SIMULATION AND FLIGHT TESTING OF AN ALGORITHM THAT USES “RF DISTANCE” TO GUIDE UAVs TO HOME POSITION IN GNSS-DENIED ENVIRONMENT

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ABSTRACT

For the last decade, unmanned aerial systems (UAS) began to be used more frequently and widely for commercial and military purposes, especially for gathering information through their payloads such as day or IR cameras. This rapid and substantial increase in usage began to worry many people, including governments, as it is not possible to determine by whom and with what intentions are these UAS being used. Therefore, several methods were found to counter this capability of UAS. These methods are divided into two main groups: methods to force the unmanned air vehicle (UAV) to immediately land or crash and methods to prevent UAV from accomplishing its objectives. One very popular method among the latter group is to jam the GPS/GNSS signals. By this method, the UAVs, which depend mostly, if not entirely on GPS data for navigation, are unable to determine their position and velocity; therefore, they turn out to be random flying objects out in the blue. Safety and survivability of this adverse conditions forced the UAV designers to mitigate by using less accurate or less available systems for navigation where GPS is made unavailable, such as INS, barometer, magnetometer, optical flow sensors, cameras (for image processing) and adding CRPA into their systems. There are advantages and disadvantages of each system developed. In this paper a novel approach is presented where a limited navigation is achieved by using “RF distance” in GNSS-denied environment. This approach uses the “RF distance” provided by an estimation of the datalink between UAS and GCS (Ground Control Station), which is assumed available since GNSS is much more prone to jamming due to its low energy signal compared to datalinks which inherit significantly different frequency bands and are much more powerful thus harder to jam.

1.0 INTRODUCTION

The “RF distance”, is the estimated distance between the UAV and the ground control station due to the time of flight of the transmitted datalink signal. The novel algorithm uses this information to guide the UAV to the home position as close as possible, by keeping track of the decrease in the RF distance and changing the direction of the UAV by a certain amount whenever it starts increasing and this is repeated until RF distance starts decreasing back again. This method can be implemented both for fixed wing, rotary wing and multirotor UAVs since it does not require any stationary (hovering) condition but more or less constant speed and altitude.

Response of the vehicle significantly changes due to the UAV type, whether it is a fixed wing or multirotor. A fixed wing will need servo inputs to its ailerons to change the direction, on the other hand a multirotor has two options for that; it can change the rotor speeds differentially on its sides to make a roll similar to the fixed wing or it might make another control assignment so that the heading is kept constant while the platform can be directed to the direction desired. That latter option is adopted for the multirotor case in this study where pitch and roll angles are commanded to direct the multirotor back to home position while its heading is kept roughly constant. This particular implementation is made possible under the assumption that constant tilt (a combination of pitch and roll) angle of the multirotor corresponds to a constant speed without knowing its exact value. Eventually that also changes the response time for the vehicle when it is commanded to change its direction. In addition, time interval for checking decrease in the distance, the delta heading angle to change after each check, the resultant value of the pitch and roll angle and the final distance value that the algorithm tries to reach constitute the parameters need to be analysed in this method. The final values of these parameters specific for each UAV type can only be assessed after carefully planned flight tests.

The response time of the vehicle due to the control input, whatever the translation of the direction change, is the essence to the tuning of the algorithm settings to reach the goal of minimum distance to the transmitter source. Like any other flight test preparation process is facilitated by introducing the reliable simulation environments and successful coverage analyses through simulation testing of the algorithm. In addition, these simulations highlighted the critical information which need to be closely monitored through testing thus such information introduced into the custom GCS interfaces even prior to the initial flight test of each different type AV. Therefore, flight testing time and risks considerably lowered. Finally, particular flight test plans are generated to observe actual life issues of the algorithm and flight tests conducted to analyse and improve the performance.

The algorithm is initially run in a simulation on the computer by using the RF distance data and UAV attributes taken from a previous successful flight. After that, the filters to be used for the RF distance data and the values of these parameters are determined to be a base for the test algorithm that will be used in flight tests. The flight tests of this algorithm are done in two groups. The first group of flight tests are to verify the RF distance value, therefore the GNSS system is available during flights. The second group of flight tests are done in GNSS-denied environment, created either by providing fake data to UAV or by using a real GPS jammer. This second group of flight tests are extended by additional tests such as flying in different weather conditions or starting the algorithm at different cruise velocities or different distances from home position during flight. According to the approach performance to home position, the parameters mentioned in the previous paragraph are modified and the tests are repeated. Simulations are also run with these flight test data and necessary corrections to the algorithm are done. As a result, a simulation platform is set up and UAV can be called back home to safety away from the jamming source.

This entire procedure has been followed for two UAV types, one with a fixed wing and one with a quadrotor drone. Constant altitude maintained on both platforms by using static pressure transducers and constant speed assumed to be realized by static pitot sensor on the fixed wing while on the quadrotor platform constant tilt of the platform assumed to be the equivalent of the constant speed.

2.0 RETURN TO HOME ALGORITHM USING RF DISTANCE

2.1 Theory

Inertial Navigation Systems rely on the high-grade expensive sensors (IMUs etc.) to estimate their velocities and positions over long-term integrations without having the correction from the GNSS. Authors studies such a concept in an earlier NATO report (Sinan PAKKAN, 2012) yet different and less expensive solutions have been studied frequently. Especially considering the low-cost UAVs available on the market such an INS system price can be in the same range of the UAV platform thus it is not considered as a solution.

The novel algorithm created here depends on the simple physical concept that once the distance is known, in here it is with respect to the measurement performed on the telemetry system through the time elapsed between the transmitter and receiver, one needs to perform a predefined act to reduce that distance in order to reach the antenna location which coincides with the home location. In control theory this is analogous to the pure P-controller which is a subset of the widely known PID controllers. There are two more aspects that support this relation of this novel algorithm to the P controller; they both have the tendency to fail/diverge in case of large time steps or ample amount of corrections used at each step. For the implementation of this algorithm two requirements need to be met; first, UAV must be kept at the same altitude so the RF distance measurement acquired here can be treated or converted to the horizontal distance; and the other is UAV must be flying at a constant speed. The second requirement can be easily met for the fixed wing UAV since the airspeed is measured through the pitot-static tube which is typically found on almost every fixed wing UAV, but a transformation of controls need to be made for the multi-rotor UAV. This challenging aspect can be overcome under the assumption that when a fixed amount of inclination, either pitch, roll or combination of both, commanded to the platform it should translate to a constant speed condition. This assumption is mostly valid for the less windy conditions or when the wind speed is considerably below the attained speed of the platform.

2.2 Numerical Implementation

A typical numerical solution to a problem requires a good initial point even before getting involved in the theory. In the case of current problem, returning to home when GNSS information is not available, last known bearing angle towards the home is used to direct the UAV back to home. This approximate initial solution to the problem brings the UAV to a fairly closer location around home. Then keeping the flight at a constant direction eventually results an increase in the distance from home as measured from the RF thus the mentioned algorithm above must be utilized.

Two major parameters emerge in this utilization, how often the RF distance need to be observed in order to decide whether it is decreasing or not, and how much correction need to be made on the UAV's heading. Sampling rate of the RF distance is a major concern to overcome the issues related with noise and obviously it is a parameter that can be affected by the flight speed where the first requirement arises. It must be set to the minimum possible value that would also eliminate the false flags due to the noise in the measurement system. Second parameter is the concern for stability of the algorithm that in case of ample amount of corrections are made UAV might diverge from approaching the base. This is due to the dynamics of the UAV, where the input is not and cannot be realized instantly. In the simulation studies it was more explicitly seen in the physics-based model though it is also apparent in the system identification based multi-rotor model where it is encapsulated in the transfer function. Flight testing of the both UAV types showed this trend.

Also, the noise needs to be handled during the numerical implementation process therefore ground and flight testing of the measurement system was performed before advancing any further with the implementation. An initial test is performed by carrying the system on a secure ground vehicle. In Figure 2-1 the results of this test are shown with the following information included. "Reference" is the obtained distance from the autopilot's navigation system (GNSS) and RF distance is the measured value with the marked (*) line corresponding to the data recorded on the GCS and the unmarked data as recorded on the autopilot. Significant noise can be seen in the long period data collection yet the measured data is following the long-term trend of the reference. Another point carried out for the numerical implementation is in case of lower frequency data gathering (as seen on GCS recording) noise is much less of a concern. Figure 2-2 shows the pre-flight test data recording of the reference and the measured data.

