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GENERATION OF TERRAIN PROFILE FOR TERRAIN FOLLOWING

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Abstract

Terrain following should maintain a flightworthy trajectory in order to fly near the ground. To acquire proper trajectory, proper terrain information should be acquired. In this paper, a method to generate the active mode profile which is the terrain profile using radar scan data, and a method to generate the passive mode profile which uses Digital Terrain Elevation Data(DTED) are proposed. After generating each terrain profile using radar scan and using DTED, two kinds of terrain profile are fused together to minimize the risk of collision. The simulations were implemented in the non-lateral directional flight case and lateral directional flight case. The generated terrain profile can be used as a source of TF trajectory.

Keywords: Terrain following, Terrain profile, Radar scan data, DTED

1. Introduction

In military aviation, terrain following(TF) has an important capability. By using TF system, aircraft flies near the ground to minimize the risks of being detected by enemy. To avoid the collision to the ground, it is essential to maintain a flightworthy trajectory which has the specific clearance height over a terrain. Proper terrain information should be acquired to provide a precise trajectory. The terrain information can be obtained from radar and from a digital terrain database[1,2,3]. In this paper, the terrain information for TF is called terrain profile. The terrain profile is composed of the terrain's altitudes which exist within certain intervals along the flightpath as shown in Figure 1. The point which contains the terrain's altitude is named generated altitude point.

Figure 1 – Terrain profile.

Generally, TF only considers longitudinal motion along the aircraft's path[4,5]. Therefore, a 2-dimensional profile should be generated. In this paper, a profile generation algorithm using Digital Terrain Elevation Data(DTED) and using radar scan data are proposed. Both terrain profile generation algorithms are developed assuming the DTED level 2.

The terrain profile generation algorithm using radar scan data is developed assuming that the radar scan data was collected under the specific condition. The radar scan data used in this paper is the result of the existing radar terrain scanning algorithm[6]. There are three noticeable characteristics of the radar scan data. First, as shown in the Figure 2, the farther away the radar scan data are from the starting point of the scan, the farther the radar scan data are detected from the flight path. Scan ID is the unique identifier which is granted to the radar scan data. When the scan frequency is 1Hz, new radar scan data is generated every second. Figure 2 is an example of the scan ID 1. Even though the scan ID is the same, the accuracy of each radar scan data is different.

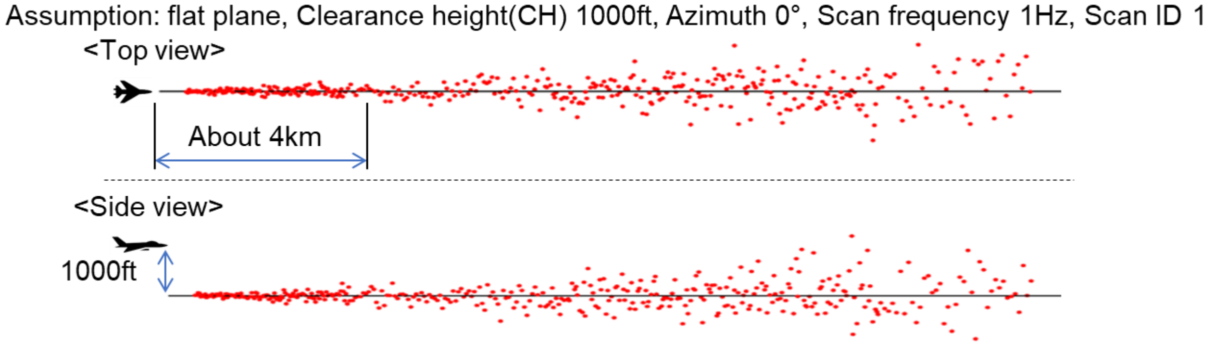


Figure 2 – Characteristic of radar scan data (1)

Second, in Figure 3, as the aircraft moves, the radar scan data are stacked. Scan ID 1 ~ 4 are stacked together. The red '.' is scan ID 1, green 'x' marker is scan ID 2, blue 'square' marker is scan ID 3, and the pink 'triangle' marker is scan ID 4. Red marker is the most accurate radar scan data at first, however, as time passes, the pink marker becomes the most accurate radar scan data among scan ID 1~4. The radar scan data which are positioned far away from flightpath should not be used in the terrain profile generation. Therefore, the data should be extracted depending on its accuracy.

