Proceedings of the 17th World Congress
The International Federation of Automatic Control
Seoul, Korea, July 6-11, 2008

A Real-Time NDGPS/INS Navigation System Based on Artificial Vision for Helicopter

Jae Hyung Kim*, Joon Lyou**

** Korea Institute of Aerospace Technology, Korean Air, Daejeon, Korea (Tel: 82-11-457-1246; e-mail: hokypoky@chol.com).*
*** Department of Electronics Engineering, Chungnam National University, Daejeon, Korea (e-mail: jlyou@cnu.ac.kr)*

Abstract: An artificial vision aided NDGPS/INS system has been developed and tested in the dynamic environment of a ground and flight vehicle to evaluate the overall system performance. The results show the significant advantages in position accuracy and situation awareness. Accuracy meets the CAT-I precision approach and landing using NDGPS/INS integration. Also we confirm the proposed system is effective to increase situational awareness and improve flight safety by using artificial vision. The system design, software algorithm, and flight test results are presented. We show our efforts of developing the capability of situation awareness in helicopter navigation.

1. INTRODUCTION

There are two main categories to navigate, VFR (Visual Flight Rules) and IFR (Instrument Flight Rules) in general aviation (Myron et al., 1997).

Generally speaking, helicopter navigation depends more on VFR than IFR. As a result, the helicopter is unable to operate during the bad weather condition such as low visibility (fog, heavy rain), as well as at night because situational awareness is critical to the safety in helicopter navigation.

But the military or emergency helicopters have to undertake search and rescue and emergency evacuations even in bad weather or at night.

Also during the instrument flight, the pilot must scan several instruments simultaneously to know what is happening correctly. This process would be big load to pilots, which must be reduced for the flight safety (D. Ballard et al., 1991).

The proposed system is developed to provide the reliable navigation data and situational information so as to undertake the mission effectively and with safety from the threat of accident.

This system acquires the position and attitude of the aircraft from the navigation system integrated with NDGPS and INS. For the flight situation awareness, it also provides the 2D and 3D visualization (a pathway-in-the-sky aircraft, and flight-path vector/predictor guidance symbology) through the Tactical Information Display Device.

The core technology of the system is precise integrated navigation system, massive image data processing, and real-time 3D terrain processing algorithm.

In this paper, we suggest the advanced navigation system especially for helicopters using NDGPS, INS, Tactical Information Processor and Display so as to improve the situational awareness even in non-visual flight conditions.

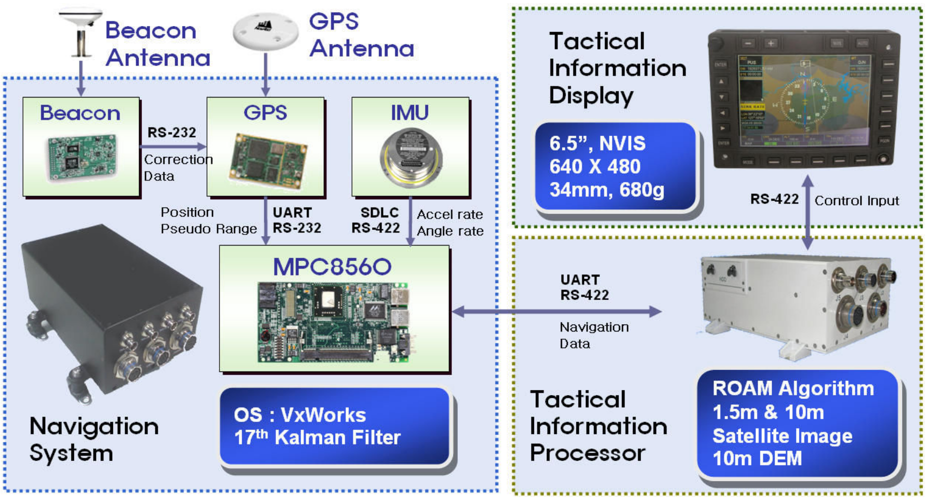


Fig. 1. Hardware block diagram of Navigation System

2. SYSTEM DESCRIPTION

The system can be broken down into three distinct components - Navigation System, Tactical Information Processor, and Display Device. The Navigation System based on NDGPS/INS provides position, attitude and reliability data to Tactical Information Processor via RS-422 serial communication protocol. The Tactical Information Processor has massive terrain data of all South Korea such as DEM (digital elevation models) and satellite images for the elaborate artificial vision. Therefore it can provide a pilot with the artificial vision similar to external cockpit view.