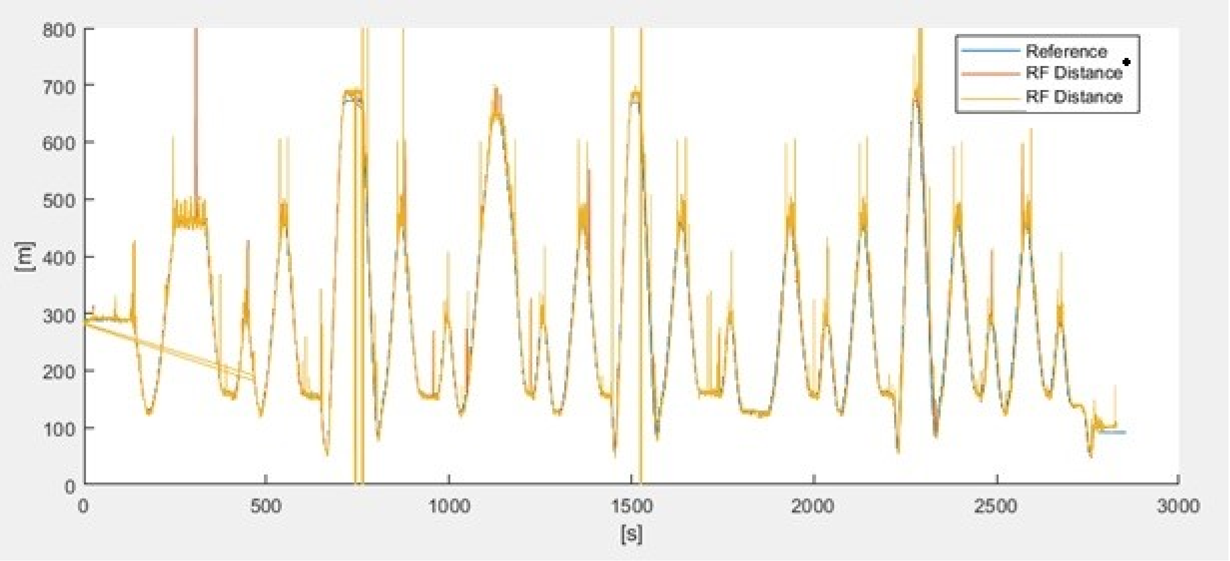


Figure 2-1 Moving Ground Test

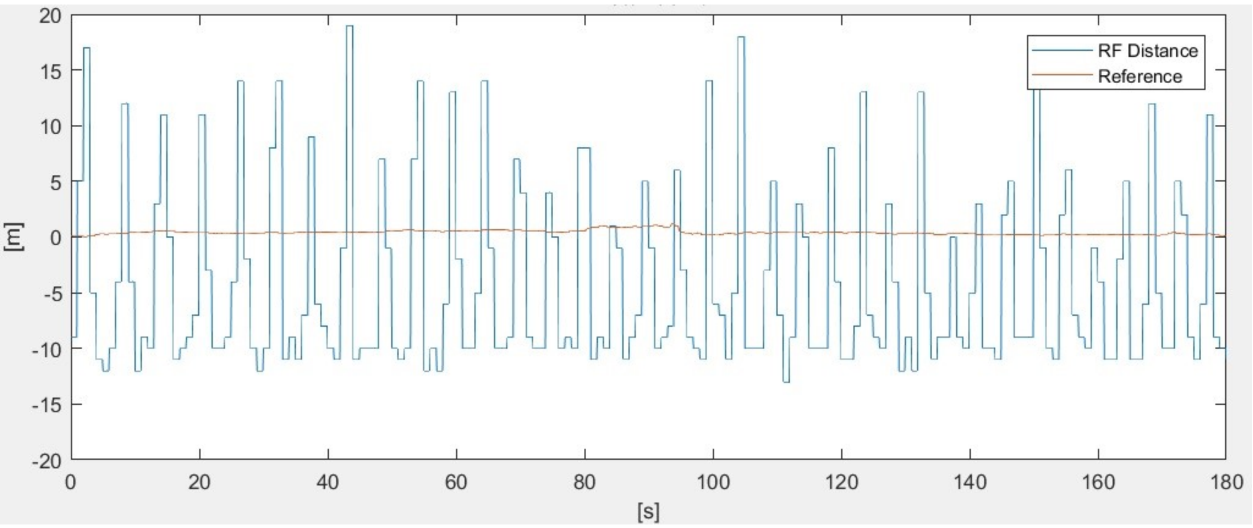


Figure 2-2 Stationary Ground Test (Pre-flight test)

3.0 SIMULATION

A simulation study prior to flight testing is an essential element in the process of troubleshooting the predictable yet unseen effects that might endanger the integrity of the test platform. Also, this risk might propagate adversely considering its effects on the ground due to possible casualties of personnel and assets. Even without the risks aforementioned, rigorous simulation studies have proved their value by decreasing the workload and time spent during the onsite flight tests. This saving becomes more outstanding when studies like this one require people from the different areas and expertise.

In this study two different type UAVs utilized for the process of returning to home location using the RF distance, one is a fixed wing aircraft which has about 8 kg takeoff weight and the other is a quad rotor which has about 7 kg takeoff weight. A formal simulation study should have three basic phases,

- Modeling,
- Validation,
- Analysis.

Modeling stage is briefly explained in the following section, and analysis results presented in the following sections. Though validation process is a strictly important part of the study, it is skipped in this one. Reasoning behind this was; for the fixed wing UAV simulation model was already in hand and presented in the literature (ÖLÇER, 2015) earlier, and for the quadrotor it followed a-posteriori method using data analysis thus validation itself becomes obsolete for this level of study presented here.

3.1 Simulation Models

Fixed wing UAV utilized in this study has been a long-term product/test-bed studied in house by the authors and the other members of the team due to its unique design. Briefly explaining that unique part is that most of the UAVs on the market carefully design their tail placement in a way to keep it off the propeller downwash it can be seen in several examples with V-shaped tails, such as TB-2 in (shephardmedia.com, 2017) or in similar sources. This is due to the highly nonlinear effects created on the tail when massive amount of downwash creates higher dynamic pressure on the tail control surfaces. In contrast with this trend the current UAV has its horizontal stabilizer and vertical tail placed precisely in the wake of the propeller in order to gain significant control power during takeoff which is initiated at a nearly zero-airspeed condition since it is hand-launched. Though it accomplishes the control power gain during the takeoff period it still does inherit the adverse nonlinear effects mentioned earlier during flight. Therefore, a physics-based modeling of the UAV had been created at the time of inception of this UAV thus it was already in hand prior to the current study. In this study, it is been utilized for the simulation of returning home algorithms developed using the distance from home information. Slight improvement added to the model to account for the noise effects of the RF distance measurements. More details of the platform and its physics-based modeling can be found in the report (ÖLÇER, 2015).

On the other hand, second platform in this study utilized similar algorithms for a multi-rotor platform thus a simple model needed to be created. System identification for the modeling of airborne vehicles is a widely used method and can be referred to many publications, least but not limited to Tischler's book (Tischler, 2006). Meanwhile, this method also can be more simplified for the isolated issues like the current study and multiple examples of such facilitating applications can be found in the earlier AGARD reports as one example (Series, 1991) given in the references. That simplified method was performed on the existing flight data of the platform to generate transfer functions to represent the relation between pitch, roll commands as inputs to the body velocities u and v as outputs, respectively. Though we have an unstable bare airframe on a multi-rotor platform, once it is controlled, thus stabilized, by an autopilot it is pretty much linear as well and can be modeled via simple first order transfer functions in each channel. This process neglects the most transitions and dynamics of the UAV which are not considered in the scope of the current study.

3.2 Simulation Results

In Figure 3-1 and Figure 3-2 simulation results for the fixed wing UAV shown for returning home at no wind and 5 m/s North-wind conditions. In both cases UAV was flown to a distance over 2 km away from home initially, then the case of GPS loss algorithm is used by neglecting the position information. In order to emulate the real-life issues in the simulations both the distance and velocity information are tainted with a considerable amount of white noise. In addition, in Figure 3-2 an improvement to the algorithm was introduced by increasing the delta command over heading to narrow the circling around the home location.