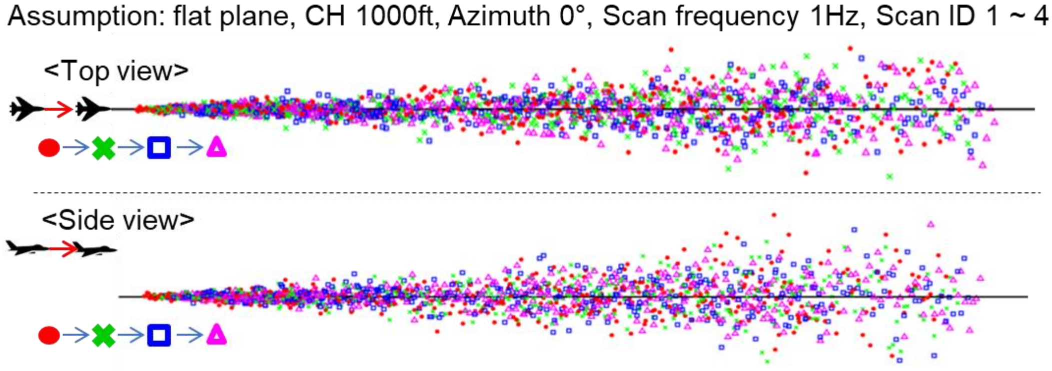


Figure 3 – Characteristic of radar scan data (2)

Lastly, Figure 4 shows that the collected patterns of the radar scan data are different depending on the terrain type. It indicates that the terrain type may have influence on generating terrain profile. The terrain profile generation algorithm using radar scan data is designed considering the characteristics of the radar scan data. The generated terrain profile will be used as a source of TF trajectory.

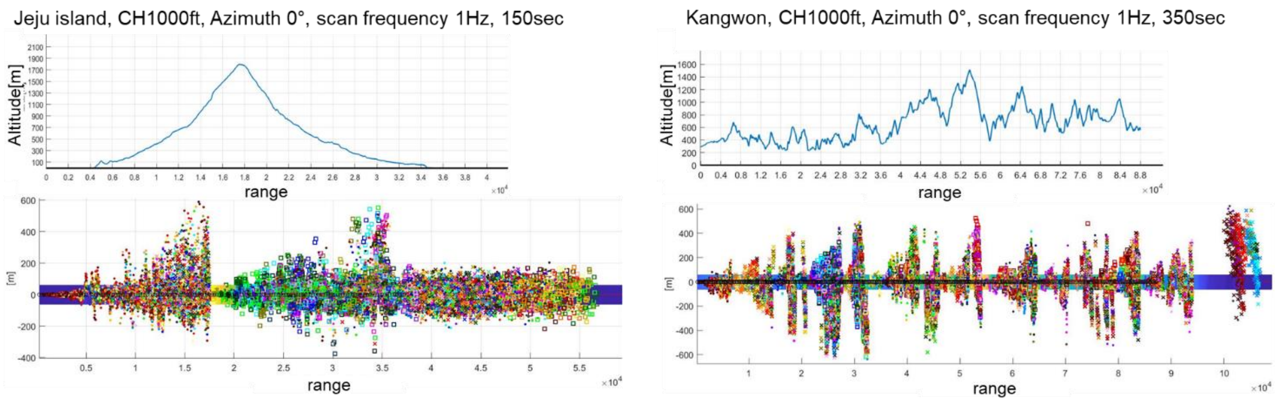


Figure 4 – Characteristic of radar scan data (3)

2. Terrain Profile Generation

The terrain profile using DTED is a passive mode profile and the terrain profile using radar scan data is called an active mode profile. If TF uses both DTED and radar scan data, the hybrid mode profile will be used.

2.1 Passive mode profile

The terrain profile generation algorithm using DTED consists of two steps. First, the start point and end point of the terrain should be defined. Then, the altitude of the generated altitude point is imported from DTED. If the grid of DTED does not match with the generated altitude point, it can be calculated by the bilinear interpolation.