2.1 Navigation System

The Navigation System consists of a beacon receiver, GPS receiver, IMU (Inertial Measurement Unit), and navigation processor board.

The system needs a powerful and flexible processor that is easily integrated and expanded with different sensors and communication devices.

The MPC8560 PowerQUICC III processor is based on Freescale's e500 system, maximum clock speed is up to 1GHz and 64bit interface RISC (Reduced Instruction Set Computing) chip (Freescale et al., 2003).

The MPC8560 has good performance enough to run navigation algorithm and process all information from the GPS receiver, IMU, and other sensors at the same time.

Table 1. Navigation Processor Board Specification

Processor	MPC8560(FREESCALE), up to 1GHz
Memory	DDRSDRAM 512MB
O/S	VxWorks
Interface	SDLC (1), RS-232 (3), RS-422 (2), Fast Ethernet (1), USB (1)

In order to improve the navigation solution and meet the navigation requirement, we use the NDGPS (National-wide Differential GPS) which provides the position correction information to GPS with low cost (E. D. Kaplan et al., 1996).

As for the DGPS/INS schemes, we use the "Loosely Coupling" for main navigation algorithm and "Tightly Coupling" for backup navigation algorithm.

In a loosely coupled DGPS/INS system, position is comparatively precise because GPS position solution is estimated by Kalman filter in GPS receiver. But in this case, GPS-only position solution is made by measurements from more than four satellites. On the other hand, in a tightly coupled DGPS/INS, we use the GPS raw pseudorange measurements to estimate the INS errors using a single integration filter instead of GPS position. Therefore when less than four GPS satellite measurements are available, we can use the tightly coupled scheme (J. A. Farrell et al., 1999 and Chiang et al., 2004).

As shown in Figure 2, we designed a tightly hybrid filter for the advanced positioning in weak GPS satellite signal area (Jamila et al., 2006). In our approach, it is selected the type of kalman filters depending on the number of visible GPS satellites. We find the optimal positioning solution from the various factor of navigation (aircraft dynamics, DOP, error probability and so on) and then feed back it to each filter.

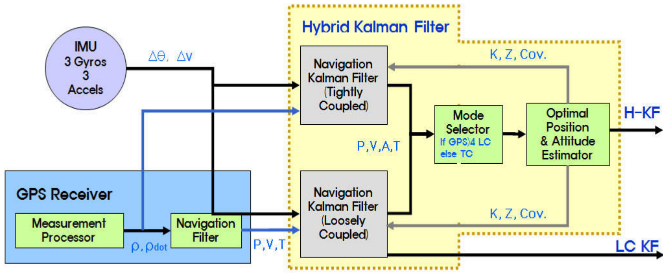


Fig. 2. Hybrid Kalman Filter Structure

As shown in Figure 3, we show that the hybrid filter we proposed gives a better location than the classical loosely coupled filter through the ground the test.

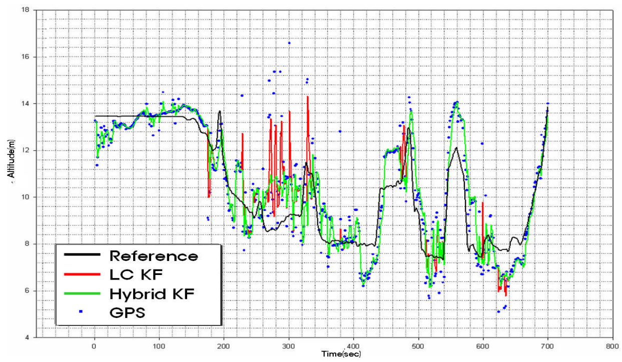


Fig. 3. Results of Filter Comparison

2.2 Tactical Information Processor

We aimed at rendering all satellite image (maximum 0.7m resolution) and DEM (10m) of South Korea. But it is not easy to render so much large volume of terrain with high resolution in real time. As the size of terrain data increases, it is increasingly difficult to process all the data in main memory during the visualization. So there are the data exchanges between main memory and secondary storage. At last it becomes a bottle-neck in terrain visualization.

To prevent the slow-down of the visualization performance, we use the modified ROAM (Real-time Optimally Adapting Meshes) algorithm which is a kind of large terrain LOD (level-of-detail) technique that works with large terrain models and allows them to be rendered in real time (Duchaineau et al., 1997).