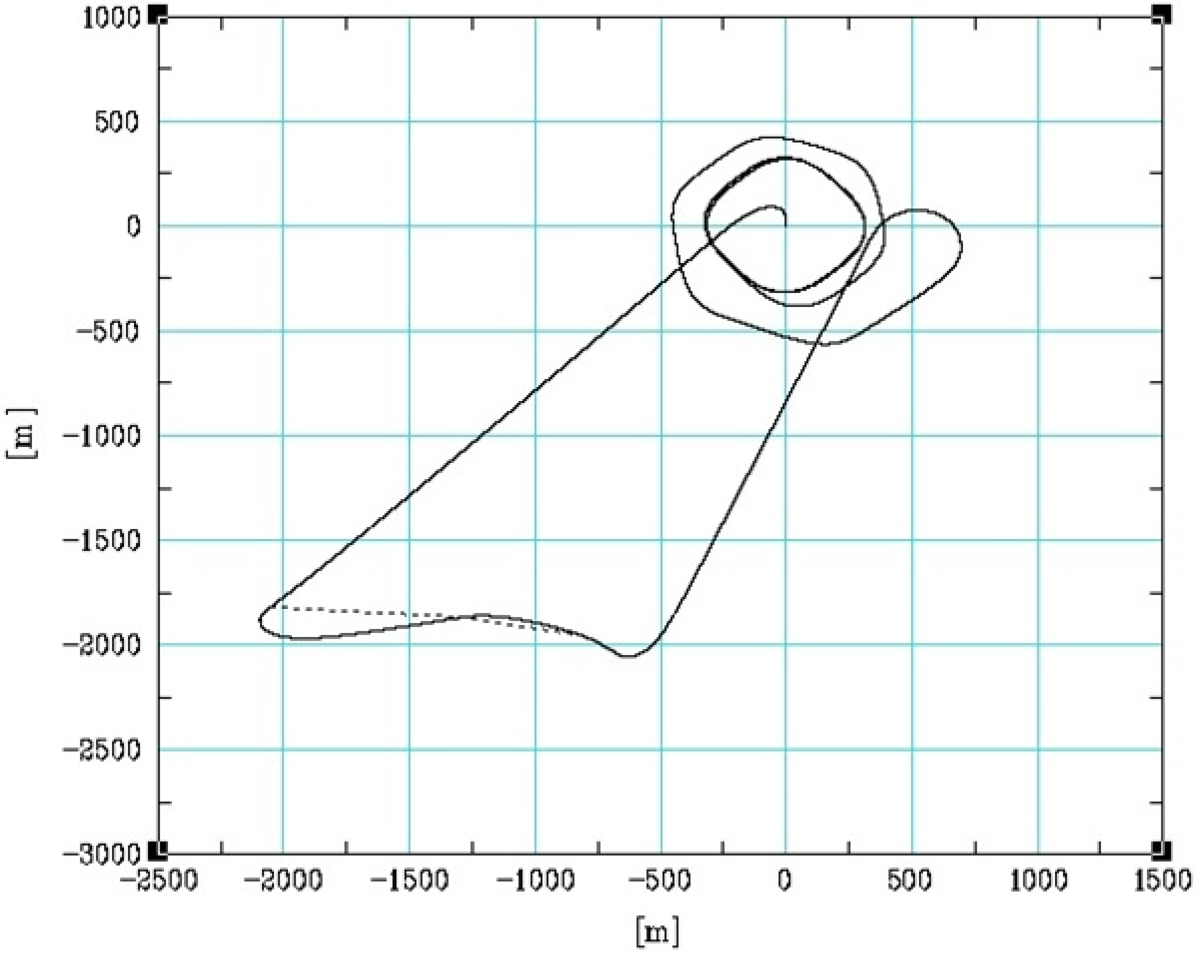


Figure 3-1 Fixed Wing Simulation; No Wind Condition

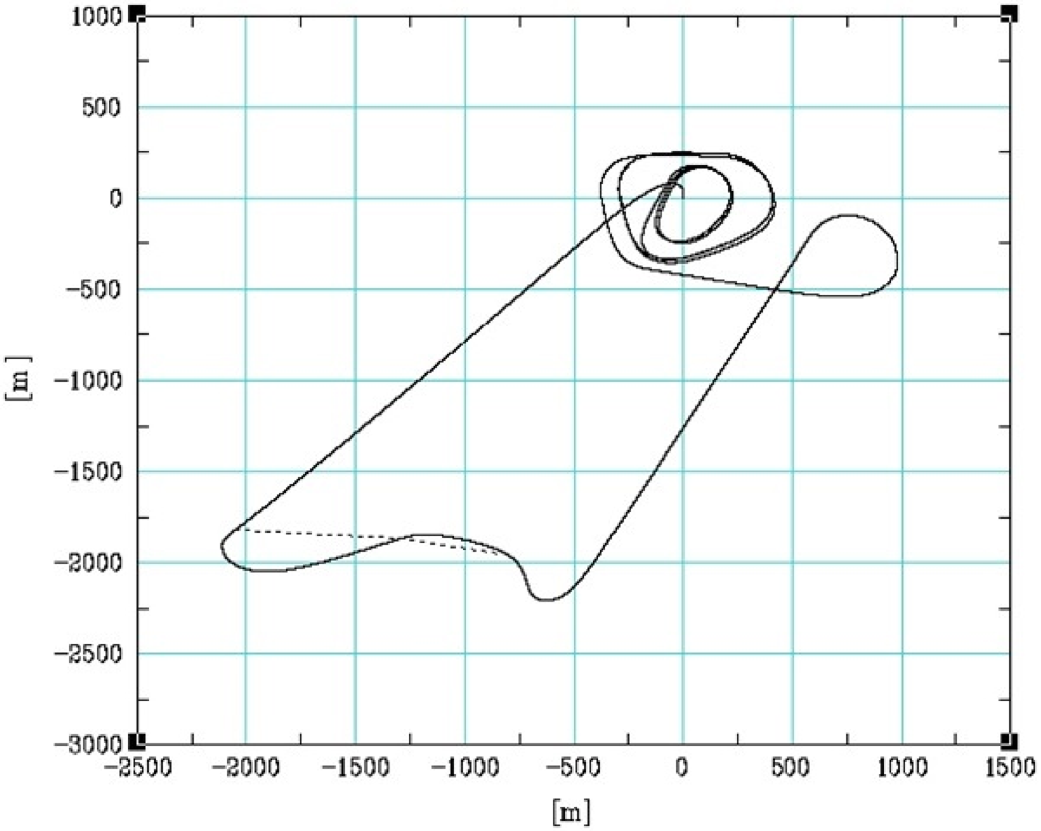


Figure 3-2 Fixed Wing Simulation with 5 m/s North-Wind Condition and Delta Heading Command Update Near Home

4.0 FLIGHT TEST RESULTS FOR FIXED WING UAV

In Figure 4-1 over half an hour flight test data presented for the distance, depicting results of both the reference (estimation from GPS) and the RF measurements. In this flight, UAV was flown at a constant altitude (400+ m) keeping out the takeoff stage. The ultimate distance was set as 10 km away from the home location where GPS loss was initiated. There was around 70 meters offset between the antenna position and the reference home location but it does not pose any significance for the scope of this study thus it was trimmed. In the following paragraphs data is analyzed stage by stage.

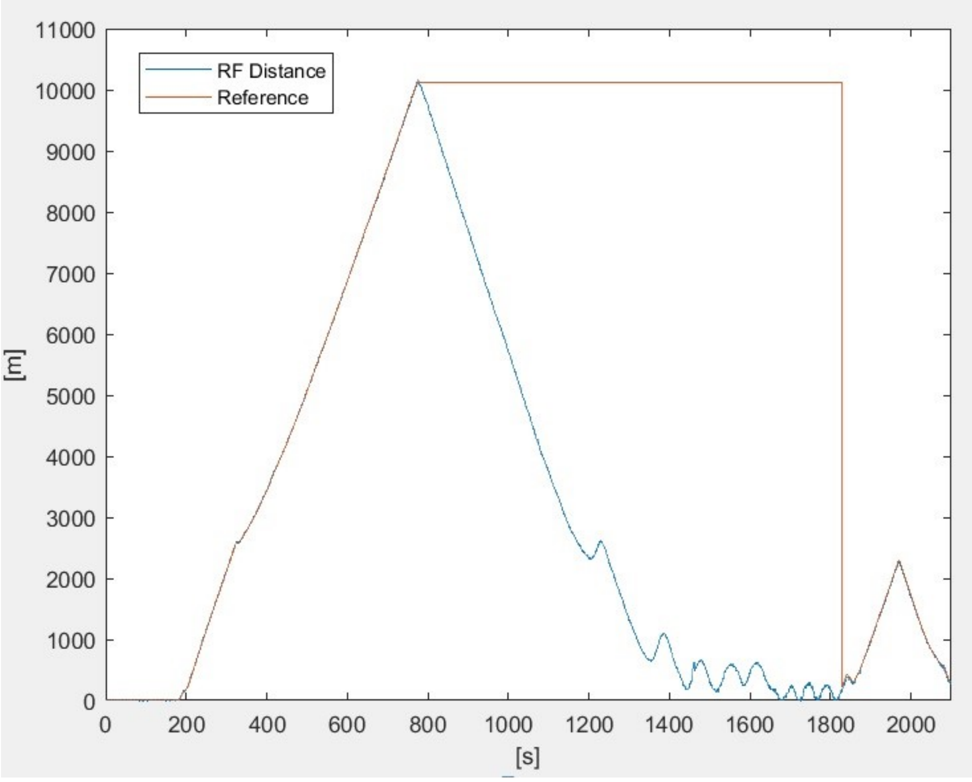


Figure 4-1 Flight Test

Take-off was performed around 200 s time position and it is followed by cruising flight for about 600 seconds where UAV was flying away from the home location. Throughout this stage which went to distances up to 10 km, reference and measured distances match perfect which creates the basis for the implementation of the algorithm.