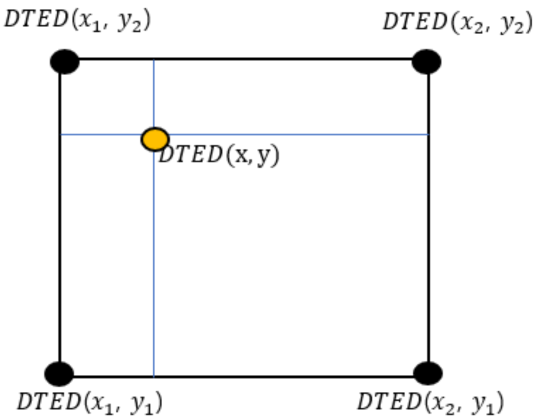


Figure 5 – Bilinear Interpolation

$$DTED(x,y) = \frac{y2-y}{y2-y1}\left(\frac{x2-x}{x2-x1}DTED(x1,y1) + \frac{x-x1}{x2-x1}DTED(x2,y1)\right) + \frac{y-y1}{y2-y1}\left(\frac{x2-x}{x2-x1}DTED(x1,y2) + \frac{x-x1}{x2-x1}DTED(x2,y2)\right) \quad (1)$$

2.2 Active mode profile

A flowchart of terrain profile generation algorithm using radar scan data is shown in Figure 6. The process consists of several steps. When the input data comes in, the radar scan data which are used for generating terrain profile are extracted. The outliers are removed from the extracted radar scan data. Then, a terrain profile using radar scan data is generated. The profile ID is granted to each terrain profile. To generate a more flightworthy terrain profile, the generated altitude points of recent three profile IDs are compounded with each other. After compounding the recent three profile IDs, the active mode profile is generated.

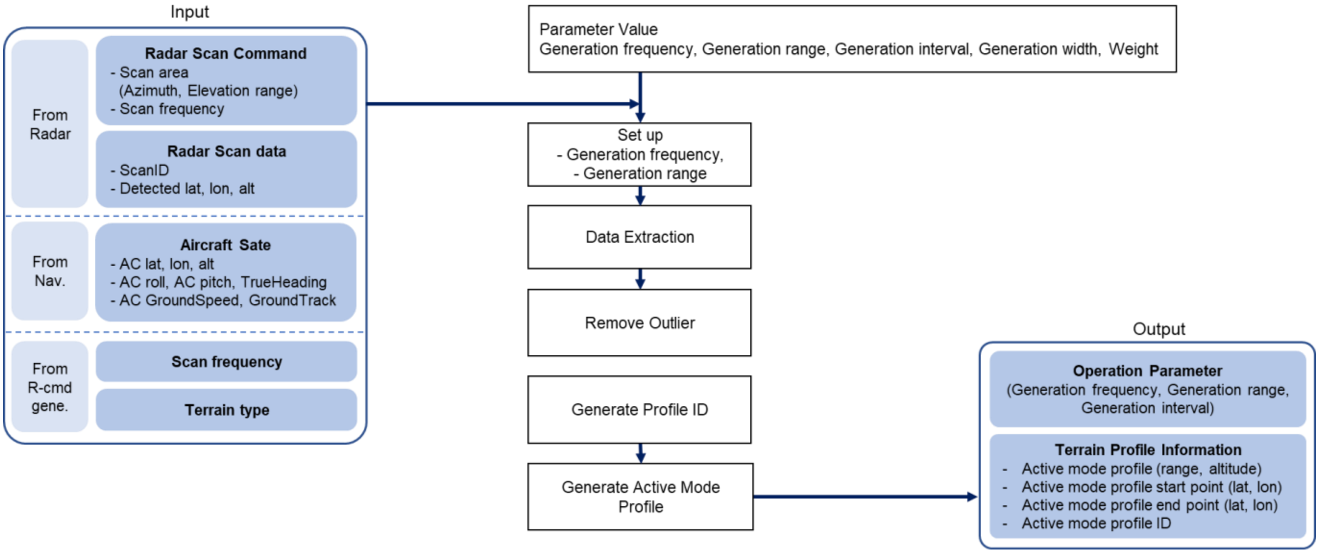


Figure 6 - Flowchart of terrain profile generation algorithm using radar scan data

2.2.1 Active mode profile generation algorithm input/output

From the radar, the radar scan command and the radar scan data come in. From the navigation, the aircraft state comes in. Radar scan frequency and the terrain type are entered from the radar command generator. According to the third characteristic of the radar scan data, the terrain profile should be considered the terrain type as the parameter. The terrain type is determined by terrain roughness[7,8,9].

