Integration of the MS ESP flight simulator with GNSS-based guidance system

OLEG ANTEMIJCZUK, DAGMARA SOKOLOWSKA,
KRZYSZTOF A. CYRAN
Institute of Informatics
Silesian University of Technology
Akademicka 16, 44-100 Gliwice
POLAND

oleg.antemijczuk@polsl.pl, dagmara.sokolowska@polsl.pl, krzysztof.cyran@polsl.pl
http://www.egalite-project.eu

Abstract: - The article describes the problem of integration into a one test and validation platform the Microsoft ESP flight simulator software and GNSS-based guidance system. The research done is performed within the EGALITE project under 7th Framework Programme of the European Union. In the paper, authors present methodology used for connection of helicopter simulator PHS designed by Flyit Simulators, Inc. (USA) working with Microsoft ESP software and located in the Virtual Flying Laboratory at the Silesian University of Technology (Poland) with typical GNSS-based flight guidance system used to design and validate LPV approach procedures. The aim of integration is to speed up and reduce the cost of designing new LPV approach procedures using GNSS EGNOS navigation satellite system for a wide range of users of civil aviation - airports, emergency services, helicopter pilotes, etc. The language C ++, Microsoft Visual Studio 2010 with Microsoft ESP SDK SimmConnect was used for this task.

Key-Words: - LPV approach procedures, ESP, FNTP II Flight Simulators, GNSS, EGNOS, Search and Rescue Services.

1 Introduction

The introduction by the European Space Agency (ESA) of the full operational usage of European Geostationary Navigation Overlay Service (EGNOS), which took place on September, 1st 2009, allowed launch of new types of services in the field of satellite navigation used in civil aviation. One of them is the possibility of global navigation satellite system (GNSS) based guidance during the landing approach. Moreover, it is specific for the EGNOS system (characterized by such parameters as: Accuracy, Integrity, Availability, Continuity [1-3]) to increase geographical positioning accuracy both in lateral and vertical dimensions. Increasing of system reliability allows to navigate the aircraft to the runway approaches with decision altitude of 200 feet (61 m) and visibility of 1/2 mile. Landing minima are similar to those in an instrument landing system (ILS). EGNOS enables localizer performance with vertical guidance (LPV) which is considered as the highest precision GPS-based, aviation instrument approach procedure, currently available without specialized aircrew training requirements, such as for example required navigation performance (RNP). This allows for the use of relatively inexpensive and reliable GNSS receivers installed on the aircraft (in particular helicopter) for support pilot during the landing approach or manoeuvring in the ground proximity, where information about electric high voltage lines included in the navigation system can help to avoid the danger. However, full operational use of the new capabilities requires to prepare new LPV approach procedures. Therefore, the increased market demand is observed in design and implementation of new LPV procedures for civil aviation. For example, Pildo Labs company the participant of the EGALITE project, is an European corporation working in the civil aviation industry, which is committed to the creation, testing, validation and approval by the air traffic control authorities of the European Union countries of new LPV procedures for growing European market. Working closely with ICAO, EUROCONTROL organizations and National Air Traffic Control authorities, the company is engaged in development of new regulations and the implementation of air EGNOS services. To create new LPV procedures the GNSS-based guidance system should be used in connection with the flight simulator. Such integrated system helps to design and validate the instruments approach path of the aircraft flight. It also allows users to visualize the dynamic behaviour of the aircraft flight during the approach to the runway. The ongoing course deviations are calculated for all the lateral and vertical coordinates of the plane. Normally, to design proper procedure, it is necessary to perform a test flight by aircraft with air GNSS receiver and record its position in real terms over the airport. Recorded data allows to reply the aircraft flight and to verify the LPV procedure design before to validate it by air traffic control authority.

Connection of the above described system with the FNTP II flight simulator (such as the one installed in the Virtual Laboratory of the Silesian University of Technology) via a network protocol, allows to verify the LPV procedure in a virtual environment. Pilot performing the approach manoeuvres using the proposed LPV procedure is monitored by the software in real time and such characteristics as behavior of the aircraft during the runway approach until to LPV decision altitude can be studied. This makes it possible to repeat multiple times the landing manoeuvres and to modify them without the need for a real plane in the real environment. This also provides measurable cost savings, reduces the time and increases the reliability of the new LPV procedure design. With a feedback navigation data transfer GNSS-guidance application to the ESP flight simulator, the latter can replay in virtual environment the whole aircraft flight with GNSS navigation data recorded during the real flight test. This is very important for the flight test verification and analysis and allows to make additional modifications to the proposed LPV procedures.

