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AIRBORNE IMAGERY and LIDAR BASED 3D RECONSTRUCTION USING COMMERCIAL DRONES

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ABSTRACT. In the study, the implementation of 3D reconstruction of buildings using drones is explained. In this project, Airsim was used as the simulation environment and images were obtained from the simulation environment using OpenCV and the Meshroom software was run on these images and modeling was done in the computer environment. For real-world studies, the engineering faculty in Ankara University 50. Yıl Campus was modeled using photogrammetry technique. In the last part, the results of different modelling algorithms were compared.

1. INTRODUCTION

The 3D reconstruction of objects is a general scientific problem and fundamental technology of fields namely, Computer Aided Geometric Design (CAGD), computer graphics, computer animation, computer vision, medical imaging, computational science, virtual reality, digital media [1].

The 3D reconstruction is basically the process of capturing the appearance of objects and creating a realistic object from these data in the computer environment.

Yastikli et al. [2] mentioned the importance of 3D city model production, which is a very popular application that can be used in many different applications such as urban planning, facility management, indoor navigation, and 3D cadastre in recent years. Within the scope of the study, a 3D model was created from photogrammetric map and LIDAR data.

Keywords. Drones, 3D reconstruction, algorithms.
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Today, the two most prominent reasons for using the internet are user-created content and social networks. A virtual environment that we encounter by hosting these two motifs is the 3D virtual worlds called metaverse, whose content is created by the users. In the last few years, owing to the creative content design possibilities these worlds offer, we have witnessed the launch of various metaverse experiments and the creation of an increasingly artistic and architectural design environment in these worlds [3]. We think that 3D restructuring techniques that will carry important structures, historical artifacts and cities around the world to digital environments will become much more popular in the future in this transformation and their use will become more common day by day.

In this study, with the help of the data obtained with the UAV LIDAR and UAV Photogrammetry techniques, which are the most common 3D reconstruction techniques, using a drone from the simulation environment, separate sensitive point clouds were created for these two methods, and then these point clouds were combined using the ICP algorithm and 3D point clouds were created. Then, for real-world studies, the engineering faculty in Ankara University 50th Year Campus was modeled using photogrammetry technique. The numerical data of the point clouds and models produced by using both methods and environments are given. In addition, using the available data set, the results of the 3D reconstructions made with the SIFT, AKAZE and DSPSIFT algorithms used in the photogrammetry technique were compared.

2. Literature Review

The Unmanned Aerial Vehicles (UAV) or drones became popular on recent years and the application area has become wider day by day [4,5]. In general drones can be used for transportation [6], military [7], education [8], tourism [9], and entertainment [10]. On the other hand, one of the most useful areas of the drones is imaging [11]. The capability of capturing wide range of areas makes drones very useful gadget for 3D reconstruction from images [12].

In the literature, there are 2 main approaches accepted in the field of 3D reconstruction. These are scanning and reconstruction with LIDAR systems using depth-based methods, and reconstruction using photogrammetry and computer vision methods [13]. In both methods, the purpose of the process is to collect a sufficiently large set of points in the computer environment by using the target and to recreate the target in the computer environment by making use of these collected points, but they have fundamental differences in terms of working principle.

Photogrammetry, by definition, is an information acquisition technology to assist the measurement and interpretation process of an object using high-resolution photographic images on a specific area or object.

For this study, it needs to be obtain a large number of photographs on an area, using a drone, to enable us to view the area from different vantage points. Similar to how the eyes use incoming information to provide depth perception in the human brain, photogrammetry uses these multiple viewpoints in images to create a 3D map. In this way, it allows to obtain various features by measuring each point on the map. It provides easier interpretation of the resulting 3D point cloud [14].

LIDAR (light detection and ranging) is technology for measuring the distance of an object or a surface using laser pulses. A LIDAR sensor sends pulses of laser light and measures the time it takes for these pulses to bounce off the surface and return. It works with the principle of obtaining the distance information of the object by using the reflected rays from these rays. It also measures the intensity of this reflection. Since it uses laser beams, it needs to work in constant motion. It constantly scans its surroundings and sends out many laser beams, creating a point cloud of millions of dots. In reconstruction methods using LIDAR, points are formed at certain distances according to the position of the scanner as data, and as a result of clustering these points, the target is reconstructed [15].

In many cases, a stand-alone LIDAR sensor will rival the cost of an entire photogrammetry data acquisition system. Precise geolocation lasers are more expensive than cameras. Therefore, it is crucial to evaluate your current and future applications to ensure that investing in LIDAR is the best decision [16].