Table 1 – Terrain roughness

RMSH (σ_T)	**Terrain Type**
800ft ~	Very Rough
200ft ~ 800ft	Rough
60ft ~ 200ft	Moderate
~ 60ft	Smooth

The terrain roughness is measured with DTED level 2. It can be measured as Eq. (2) and (3) which mean Root-Mean-Square-Height (RMSH)[9]. To measure the terrain roughness, the terrain is divided into 1.2km[8], and each section has its own RMSH. According to the Table 1, the majority of the RMSH refers the terrain type.

$$T_{mean} = \frac{1}{N}\sum_{n=1}^{N} T_n \quad (2)$$

$$\sigma_T = \sqrt{\frac{1}{N}\sum_{n=1}^{N}(T_n - T_{mean})^2} \quad (3)$$

There are two outputs, such as, the terrain profile parameter values and the terrain profile information. The generation frequency, generation range and the generation interval are the outputs of the terrain profile parameter values. The active mode profile(range, altitude), active mode profile start point(lat, lon), active mode profile end point(lat, lon), and active mode profile ID come out as a terrain profile information. The active mode profile ID is the given ID to every active mode profile.

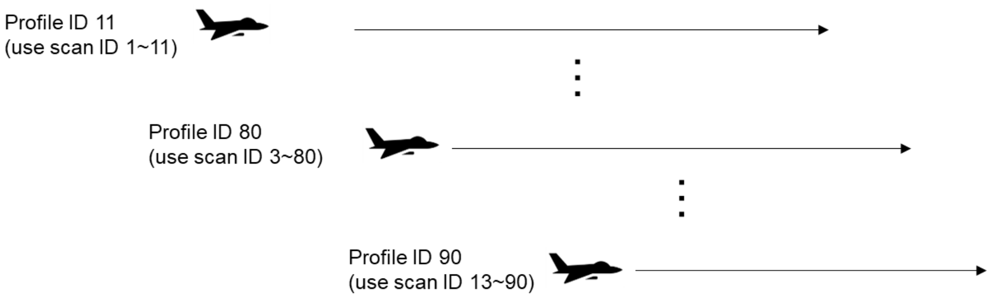


Figure 7 – Active mode profile ID

2.2.2 *Active mode profile generation algorithm*

As the input entered in, the operation parameter values are decided. There are five parameters, the generation frequency, generation range, generation interval, generation width and weight. These parameters can be decided by numerous simulations.

Table 3 – Operation parameter

Operation parameter				
Generation frequency	Generation range	Generation interval	Generation width	Weight

Generation frequency is a frequency of profile generation. It does not need to generate the profile shorter than the scan frequency, because the radar scan data is generated in scan frequency. The scan frequency is one of the active mode profile generation algorithm inputs. Generation range is a range of the profile. Generation interval is an interval of generating altitude. Generation width is a width which can contain radar scan data regarded as having the altitude of the flight path. The profile in the direction of flight path is generated among the scattered scan data. Therefore, data extraction is essential to use the radar scan data which has similar altitude with the flight path's altitude. However, even though the radar scan data exist in the same width, each of them has a different altitude. It is necessary to give different weights considering the accuracy of the scan data. To determine the accuracy of scan data, scan ID and the distance are used. The term 'distance' used in this paper, is the distance between the scan data and generated altitude point of the profile.