Table 2 shows the specification of the Tactical Information Processor which is very compact and light, so it can be easily installed on any vehicle.

Table 2. Tactical Information Processor Specification

System	CPU	Intel Pentium M Processor 760 (2.0GHZ)
	Main Chipset	Intel 915 Chipset, 533MHZ
	Main Memory	512MB (DD2/533FSB/PCS-4200)
	O/S	XP-Embedded
Video	Graphics Card	Intel 915GM 128MB Video RAM
I/O	Serial Interface	2 X RS-232, 3 X RS-422, 1 X TTL
	USB	4 X USB, 1 X Ethernet, 1 X KBD & Mouse
	MIL-1553	PC104 Type 1553 PCI Slot
Audio	Audio Chipset	Realtek ALC880
HDD	System : PATA 100G, Data Storage : SATA 160G	
Power	Power Input/ Max. Current	DC +28V, Normal 2A / MAX 3A (MFD Heating)
	Battery capacity	8 X 1.2V / 2700MAH(NI-MH)
Size	230 X 138 X 90 mm	
Weight	3KG	

2.3 Tactical Information Display

The Tactical Information Display device is a 6.5 inch 640X480 pixel flat panel display, which supports the function of NVIS (Night Vision Imaging System) and complies with the most hostile specifications regarding shock, vibration, temperature, and EMC.

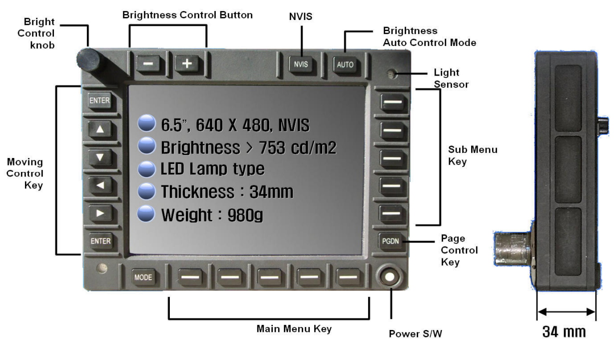


Fig. 4. Specification of Tactical Information Display (MFD)

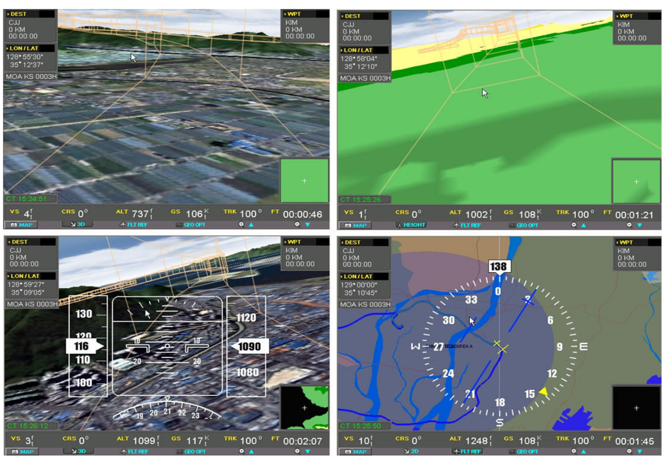


Fig. 5. Tactical Information Display(S/W)

The functions provided by the MFD include display of attitude, speed, air data, airframe status, airport information, terrain and obstacle alerting, and also situational awareness via 2D moving map display and 3D artificial vision. In addition, display device is controlled by knobs and selector keys located on the MFD bezels.

Figure 5 shows the pathway-in-the-sky view, height map view, and major aircraft instruments - VSI (Vertical situation indicator) and HSI (Horizontal situation indicator). VSI provides the aircraft heading, altimeter, ground speed, roll, and yaw. HSI provides track angle and aircraft heading.

3. TEST RESULTS

3.1 Ground Test

The ground test was conducted to evaluate the proposed system prior to the flight test. The first ground test was performed at Pusan Express way for 80 minutes. The results of the ground test show that the navigation solution was provided well even when GPS was unavailable such as tunnel.

To evaluate the navigation performance, a highly precise navigation system was required as a reference trajectory. So we used the Honeywell's MAPS INS system, which gyro and accelerometer bias is 0.00245 deg/hr and 56μ g respectively.