The drone-based systems using photogrammetry are cost-effective. It gives you flexibility in where and when you get the data. Therefore, we can say that it is more useful.

Senol et al. [17], worked on the modeling of historical buildings using UAV photogrammetry and close-up photogrammetry methods. During their studies, they produced sensitive dense point clouds with UAV photogrammetry and close-up photogrammetry techniques of the Kanlıdivane basilica and modeled by combining the produced clouds. In their study, they stated that the shots taken from the ground caused difficulties in documenting the upper surfaces of the structures. In addition, they stated that the use of modern technologies in their studies is more cost and time efficient than traditional methods in documenting historical structures.

Ulvi et al. [18] used UAV photogrammetry techniques to model the Red Church in their work. In their study, they mentioned that in terrestrial photogrammetry, data could not be obtained at the desired density from some parts of the target, and they stated that UAV photogrammetry is suitable for reconstruction studies.

3. METHODOLOGY

In the past years, 3D reconstruction process performed using gadget on the ground. With the development in the area of UAV technology, the practicality of the reconstruction works was increased by loading the necessary equipment on these platforms and the problem of reaching the high points of the reconstructed objects were handled.

In the first step of the study, Airsim [19] simulation environment which is a medium to simulate different vehicles, gadget and drones, was utilized. It was developed by Microsoft as open source project and built on the Unreal Engine. The biggest advantage of the Airsim simulation environment is that the installation process is simple and it has the Python API, allowing rapid development using simulation. The properties of the tools used in Airsim can be determined by editing a json file. In this way, cameras and sensors can be easily attached to the vehicle. And the settings of these hardware can be made within the same file. Making basic adjustments easily has reduced the share of learning the use of the simulation environment in the time spent on the project, allowing more time to be devoted to the development of the 3D modeling, which is the main focus.

A virtual camera and LIDAR [20] system are installed on the aircraft in the simulation environment. In Figure 1, the parameters of the camera loaded on the UAV can be seen. Photographing process was carried out from a determined trajectory over the targeted area using a camera. Similarly, scanning from the orbit determined using LIDAR was performed. In Figure 2, the LIDAR parameters on the simulation are indicated.

```
"Cameras" : {
  "high_res_bottom": {
      "CaptureSettings" : [
          {
              "ImageType" : 0,
              "Width" : 2048,
              "Height" : 1080
          }
      ],
      "X": 0, "Y": 0, "Z": 2,
      "Roll": 0, "Pitch": -45, "Yaw" : 0
    }
},
```

FIGURE 1. Drone camera parameters in AirSim.

```
    "LidarSensor2": {
      "SensorType": 6,
      "Enabled" : true,
      "NumberOfChannels": 16,
      "RotationsPerSecond": 10,
      "PointsPerSecond": 90000,
      "X": 0, "Y": 0, "Z": -1,
      "Roll": 0, "Pitch": -45, "Yaw" : 0,
      "VerticalFOVUpper": -45,
      "VerticalFOVLower": 15,
      "HorizontalFOVStart": -40,
      "HorizontalFOVEnd": 40,
      "DrawDebugPoints": true,
      "DataFrame": "SensorLocalFrame"
  }
}
```

FIGURE 2. Drone LIDAR parameters in AirSim.

Since the first step of the study was carried out in the simulation environment, the control of the UAV was yielded using the Python libraries provided by the simulation environment. OpenCV [21] library was used to take photos from the camera. Simulation libraries were sufficient for recording LIDAR data. Structure From Motion technique was used in the photogrammetry part of the study, and Meshroom software, which is an open source and free software, was used to perform this technique. Scale-Invariant Feature Transform (SIFT) algorithm is used during point cloud generation. In this way, a 3D model was obtained using the images taken in the simulation environment through the Meshroom software.

Two separate point clouds were created from the LIDAR data and photographs obtained from the field, and these two point clouds were combined with the ICP algorithm. In this way, it was aimed to increase the accuracy of the model to be created from the data obtained, and at the same time, the data obtained from the two point clouds were compared. CloudCompare software was used for these processes.

After the simulation phase of the project was completed and the necessary findings were obtained, the 3D models obtained from various photogrammetry algorithms on the real world were compared. DJI Phantom 3 Professional Drone [22] given in Figure 3 was used for real world photogrammetry. In Table 1, the technical specifications of the drone used are given.

FIGURE 3. DJI Phantom 3 Professional Drone [22].

TABLE 1. DJI Phantom 3 Professional Drone Features.