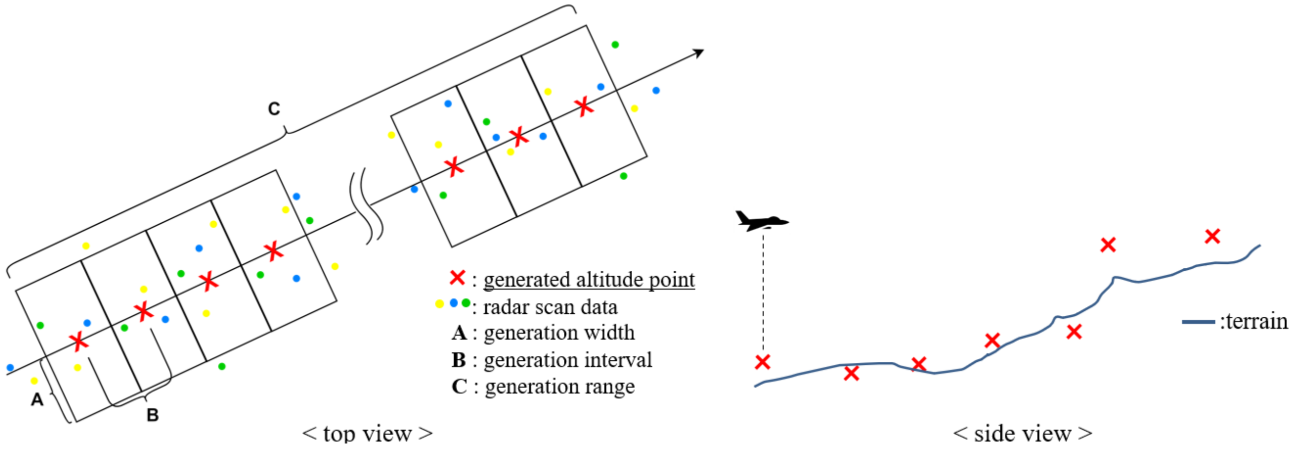


Figure 8 – Description of profile generation algorithm

After deciding the operation parameter, the radar scan data which satisfies the generation width is extracted. The weight is given to the extracted radar scan data. Then the outliers are removed from the extracted radar scan data. By using these radar scan data, the generated altitude points are generated according to the generation frequency, generation range, and the generation interval. The profile is generated in every generation frequency and each profile has its own profile ID. To prevent having a lower altitude than the real terrain, the terrain profile needs to compare the generated altitude points' altitudes of recent three profile IDs.

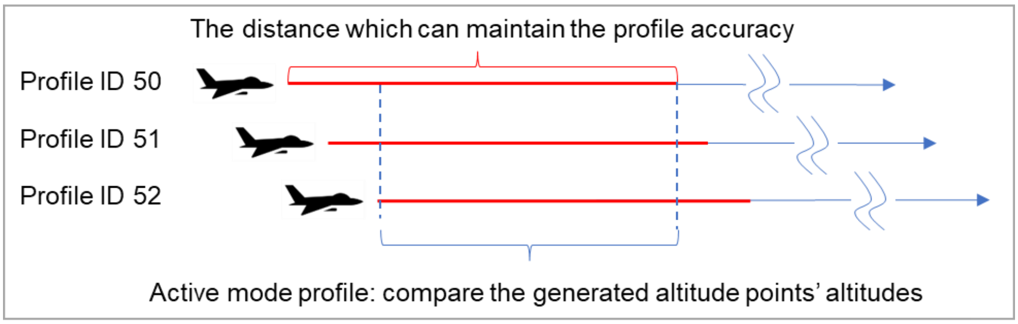


Figure 9 – Comparison of recent three profile IDs

However, while comparing the generated altitude points' altitudes, the number of generated altitude points for comparison should be fixed. From the characteristic of the radar scan data, the radar scan data has inaccurate altitude as the radar scan data far away from the aircraft's position. Therefore, the profile also has lower accuracy as the distance between the generated altitude point and the profile start point gets longer. It is essential to define the accurate distance which can maintain the profile accuracy. The profile accuracy, in this paper, is defined as:

18m / 98% confidence of vertical linear error

which refers to the accuracy of DTED. The accurate distance which can maintain the profile accuracy is about 4km assuming that

- Radar scan frequency, Profile generation frequency are both 1Hz.
- Aircraft groundspeed is 250m/s.
- Moderate terrain.

The number of generated altitude points for comparison can be determined by dividing the accurate distance with generation interval. After comparing the generated altitude points' altitudes, the highest altitude becomes the altitude of the active mode profile. The active mode profile also generates in every generation frequency.

2.3 Hybrid mode profile

After generating a terrain profile using radar scan data and using DTED, the two terrain profiles are fused together. Sometimes the active mode profile has a higher altitude profile than the passive mode profile and vice versa. The higher altitude will be the altitude of the generated altitude point.