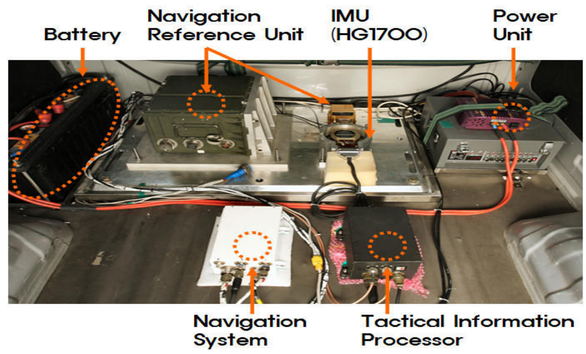


Fig. 6. Ground Test Environment

Figure 7 shows the navigation trajectories (clockwise and counter-clockwise) on the satellite images coincide with the Pusan highway without overlapping each other.

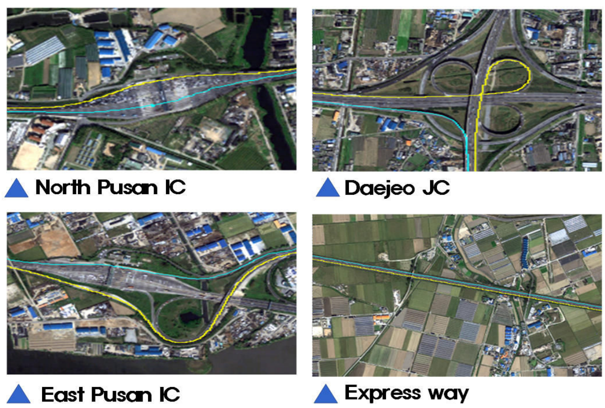


Fig. 7. Trajectory of ground test in Pusan

Another test on the ground was carried out on the Daejeon South Circular Expressway for 90 minutes, which is one of the best area to evaluate the GPS/INS system because of five tunnels where the GPS signal is unavailable.

Figure 8 shows the navigation algorithm worked well even in the tunnels. Test results in Table 3 show that hybrid KF method meets the CAT-I requirement.

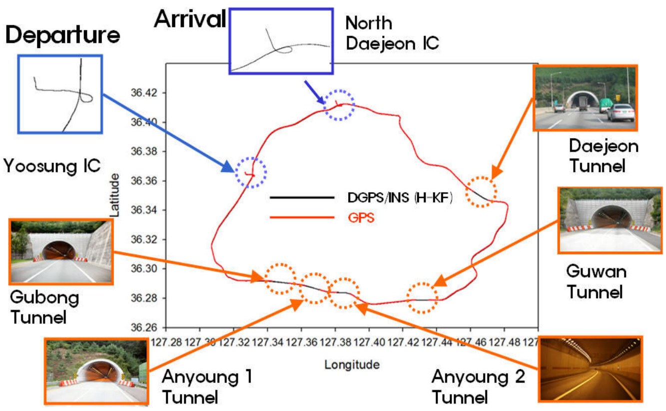


Fig. 8. Trajectory of ground test in Daejeon

Table 3. Results of the ground test

		Position Error (m)			Velocity Error (m/s)			Attitude Error (deg)		
		N	E	D	Vn	Ve	Vd	Roll	Pitch	Yaw
LC	AVR	0.23	0.28	-0.19	-1.41	0.53	0.1	-0.06	0.07	1.23
	RMS	1.1	1.57	1.21	2.63	2.85	0.84	0.82	0.83	2.74
H -KF	AVR	0.21	0.27	-0.16	-1.38	0.46	0.09	-0.06	0.05	1.09
	RMS	0.92	1.49	1.06	2.36	2.73	0.83	0.817	0.77	2.38

3.2 Flight Test

The artificial vision based navigation system of the evaluation version was mounted in MD500 helicopter and a flight test was performed at Daejeon on August 2, 2007.

The Tactical Information Display device was installed at cockpit frame for a pilot to evaluate the coincidence of the artificial vision. Also the Navigation System and Tactical Information Processor were installed on cabin to collect the data for the evaluation. Another MEMS GPS/INS (Crossbow's NAV-420) was also tested together for the data verification.