Around 800 s time position intentionally GPS information is lost by triggering a false GPS data type in the autopilot. From this point forward GPS loss is accomplished in the true sense thus the reference value is not changed at all till the trigger is switched back to normal position at around 1850 s time position. After that point reference and measurement values match well back again till the end of the data presented here.

Time between 800 s and 1850s is the stage where the algorithm presented here is tested. In this stage UAV entirely lacks the GPS information but still flying stable, at a constant altitude and constant airspeed in accordance with its gyros and pitot-static pressure sensors, respectively. This stage can be seen in four substages;

- Initial stage,
- Corrections to approach home,
- Circling around home,
- Narrowing the circle around home.

Initial Stage: In this sub stage UAV is directed towards home by using the last known bearing to home direction stored in the auto pilot. Since the distance is high, the change in the bearing angle during maneuvering is neglected. This process provides the best initial heading value towards home.

Correction Stage: As the UAV approaches towards home it would be inevitable to miss the home location therefore starting at some point distance measured from home location starts to increase. The first two occurrences of that situation can be noticed in the figure around 1200 and 1400 seconds. The algorithm implemented on the GCS and Autopilot combined system dictates the UAV to change its heading command (with respect to compass) and this is iterated until a decrease in measured distance is achieved. A slight increase in the distance is noticed at both of those two instances due to that algorithm which caused the UAV to fly away even more distance from home due to the wrong change in the heading command but eventually a satisfying direction is found.

Circling: When the UAV reaches to a distance, which is around 1450 s in the figure, algorithm with the current configuration settings cannot bring the UAV to a better location. This condition is observed in this flight test for between 1450 and 1650 seconds where the UAV circled around the home position getting as close as 150 meters and the diameter of the circling observed around 800 meters. The home location is not exactly centered due to the apparent wind conditions.

Narrowing the Circle: Though we can assume the UAV is returned to home as it reached to a distance below 200 meters where it can be noticed by the GCS crew, this condition can be improved. It is observed in the simulations and later verified in flight tests that in case of increasing the heading command change after the circling substage can lead to narrow circling around the home position. In the figure that stage is observed between 1650 and 1850 s. In that final stage diameter of circle made by the UAV around home position is reduced to 250 meters approximately and through that time UAV repeatedly passed exactly over the home location which concludes the objective of the algorithm.

5.0 FLIGHT TEST RESULTS FOR MULTIROTOR UAV

Flight tests for multirotor UAV are done at an airfield at 900 m MSL altitude. The temperature was 15°C and wind speed was 8 m/s during testing. The multirotor UAV used in the tests was "SERCE-3" multirotor UAV, a product of ASELSAN. General specifications of this UAV are listed in the Table 1.

Table 1 Serçe UAV Specifications

Specification	Value
No. Rotors and Their Combination	4 Rotors (X Configuration)
Endurance	50 min.
MTOW	7.2 kg
Payload	1 kg (EO+LRF)
Maximum Speed	12 m/s
Mission Radius	10 km
Wind Resistance	10 m/s
Ceiling	4000 m (MSL)

SERCE-3 UAV uses other sensors on it such as IMU to keep itself stationary and level when GNSS is lost and it does so until it gets a command from Ground Control Station (GCS). In the "GNSS LOST" mode, the

UAV autopilot tries to maintain its position and generates roll and pitch angle commands. The detailed information can be seen in (KADEM, 2018). In this mode, as link is still available, the user can give command to the UAV by using joystick interface and generated roll and pitch commands are sent to the UAV by GCS. By this way, the UAV can be brought to any position, including home position, by manual control.

In the following sections of this paper, the testing of the automation process of returning to home position in "GNSS LOST" mode by using RF distance data will be explained. In this process, when UAV is in the "GNSS LOST" mode, the RF distance algorithm supplies the roll and pitch commands through the GCS to the UAV. The architecture of this process is as follows: The algorithm runs in a hardware that is connected to the ground datalink unit. This hardware, running linux operating system, has a message structure with GCS. It calculates the required roll and pitch angle commands to return the UAV to home using RF distance data and sends them to the GCS. Similar to the user-created manual joystick commands, GCS sends these commands to the UAV's autopilot directly and the UAV returns to home position by these commands.

The tests are done to implement the algorithm for the multirotor UAV. Algorithm verification is not practiced in these tests, as it was done and explained in the previous chapters. In order to test and optimize the process, a computer is directly connected to the hardware to change the parameters live during flight testing.

The test procedure followed for SERCE-3 multirotor UAV is as follows:

- For the first flight, UAV takes-off from home position and it is sent to a point 2000 m away from home. Then, it is called back to home and lands at home,
- During this first flight, RF distance data and "distance to home" data (calculated from GNSS data) are logged,
- Both data are analyzed and are compared to eachother, to verify the RF distance data.
- Once RF distance data is verified, second flight is performed
- For the second flight, UAV takes-off from home position and it is sent to a point 1000 m away from home and hovers at that point,
- The UAV starts returning home, its return flight is monitored and commanded roll and pitch angle values along with RF distance data are logged,
- In the following flights, steps 5,6 and 7 are repeated for delta heading command values of 20°, 30° and 45° and for speed constants (magnitude) of generated roll and pitch commands at %100 and %70.
- When all data are collected and are compared to eachother, most suitable delta heading command value and speed constant of generated roll and pitch commands are determined,
- A final flight is then performed, again sending the UAV to a point 1000 m away from home but this time, fake GNSS loss command is sent to the UAV while it is travelling to the point at its maximum flight speed of 12 m/s, causing the UAV to enter "GNSS LOST" mode during cruise instead of hover,
- Its return flight is monitored and commanded roll and pitch angle values along with RF distance data are logged,
- This data is compared to the data of the previous tests to see if the required performance is still met.

In accordance with the test procedure, first flight was done to compare the RF distance between the UAV and home position (or actually to the ground station, generally close to home position) and actual distance taken from GNSS sensor, in order to be sure that the algorithm uses correct distance data. In the flight test, UAV was sent to a point at 2 km distance. During the flight it was seen that if the link quality decreases, the accuracy of the RF distance estimation also decreases. As it can be seen in Figure 5-1, RF distance has generally accurate values, with respect to distance values calculated from GPS data. In between 700 and 800 time interval, there is a distortion effect. In this interval RSSI value of modem was decreased, which means the link quality was decreased. As a result, during the tests, link quality was carefully monitored to not to drop below %100, so that RF distance algorithm can get accurate distance value and can work properly.

