconstructed by a visible light image. Researches on abnormality detection using infrared images have been actively conducted for discovering tile deterioration, concrete cracks, or estimate distortion from the temperature of the structure by utilizing artificial intelligence. The resolution of the infrared camera used this time is not sufficient, although it can distinguish a specific temperature difference.

4 Conclusion

We developed highly safe UAV and verified the performance for improvement the productivity of inspection work at a construction site. To ensure reliable safety at any time, a balloon-type multirotor was manufactured. Collision tests and drop tests were carried out to confirm that it was extremely safe. We also conducted a flight test at the construction site of the large indoor space using the multirotor and demonstrated that it could be used for inspection work using the equipped camera.

In the flight experiment of this time, The airflow due to convection was confirmed although the influx of wind was also shut out at the experimental site, stable flight was possible with adequate tuning of the attitude control parameter of the multirotor. However, it easily drifts against the wind and the attitude stability is not sufficient due to its shape of the fuselage. Therefore, future improvement of the robustness against environmental uncertainties is necessary. Also, since the size of the fuselage is slightly big at 1.2 m, it should be miniaturized to a size of less than 80 cm which can pass through the door. Further, since it is not easy to handle helium gas at all times from the viewpoint of cost and operation, it is necessary to improve so that handling can be easily performed with air injection.

Three-dimensional reconstruction by SfM using action camera images is expected, however artificial correction information such as markers is indispensable for highly accurate reconstruction currently. The situation and environment at the site that change every day, it is not desirable to increase the amount of people's work at the site, and it is a future subject to make everything automatic and unattended. Regarding infrared images, if high-resolution cameras are used to make meaningful data, there is a possibility that defects can be found by using machine learning techniques. For the whole sky ball image, we created a walkthrough view to facilitate day-to-day progress management. As the results, it was confirmed that some works of walking around the construction site for checking would be reduced, and productivity will be improved. However, although it is useful software in visualization, it has a disadvantage that it requires human work such as registration of a position of an image. The software that can automatically perform localization and extraction is needed.

In the future, we plan to aggregate data by autonomous flight through the night when work is stopped and to create a database of daily information automatically.

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