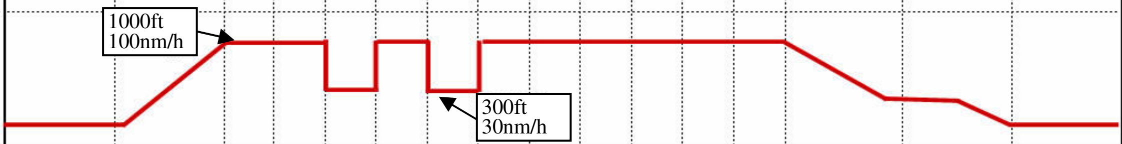
The main purpose of this test was to analysis test environment, collect GPS/IMU sensor data, tune the hybrid kalman filter, and check the coincidence of flight instruments and vision between in the aircraft and MFD of the proposed system.

Before the flight we generated the guidance corridor view from take-off to landing point. During the flight test we followed the corridor by assuming that we are in the low visibility condition.

Table 4 is the test scenario to evaluate the navigation system. By changing altitude and attitude, we evaluated the visibility and correctness between the real visions of pilot and the artificial vision. Also for warning/alarm test, even when we approached the terrain intentionally we could fly with safety without aircraft crash using the function of warning/alarm and height map view.

The flight test was performed above the Daejeon South Circular Expressway for 20 minutes. As for the test environment, maximum altitude was 1150ft above ground, the maximum ground speed was 100nm/h and the roll range was very dynamic between -33°and 63°.

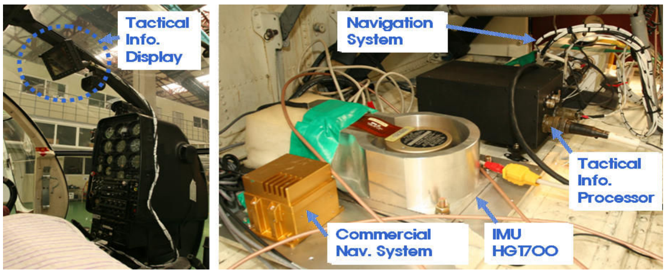
Table 4. Example of Flight Test Scenario

Posotion	1	2	3	4	5	6	7	8	9		10
Flight Altitude											
Flight Phase	Take Off	Climb	Cruise						Descent	Approach	Landing
Test Issue	○ Equipment Check ○ Installation Check ○ Basic Operation Check	○ Warning /Alarm Test (Attitude)	○ Accuracy Comparison Between Aircraft Instrument & MFD of Tactical Info. Display ○ Warning/Alarm Test(Altitude/Attitude) ○ GPS acquisition rate depending on bank angle.						○ Warning /Alarm Test (Attitude)	○ Corridor View Test	○ Terrain Approach
Navifation	○ Init. Alignment ○ Position ○ Attitude		○ Navigation Data Status Check	○ Steep Banking Test ○ NDGPS Data Correction Data Accauisitiont		○ Navigation Data Status Check		○ Navigation Data Status Check	○ Corridor View Test ○ Vertical Position Accuracy		○ Navi. Data Recording Complete
Tactical Info. Process & Display	○ Comm. Check ○ MFD Operaion Check	○ Instrument Check		○ Warning /Alarm Test (Altitude)		○ Warning /Alarm Test (Attitude)			○ Instrument ○ Warning/Alarm	○ Corridor Recognition	
	○ Visual Display Check	○ Instrument Display		○ Height Map Display check						○ Corridor Generation	

The visibility of GPS SV (space vehicle) was not good. The number of SV observed was 10 at maximum and dropped to under 4 during steep banking as shown in Figure 16. This problem came from the bad location selection of the GPS antenna as well as steep banking. Due to the installation limitation GPS antenna installed near the rotor of the helicopter. So this reason caused to make interference with GPS receiver.

But in spite of GPS blockage, Figure 14 shows that the NDGPS/INS solution from the hybrid filter worked well.

Fig. 9. Flight Test Helicopter

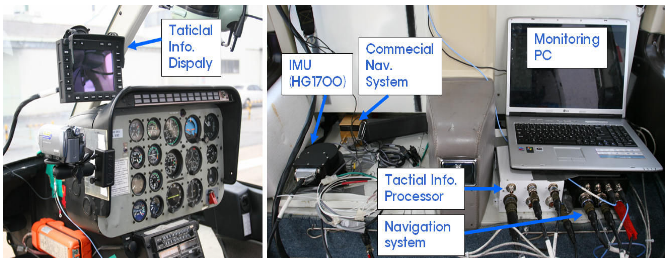


(a) Cockpit (b) Cabin .