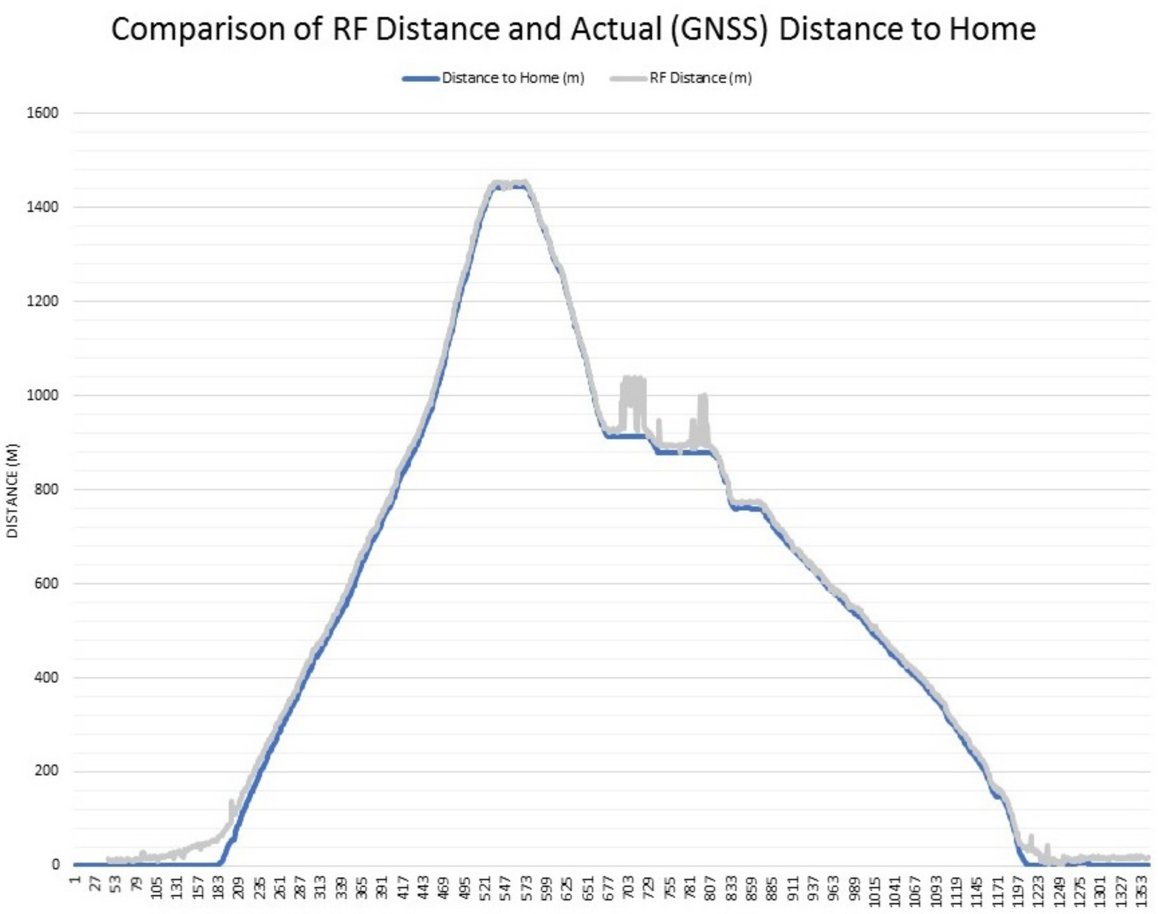
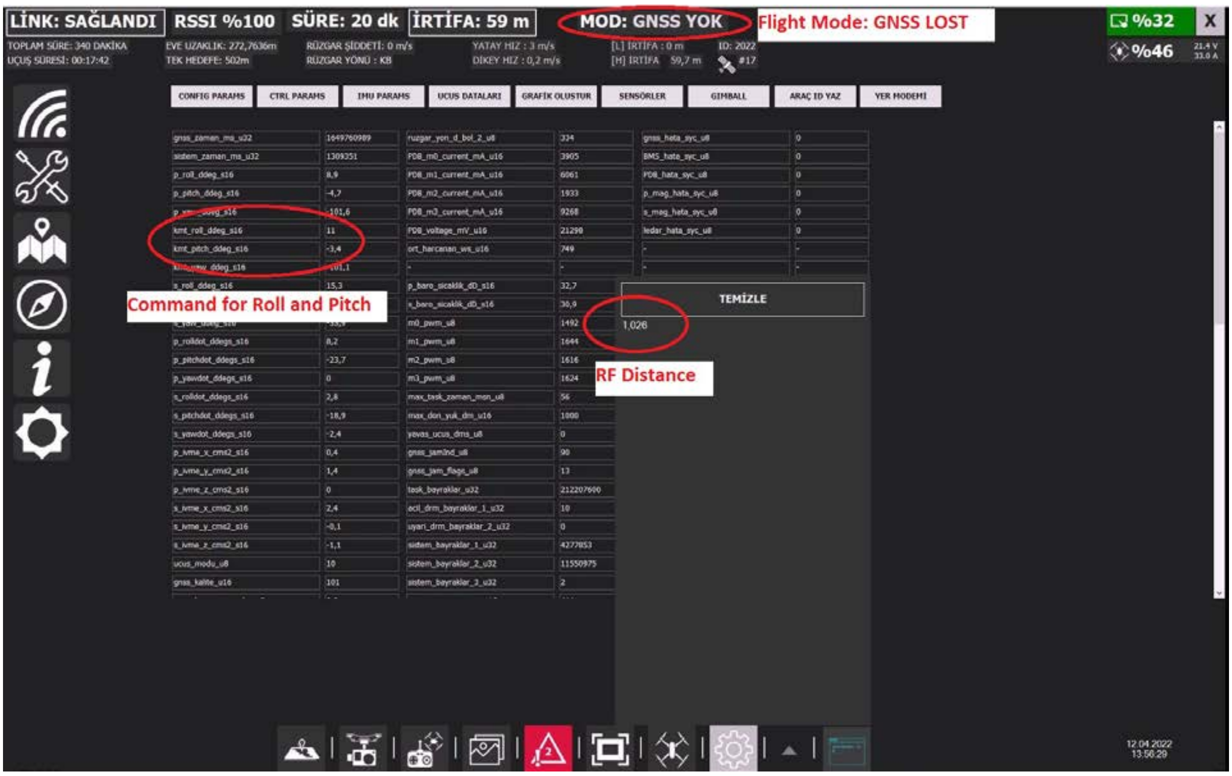


Figure 5-1 Comparison of RF Distance and Actual Distance from Home to UAV

For the second flight, a point at 1000 m away from the home position was determined. Before GNSS loss command, the UAV was sent to this point by clicking on the map from GCS user interface. When the UAV reached that point and started hovering there, GNSS loss command was given and the UAV changed its mode to "GNSS LOST" mode. The log of RF distance and roll and pitch command changes can be monitored from GCS interface as seen in Figure 5-2.



LİNK: SAĞLANDI RSSI %100 SÜRE: 20 dk İRTİFA: 59 m MOD: GNSS YOK

Flight Mode: GNSS LOST

TOPLAM SÜRE: 340 DAKİKA
UÇUŞ SÜRESİ: 00:17:42
EVE UZAKLIK: 272,7636m
TEK HEDEFE: 502m
RÜZGAR ŞİDDETİ: 0 m/s
RÜZGAR YÖNÜ : KB
YATAY HIZ : 3 m/s
DİKEY HIZ : 0,2 m/s
[L] İRTİFA : 0 m
[H] İRTİFA 59,7 m
ID: 2022
#17

gnss_zaman_ms_u32	1649760989	ruzgar_yon_d_bol_2_u8	334	gnss_hata_syc_u8	0
sistem_zaman_ms_u32	1309351	PDB_m0_current_mA_u16	3905	BMS_hata_syc_u8	0
p_roll_ddeg_s16	8,9	PDB_m1_current_mA_u16	6061	PDB_hata_syc_u8	0
p_pitch_ddeg_s16	-4,7	PDB_m2_current_mA_u16	1933	p_mag_hata_syc_u8	0
p_yaw_ddeg_s16	-101,6	PDB_m3_current_mA_u16	9268	s_mag_hata_syc_u8	0
kmt_roll_ddeg_s16	11	PDB_voltage_mV_u16	21290	ledar_hata_syc_u8	0
kmt_pitch_ddeg_s16	-3,4	ort_harcanan_ws_u16	749	-	-
kmt_yaw_ddeg_s16	-101,1	-	-	-	-
s_roll_ddeg_s16	15,3	p_baro_sicaklik_dD_s16	32,7		
[illegible]	[illegible]	s_baro_sicaklik_dD_s16	30,9		
s_yaw_ddeg_s16	-33,9	m0_pwm_u8	1492		
p_rolldot_ddegs_s16	8,2	m1_pwm_u8	1644		
p_pitchdot_ddegs_s16	-23,7	m2_pwm_u8	1616		
p_yawdot_ddegs_s16	0	m3_pwm_u8	1624		
s_rolldot_ddegs_s16	2,8	max_task_zaman_msn_u8	56		
s_pitchdot_ddegs_s16	-18,9	max_don_yuk_dm_u16	1000		
s_yawdot_ddegs_s16	-2,4	yavas_ucus_dms_u8	0		
p_ivme_x_cms2_s16	0,4	gnss_jamInd_u8	90		
p_ivme_y_cms2_s16	1,4	gnss_jam_flags_u8	13		
p_ivme_z_cms2_s16	0	task_bayraklar_u32	212207600		
s_ivme_x_cms2_s16	2,4	acil_drm_bayraklar_1_u32	10		
s_ivme_y_cms2_s16	-0,1	uyari_drm_bayraklar_2_u32	0		
s_ivme_z_cms2_s16	-1,1	sistem_bayraklar_1_u32	4277853		
ucus_modu_u8	10	sistem_bayraklar_2_u32	11550975		
gnss_kalite_u16	101	sistem_bayraklar_3_u32	2		

Command for Roll and Pitch

1,026

RF Distance

12.04.2022
13:56:29

Figure 5-2 GCS User Interface Development Test Tab

For the following flights, the parameters are changed by the other computer (different from GCS) which is connected to the hardware that runs the algorithm. Three different delta heading values (20°, 30° and 45°) are tested first to find the value that results in better performance. Delta heading values are used in the algorithm for the UAV to converge to the home position while returning. The algorithm uses this value to turn the UAV by that desired amount to make it converge to the position where RF distance is minimum (closest to the home position). During the flights, it was seen that the UAV could not converge to home position easily if it was turned by 20° and 30°, as shown in Figure 5-3 and Figure 5-4. On the other hand, if it was turned by 45°, it was seen that UAV starts to converge to home position more easily as shown in Figure 5-5.