Property	**Value**
Weight	1280 g
Flight time	23 min
GPS	Yes
autopilot	Yes
Maximum Flight Speed	16 m/s
Maximum Distance	6000 m
Camera Resolution	4000*3000
Camera Sensor	1/2.3" CMOS Effective pixels: 12.4 M
Lens	FOV 94° 20mm
Battery	4480mAh
Battery Type	LiPo 4S
Strength	68Wh

FIGURE 4. AirSimNH Map.

FIGURE 5. Panoramic view of buildings of Ankara University Faculty of Engineering.

For the simulation phase of the study, the AirsimNH map, which is included in the AirSim software by default, was used as the modeling area. This map is a neighborhood consisting of houses with gardens (Figure 4). There are no moving entities on the map.

After the simulation phase was completed, the Faculty of Engineering in Ankara University 50. Yıl Campus was selected for the real world phase (Figure 5).

The software to control the drone was developed in the simulation environment. In this way, it is ensured that the drone implements a trajectory of the determined diameter in a form directed towards the center of the orbit. Later, a camera and LIDAR were added to the drone, and configurations were made for these equipment to record at an inclined angle towards the orbital center. After the UAV equipment was adjusted, the flight was carried out over the designated house. During the flight, environmental photographs of the target area were taken and a LIDAR scan of the area was performed.

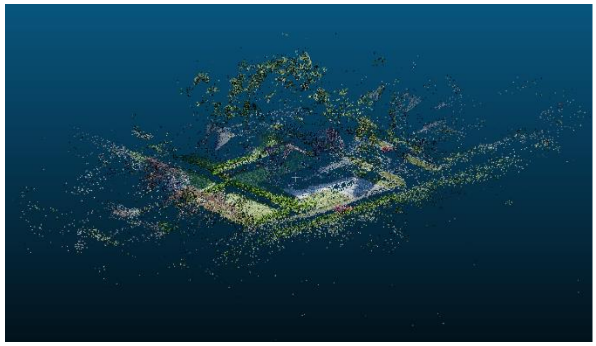

FIGURE 6. Colored point cloud formed by photogrammetry.

The captured photos were processed with the help of Meshroom software and a colored point cloud was obtained at the end of this process (Figure 6).

The color point cloud obtained and the point cloud obtained from the LIDAR scan were loaded into the CloudCompare software. The step to get the 3D reconstruction can be seen in Figure 7. At this stage, firstly, the cleaning process was applied on the point clouds. The state of the point cloud before and after the cleaning can be seen in Figure 8 and 9, respectively.

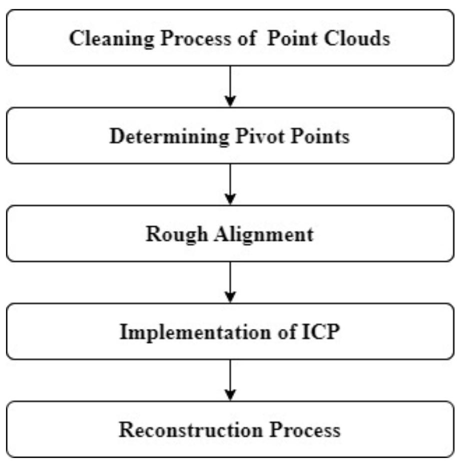

FIGURE 7. Cloud compare steps.

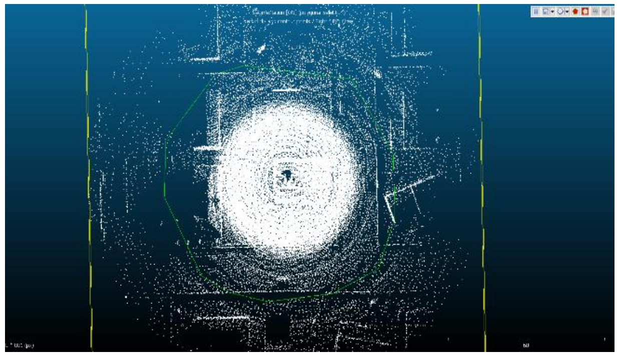

FIGURE 8. Point cloud before cleaning.

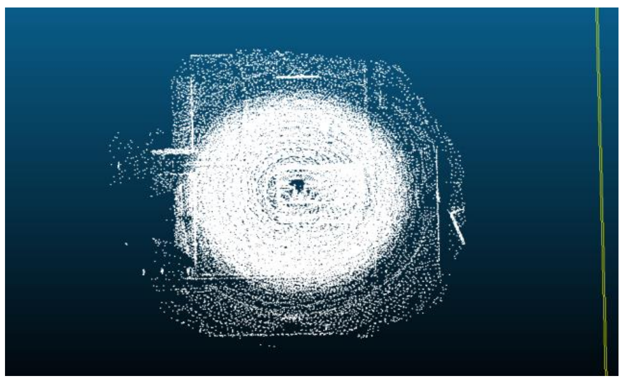

FIGURE 9. State of the point cloud after cleaning.