Fig. 10. Flight Test Environment (MD500)

The latest artificial vision based navigation system of the final version was mounted in B-206 helicopter and a final flight test was performed at Mt. Deukyoo on February 11, 2008 for 80 minutes.

Fig. 11. Trajectory of ground test in Pusan



(a) Cockpit (b) Cabin .

Fig. 12. Flight Test Environment (B-206)

However due to the limited payload and electric power capacity of the helicopter, the reference system (MAPS INS) could not be mounted. Instead of that, the post-processing DGPS was used to evaluate performance and consistency. Test results in Table 5 show that hybrid KF method meets the CAT-I requirement.

Table 5. Results of the flight test

Flight Test (B-206)		Position Error (m)		
		N	E	D
H-KF	AVR	1.0898	0.4857	-0.5593
	RMS	0.7415	1.4659	1.9192

From the several test, we confirmed the coincident with artificial view and instruments and also the advantages of using artificial vision. Using the guidance corridor view generated from the ground control system, we could fly the cannon in the Mt. Deukyoo with safety even the low visibility condition such as fog, haze, and clouds.

The artificial vision based navigation shows not only the future trajectories but also identification of terrain and hazardous ground obstacles, which is helpful to understand situational awareness.

(a) Real Vision (b) Artificial Vision

Fig. 13. Comparison between Real & Artificial Vision

4. CONCLUSION

Flight tests were carried out to evaluate the overall system performance of an artificial based navigation system using hybrid NDGPS/INS.

The results presented in this paper show that the proposed hybrid kalman filter integration is validated with the experimental results and improves navigation accuracy, particularly in poor operational environments.

The results of development for the next generation navigation system based on the artificial vision are able to apply to various applications such as airplanes, GCS (Ground Control System) in UAV (Unmanned Aerial Vehicle), ships, cars, remote investigation, flight simulators as well as helicopters.

Future work is to elaborate the artificial vision and navigation system with synthetic vision integration designed to increase situational awareness and accuracy of navigation.

REFERENCES

Chiang, K.W., INS/GPS Integration Using Neural Networks for Land Vehicular Navigation Applications, Department of Geomatics Engineering, The University of Calgary, Calgary, Canada, UCGE Report 20209, 2004

Duchaineau, Mark, Murray Wolinsky, David E. Sigeti, Mark C. Miller, Charles Aldrich, and Mark B. Mineev-Weinstein, “ROAMing Terrain: Real-time Optimally Adapting Meshes,” IEEE Visualization, 1997

D. Ballard, "Artificial intelligence in the helicopter cockpit of the future," Proceedings of 10th Digital Avionics Systems Conference, Los Angeles, CA, 1991, pp. 125 - 130.

E. D. Kaplan(ed.). “Understanding GPS : Principle And Applications,” Artech House, Boston, 1996.

J. A. Farrell and M. Barth, The Global Positioning System & Inertial Navigation, New York: McGraw-Hill, 1999.

Jamila Kacemi, "Information Fusion in a Hybrid Tightly Coupled GPS/Dead-Reckoning Positioning System," Multisensor Fusion and Integration for Intelligent Systems, 2006 IEEE International Conference, Heidelberg, 2006, pp. 450 – 455.

MPC8560 Reference Manual, Freescale Inc. 2003.

Myron Kayton and Walter R. Fried, Avionics - Navigation Systems, John Willey and Sons. Inc., London (UK), 2 editions, 1997.

Appendix A. THE FIRST FLIGHT TEST RESULTS

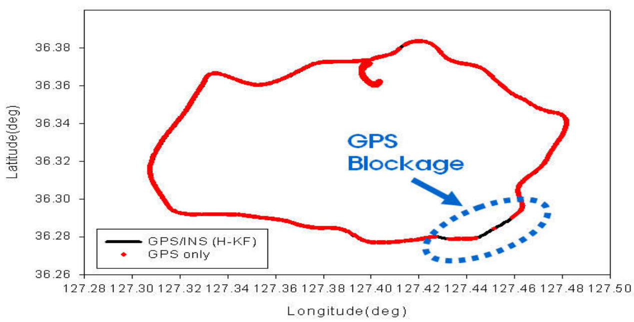


Fig. 14. Flight Test Results (2D)