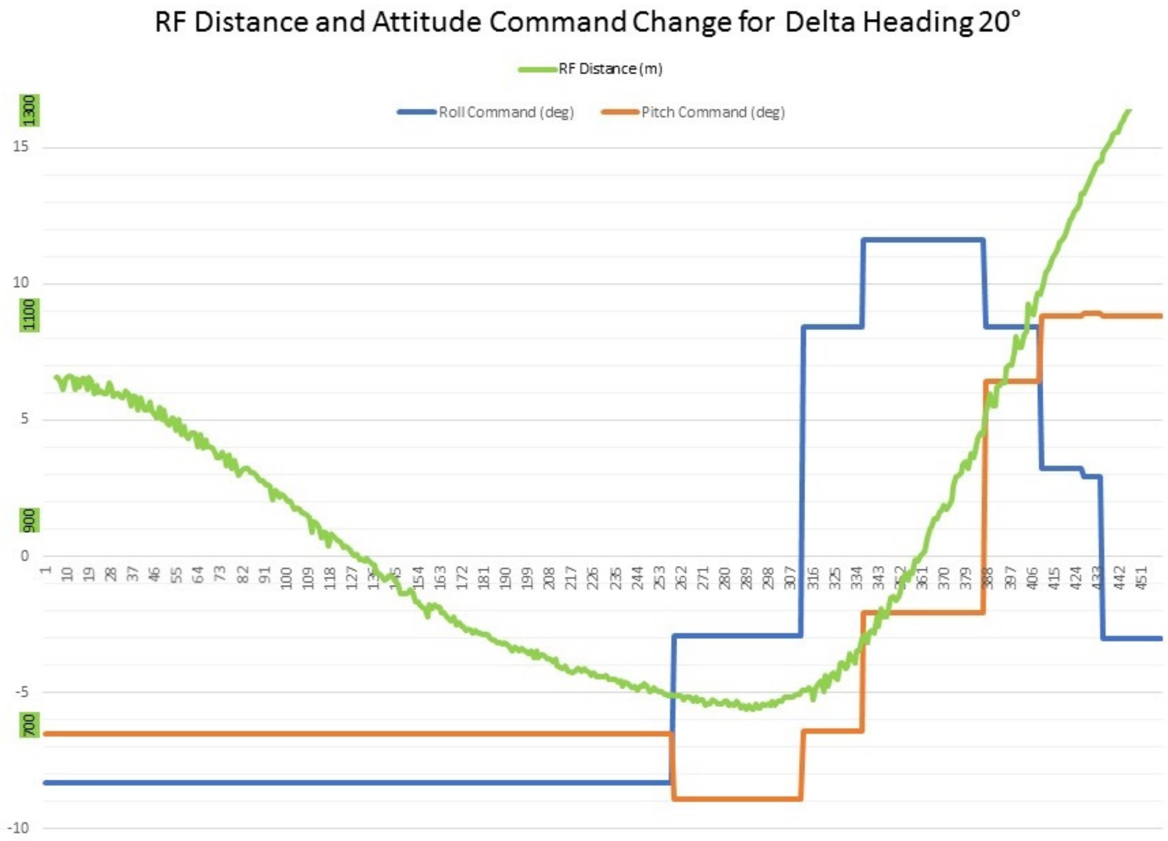


Figure 5-3 Returning Home Performance for Delta Heading Value 20°

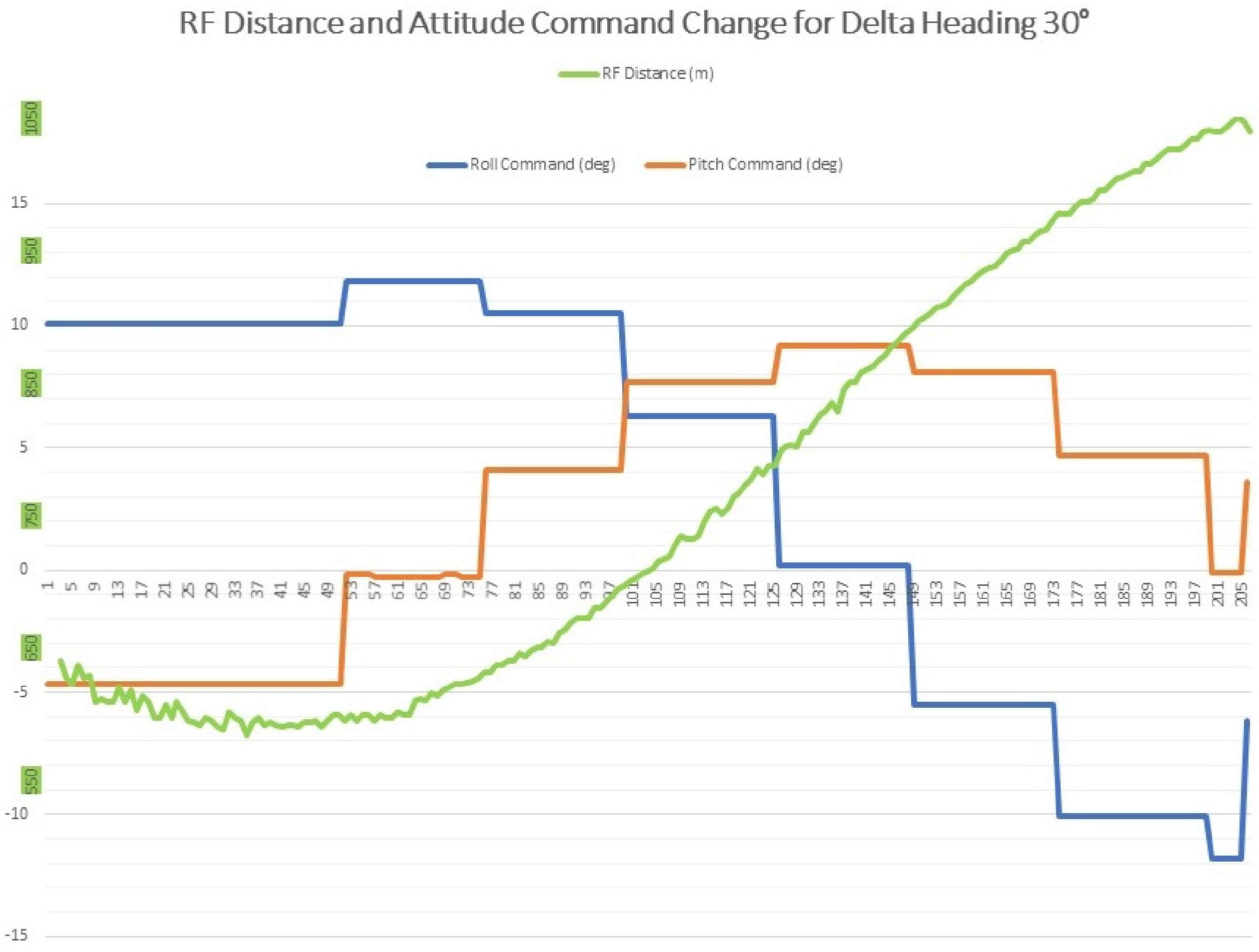


Figure 5-4 Returning Home Performance for Delta Heading Value 30°

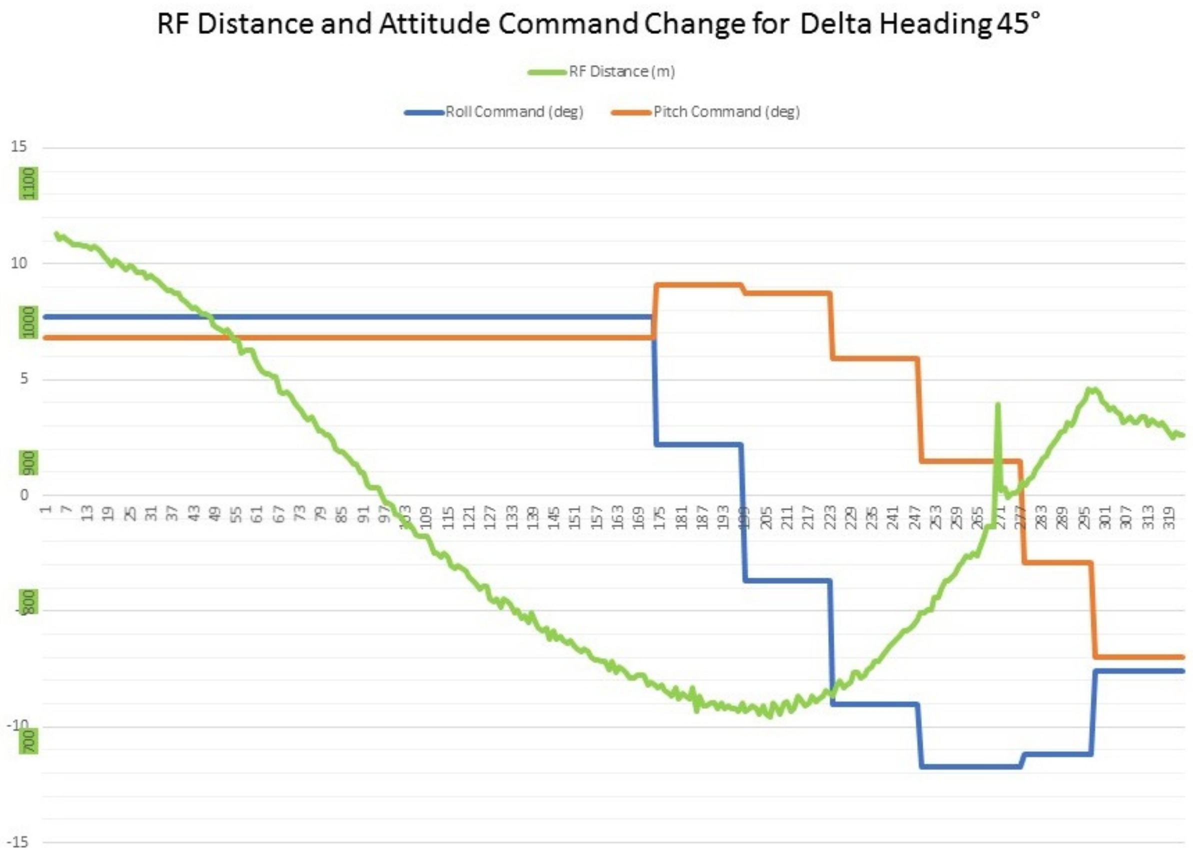


Figure 5-5 Returning Home Performance for Delta Heading Value 45°

Similar to these flights, another flight test was done for decreasing the magnitude of the generated roll and pitch commands. As SERCE-3 UAV is a multirotor UAV, it does not need to change its heading to follow a path, instead it changes course by roll and pitch commands combined without any yaw command. When there is no GNSS, the speed of the UAV cannot be obtained so this value becomes the angle command. Speed constant can be defined as magnitude limit in degrees of the resultant of the roll and pitch commands that are generated. Therefore, when speed constant is %100, it means that maximum angle command can be 12 degrees. All the previous tests are done with %100 as speed constant. In this test, speed constant is decreased to %70 while delta heading value is kept at 45°, as it was the best value from previous tests. The results are shown in Figure 5-6, which shows that the UAV could not converge to home position.

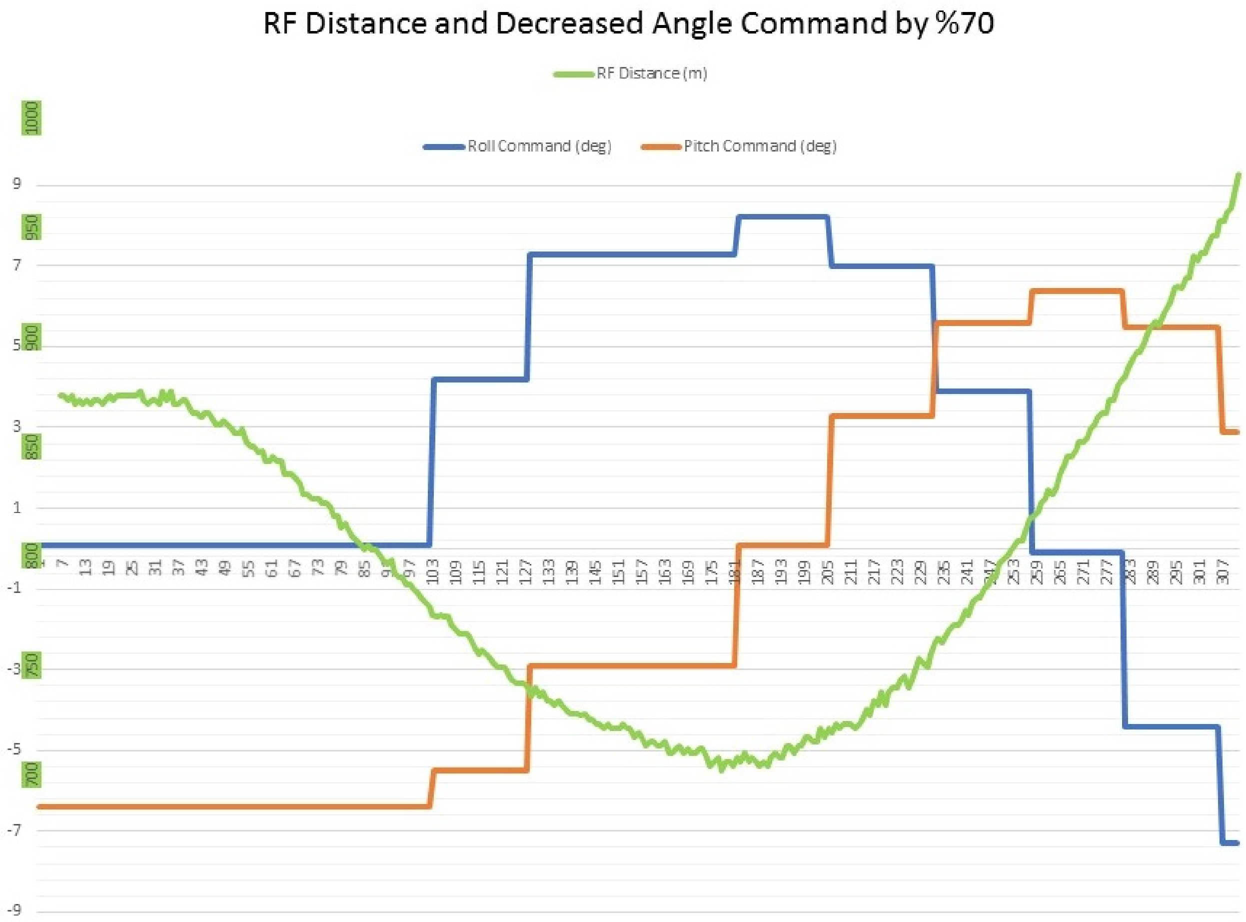


Figure 5-6 Returning Home Performance for Decreased Angle Command

During these tests, the weather was windy, with wind speeds around 5 m/s. Considering the maximum speed of SERCE-3 UAV being 12 m/s, the pitch and roll angles generated were not enough to produce the speed that can overcome this wind speed. This caused the UAV to drift in the wind direction, generally away from home position. Therefore, it was seen that the performance of the algorithm was also dependant on the wind speed.

For the last flight, the UAV was commanded to do waypoint navigation in a given mission path (shown in Figure 5-7). In the middle of this mission, GNSS loss command was sent and the UAV entered “GNSS LOST” mode while moving. This was done to see whether the differences in initial conditions of GNSS loss are effective on the performance or not. For all the previous flights, the UAV was at hover when the GNSS loss command was given so it did not need to stop when it entered “GNSS LOST” mode. However, for this final flight, the UAV was in cruise when the GNSS loss command was given, so the first thing UAV did was to try to stop and hover and generate the real angle commands. This caused it to slip from the point where it obtained the last GNSS coordinate before losing GNSS. As a result, this created an error in calculation of returning to home from the beginning. Especially when the weather is windy, the UAV could not return to home directly.