3. Non-Lateral Directional Flight Case

3.1 Simulation condition

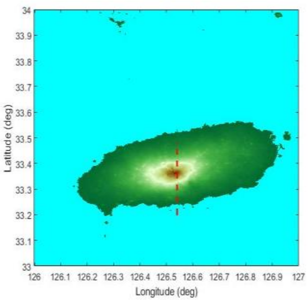
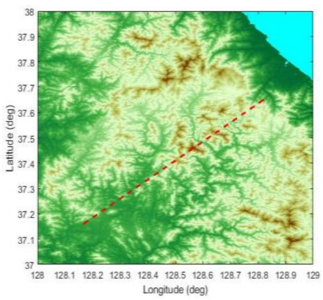
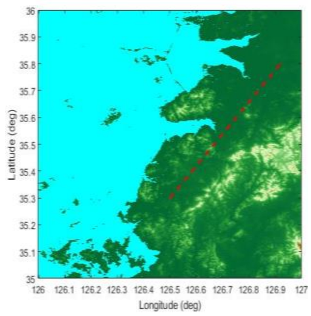
The terrain profiles are generated under the conditions shown in Table 5. After gathering 10 scan data, the profile starts to be generated.

Table 5 – Simulation condition

Conditions			Value	
AC State	Ground Speed		250 m/s	
	AC Attitude		Roll = 0 ˚	
			Yaw = const.	
	AC Angular Velocity		Roll rate = 0	
			Yaw rate = 0	
	Set Clearance		1000 feet	
Radar Scan Command	Scan region	Azimuth	0 ˚	
		Elevation	-00 ˚ / 00 ˚	
Scan Frequency			1 Hz	
Operation parameter	Generation Frequency		1 Hz	
	Generation Range		20 km	
	Generation Interval		30 m	
	Generation Width		60 m	
	Weight		Recent 16 radar scan data	$1 + 1/\sqrt{distance}$
			Else	-

Three terrains are selected for the simulation. Each terrain has different terrain type. The terrain type is determined by the abovementioned method in 2.2.1.

Table 6 – Simulated terrains

Jeju island: Moderate	**Kangwon: Rough**	**Yeonggwang: Smooth**
		
Start point: N33.20 E126.54 End point: N33.60 E126.54 True Heading: 0˚ Scan Time: 150sec	Start point: N37.16 E128.17 End point: N37.65 E128.82 True Heading: 53.13˚ Scan Time: 350sec	Start point: N35.30 E126.50 End point: N35.80 E126.92 True Heading: 40.03˚ Scan Time: 200sec

Jeju island contains 56% moderate terrain, 24% rough, and 20% smooth when excluding the sea. Kangwon contains 47% rough terrain, 42% moderate, and 11% smooth. Yeonggwang has 93% smooth terrain.

3.2 Simulation result

Figure 10 is an example of Profile ID 11 in Jeju island. The black line is the passive mode profile and the red dots are the active mode profile. Blue 'star' marker refers the position of the aircraft. The generated altitude points near 17,500m has an inaccurate altitude while the generated altitude point near 2,500m has more accurate altitude. The active mode profile's generated altitude point has more accurate altitude when the range of the profile is short. It refers that the active mode profile reflected the characteristic of the radar scan data. In range of 5,000 ~ 5,500m, the generated altitude point does not exist, because the radar scan data does not detect due to the high-altitude terrain at the range of 5,000m. Also, even though, generation range is set as 20,000m, the active mode profile only generated until 17,500m due to the high-altitude terrain. On the other hand, passive mode profile shows the whole range of the profile because it does not have any restriction such as radar max range.