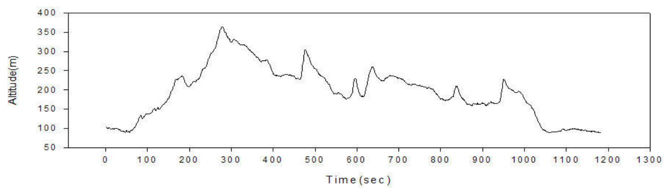


Fig. 15. Flight Altitude from Hybrid-KF

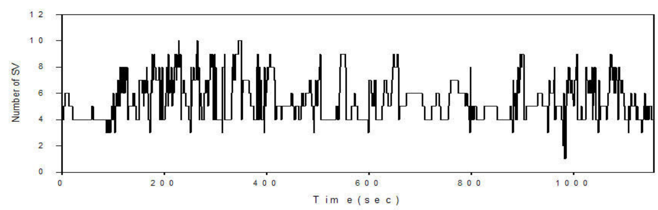


Fig. 16. Number of GPS SV during flight

Appendix B. THE FINAL FLIGHT TEST RESULTS

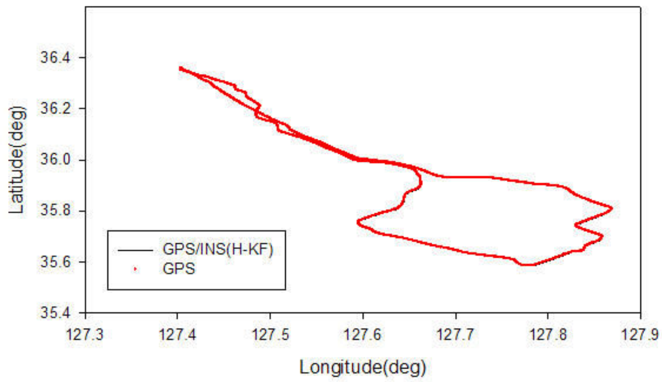


Fig. 17. Flight Test Results (2D)

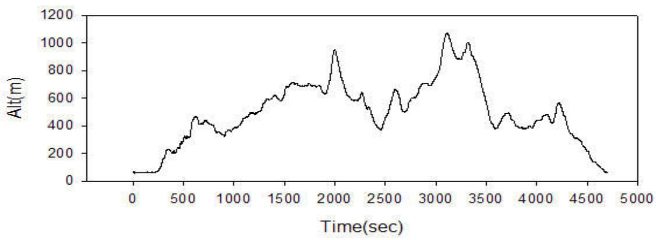


Fig. 18. Flight Altitude from Hybrid-KF

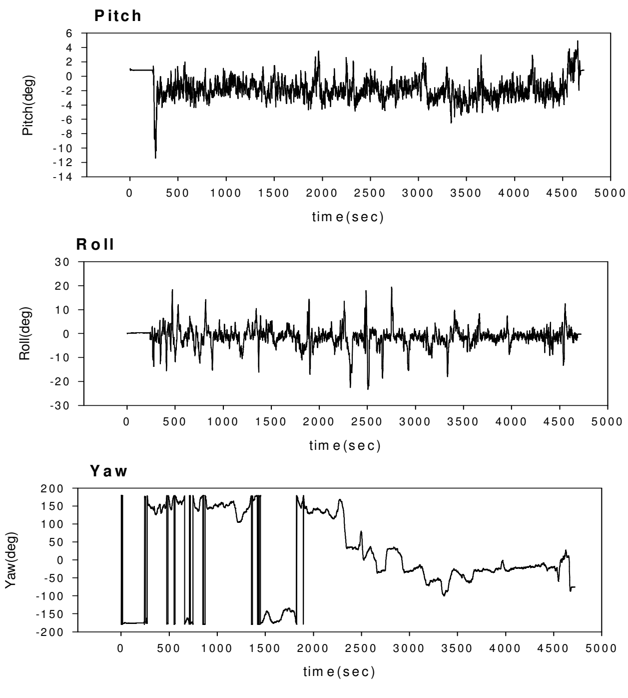


Fig. 19. Flight Attitude from the Hybrid-KF

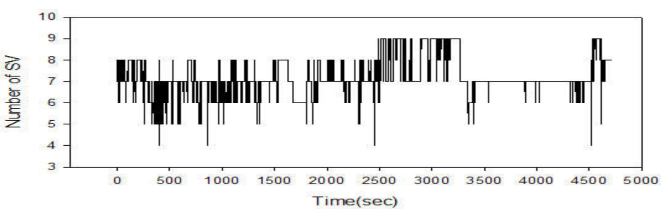


Fig. 20. Number of GPS SV during flight