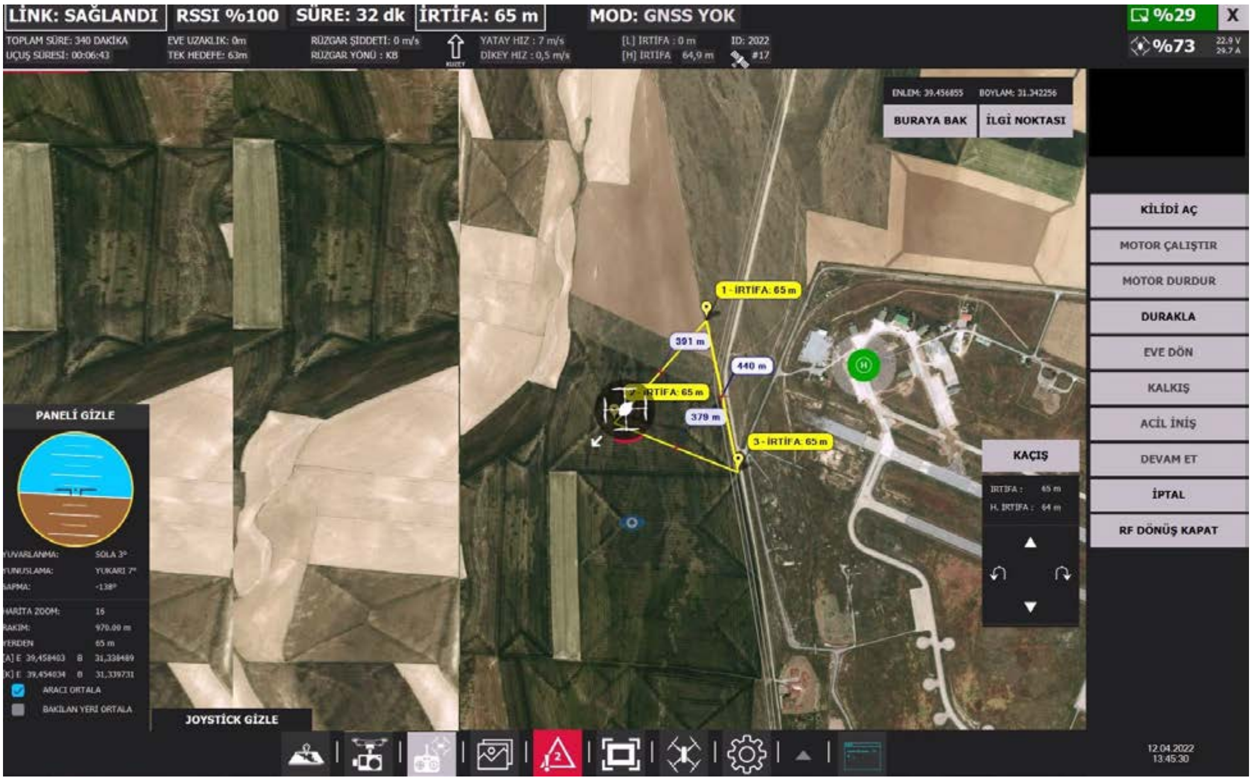


Figure 5-7 GNSS Loss in Waypoint Navigation

When all the results of the flight tests are compared and analysed, the suitable values for the algorithm are found and were implemented. A successful return-to-home confirmation test flight from beginning to the end using this algorithm can be seen in Figure 5-8. For this test flight, values used in the algorithm and weather conditions are summarized below:

- Initial mode (just before the GNSS loss) is hover,
- Delta heading angle is 45,
- Speed constant is %100,
- Wind speed was less than 4 m/s.

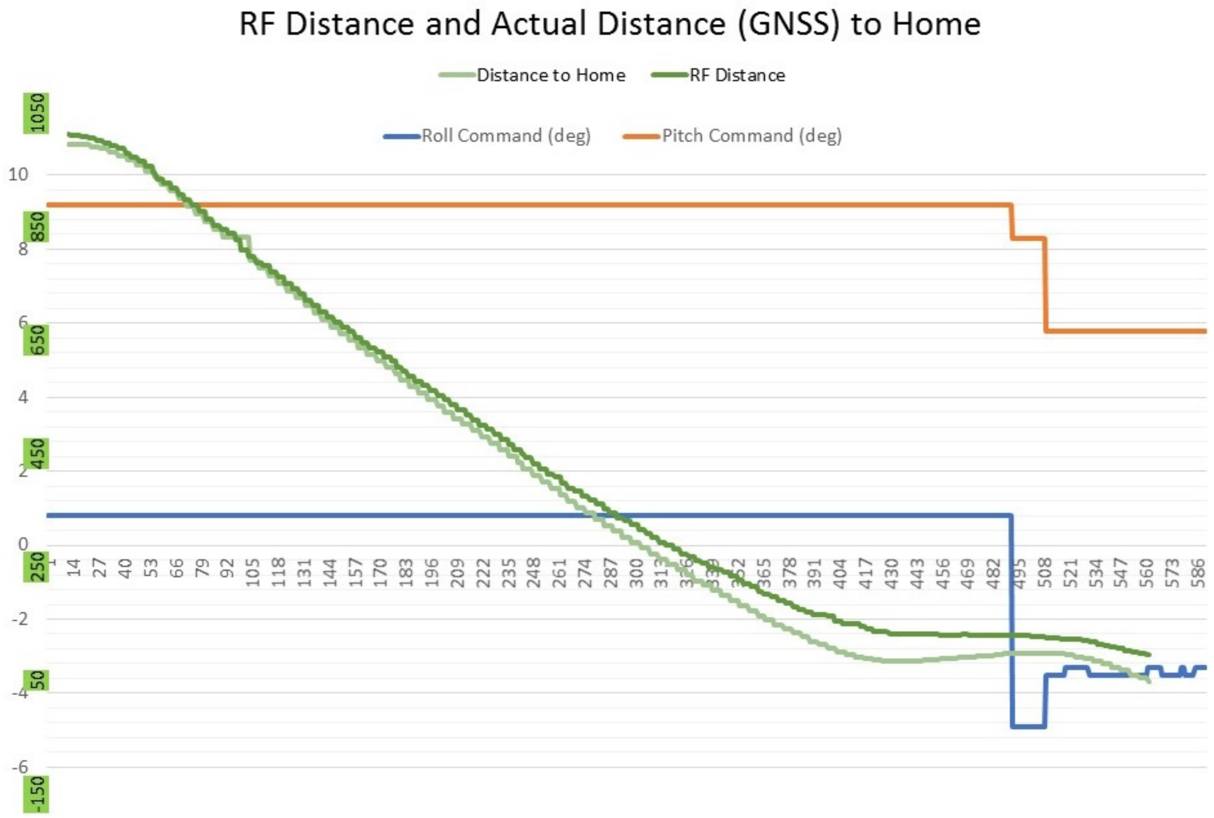


Figure 5-8 Successful Return Home in GNSS Denied Environment

6.0 CONCLUSION AND FUTURE WORK

The novel algorithm presented here has been shown and proved to work on two different type UAVs. It makes use of the distance data as acquired from the telemetry system and works on minimizing this distance in a discrete form which have different settings depending on the UAV type. This method of minimizing the error resembles the P only type PID controller and its configuration parameters need to be carefully adjusted through flight testing. Also a simulation methodology was followed in this study to minimize the risks associated with the flight testing. Results of the simulation framework over the fixed wing platform and both flight test results of the UAVs are presented.

The importance of the novel method presented here suggests no additional hardware or any other addons, neither on ground or in the air therefore it should be applicable for any type UAV without additional cost. Since it is presented here that the UAV can be controlled via the distance, in the future this baseline study and method can be modified to keep the aforementioned RF distance constant to create a fence control over a base.

In addition to these, for the multirotor UAV, as it can be seen from the test results, the algorithm is very useful in GNSS denied environment. Especially, when the UAV is far away from home it is a very hard task for the GCS crew to orient the UAV towards home using visual cues over the payload. However, for multirotor UAV's, there is only constant angle control; true speed controller cannot be achieved, since UAV is not included a sensor such as a pitot tube. This situation makes the algorithm depended to the weather conditions/wind speed and direction. The algorithm can be improved by following future works:

- Speed constant can be adaptive; if RF distance can not be reduced for a certain time or for a certain number of heading command change, speed constant can be increased,
- Another improvement can be done in the UAV controller itself; speed constant can be stationary, but its corresponding angle can be increased,
- Similar comparison tests can be done for other parameters such as RF distance checking period (it is normally 5 sec), the distance that the algorithm is ended,
- The conditions that the heading command is changed; the comparison of RF distance for each period can be done between the actual RF distance and not the just previous data but the data from the previous checking period.

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