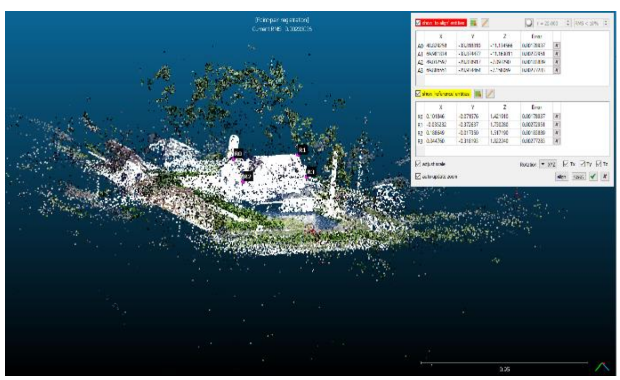

FIGURE 10. Rough alignment of LIDAR and photogrammetry point clouds.

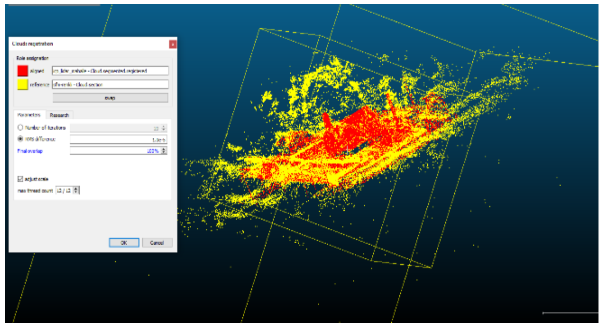

FIGURE 11. Aligning LIDAR and photogrammetry point clouds using ICP algorithm.

The cleared point clouds were first subjected to a rough alignment and proportioning process by manually determining the pivot points (Figure 10).

By applying the ICP process on the roughly aligned point clouds, precise alignment of the point clouds with each other was achieved (Figure 11).

The point cloud obtained by the photogrammetry technique consists of X points. The point cloud obtained by the LIDAR scanning technique consists of X points. The point cloud obtained as a result of combining two point clouds using the ICP algorithm consists of X points.

At this stage, the interpolation process for the colors was carried out by taking the photogrammetry point cloud as a guide for the coloration of the LIDAR point cloud.

The obtained colored LIDAR point cloud was combined with the photogrammetry point cloud and at the end of this process, a single colored point cloud was obtained (Figure 12).

FIGURE 12. Concatenated point cloud using ICP algorithm.

FIGURE 13. A photograph from the data set used for modelling the faculty building.

FIGURE 14. Reconstructed model created by SIFT algorithm.

After the simulation phase was completed, real-world studies were started. At this stage, first of all, photography was taken on the campus using a drone. (Figure 13).

The photographs taken were processed using the SIFT algorithm in the meshroom software, and as a result, a 3D model of the faculty building was created. Below is a sample photo of the 3D model created with the SIFT algorithm. (Figure 14).

4. EXPERIMENTAL CONFIGURATION AND RESULTS

It has been concluded that the use of aircraft provides sufficient viewing angles to these points and is appropriate to use, since there are difficulties in taking pictures of high points and thus creating a 3D model of the structure during the studies.

Today, with the development of technology, technologies targeting Metaverse and similar virtual worlds are becoming popular day by day. Investments are made in technologies that will carry important structures, historical artifacts and cities around the world to digital environments. It has been concluded that the use of 3D reconstruction techniques for this transformation is appropriate and facilitates these processes.

A data set of 66 photographs was used to model the faculty building. SIFT, DSPSIFT and AKAZE algorithms were tested on the data set and point clouds consisting of 125,498 points for SIFT, 147,554 points for DSPSIFT and 111,589 points for AKAZE were obtained. In the case of converting these clouds into models, models consisting of 2,557,802 polygons for SIFT, 2,704,615 polygons for DSPSIFT and 2,577,180 polygons for AKAZE were produced. In the scenario where three algorithms are used together, a point cloud consisting of 366,162 points and a model consisting of 2,522,214 polygons were obtained. The results can be seen in Table 2.

TABLE 2. Comparison of algorithms used in photogrammetry technique.

Algorithms	**Number of Points**	**Number of Polygons**
SIFT	125,498	2,557,802
AKAZE	111,589	2,577,180
DSPSIFT	147,554	2,704,615
SIFT+AKAZE +DSPSIFT	366,162	2,522,214

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