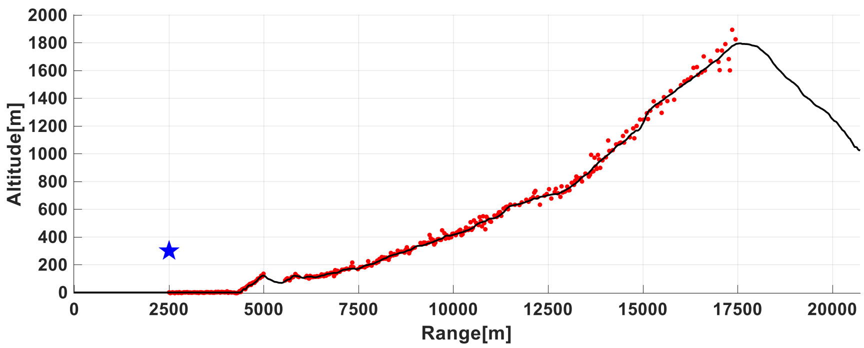


Figure 10 – Profile ID 11 of Jeju island

In case of active mode, profile ID 11 should be generated with scan ID 1 ~ 11, however, scan ID 1, 9, 10, 11 are not existed in the generation width 60m. Therefore, only the data shown in Table 7 are used in generating the first generated altitude point of profile ID 11.

Table 7 – Data used in generating the first generated altitude of profile ID 11 in Jeju island

Scan ID	[lat (m), lon (m), alt (m)]	Weight
2	[24142, 58306, -2.70300]	1.2507
3	[24145, 58314, -15.7015]	1.3680
4	[24153, 58313, -12.0528]	1.3696
5	[24159, 58323, 1.22040]	1.3221
6	[24163, 58316, 6.44120]	1.2687
7	[24161, 58315, -3.99210]	1.2881
8	[24155, 58314, -2.94800]	1.3719

The profile ID 11 of Kangwon and Yeonggwang are described in Figure 11. Kangwon has shorter active mode profile rather than Yeonggwang due to the terrain type. Kangwon is rough terrain, therefore, there are less usable radar scan data. On the other hand, Yeonggwang is smooth terrain so that the active mode profile can be generated up to the generation range.

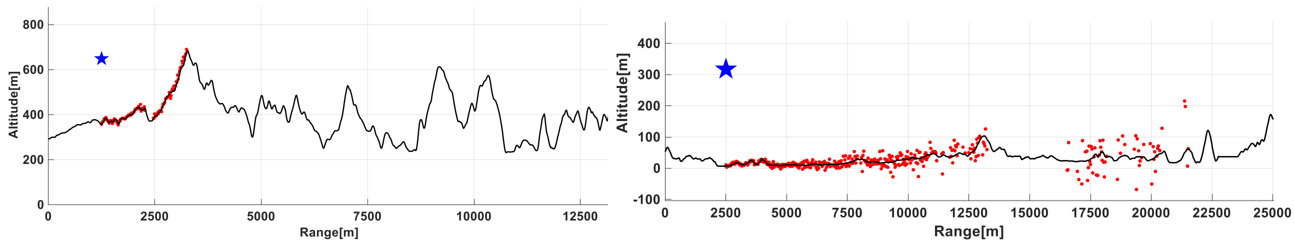


Figure 11 – Profile ID 11 of Kangwon(left) and Yeonggwang(right)

The hybrid mode profile can be generated by fusing the red dots and black line. The higher altitude will become the generated altitude point of the hybrid mode profile.

4. Future Work – Lateral Directional Flight Case

In this paper, the lateral directional case defines as straight flight after the aircraft has manual roll. There are several assumptions as follows:

- The aircraft has constant speed.
- The start time of the straight flight after the manual roll is known.
- The aircraft's rate of turn is known.

As a future work, it is essential to obtain the radar scan data in the direction of the roll. The analysis of the radar scan data should be implemented.

5. Conclusion

The terrain profile generation algorithm using radar scan data is proposed. The profile generated by the algorithm is called an active mode profile. And a passive mode profile is generated using DTED. Also, the mixture of the two profiles is called a hybrid mode profile, which is more flightworthy. The passive mode profile generation algorithm consists of two steps which uses DTED level 2. The active mode profile can be generated in several steps. After introducing the profile generation algorithm, the non-lateral directional simulation is implemented in the three terrains. The active mode profile shows similar characteristic of the radar scan data. As mentioned previously, the farther away the radar scan data are from the starting point of the scan, the farther the radar scan data are detected from the flight path. The active mode profile's generated altitude point has more accurate altitude when the range of the profile is short. It refers that the active mode profile generation algorithm reflects the characteristic of the radar scan data properly. The idea of the lateral-directional case is shown in chapter 4. After simulating in lateral-directional case, the generated terrain profile can be used in the trajectory generation.

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7. Copyright Statement

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