2. Problem Formulation

Within the EGALITE project, one of the sub-goals was to design and develop the interface connecting ESP flight Simulator to the GNSS-based guidance system for increasing safety of the flight in the proximity of ground obstacles (for example the electric high voltage lines). The electromagnetic sensors indications should be incorporated into database of the guidance system in order to avoid further collisions with them. The guidance system can be also used in approach procedures and the system Platero developed by Pildo Labs is an example of such application. Integration of ESP flight simulator with GNSS-based guidance system requires a special application, which sends positioning data of the aircraft flying in the virtual world generated by simulator to the guidance application, and receives navigation data computed according the LPV procedure which are displayed on the CDI gauge in the virtual cockpit allowing pilot to safely fly in the proximity of electric lines or follow the approach path to the runway.

3. Problem Solution

An important factor, which has to be taken into consideration in the actual solution is the data transfer time and the frequency appropriate to support transfer of collected data about the position of the plane in the ESP environment. Transmitted data about the position of the aircraft are kept in in WGS84 format - latitude, longitude and its height converted from meters to feet's. SimAI intermediary application is written in the form of the system service working in the Windows environment. It provides detection of the simulator start-up and initiates the network connection to the GNSS-based guidance application. It works as the

ISBN: 978-1-61804-141-8

typical client - server configuration. During the flight, pilot has at his disposal the modified CDI gauge located on the control panel that allows him to observe the aircraft trajectory and provides the course modifications of the aircraft position data generated by a GNSS-based guidance according to LPV selected procedure or terrain map. This application calculates in real time the aircraft deviation relative to its course, and generates appropriate corrections to ensure proper flight to the airport or proper path around electric high-voltage lines. Different mathematical models were examined to determine the airplane LPV course implemented in the flight simulator and by comparing them with GNSS-guidance application the trajectory basis of EGNOS GNSS simulation was created. In addition, the special functions were implemented to allow replay of the previously recorded real test flight. Aircraft position, its height, pitch and heading are continuously computed allowing to fully restore all flight parameters in the flight simulator environment. The Fig. 1 shows developed system structure. Modes LPV Simulator Flights and SimAI Reply Mode where implemented into SimAI application as described below.

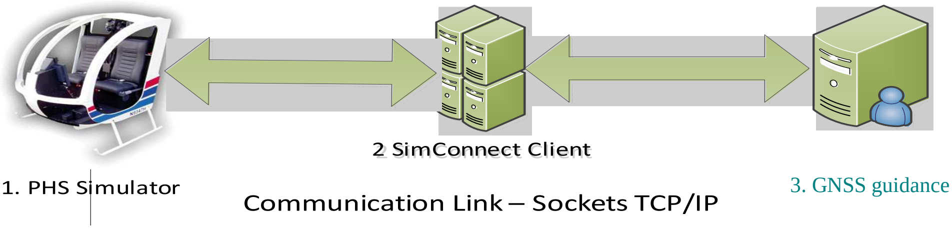

Fig. 1 ESP- GNSS-guidance solution

3.1 LPV Simulator Flights

In this mode the SimAI software enables the pilot to exercise the LPV approach procedure during the flight in the ESP simulator virtual world. Changing configuration settings in the SimAI starts to send virtual aircraft position coordinates to the GNSS-based guidance software. The designed by us communication network protocol transfers set of data from the ESP to that application. Table 1 shows what data variables are necessary for proper trajectory computation. SimAI interconnect software requests ESP flight simulator for a set of positioning data, the aircraft status, and waypoints coordinates [4], translates it to the format acceptable by given GNSS-based guidance application, and sends them to that application with selected frequency.

Table 1 ESP –GNSS guidance communication

VAR TYPE	VAR NAME	COMMENT
int	nRX_WEEK	GPS Week of receiver epoch [week]
int	nRX_TOM	Receiver Epoch of navigation solution in receiver time
int	nPOS_TYPE	Navigation Move
int	nNSV_USED	Number of Satellites used in navigation solution
int	nNSV_LOCK	Number of satellites locked by the receiver
double	dNS_HPL	Protection Level (either provided by SBAS or by GBAS)
double	dNS_VPL	Vertical Protection Level (either provided by SBAS or GBAS)
double	dNS_LAT	Latitude in WGS84 of position solution
double	dNS_LON	Longitude in WGS84 of position solution
double	dNS_ALT	Altitude in WGS84 (above WGS84 ellipsoid) of position solution
double	dNS_DEW	EAST/West distance to a reference point of position solution (East positive)
double	dNS_DNS	North distance to a reference point of position solution (North positive)
double	dNS_DUP	Up distance to a reference point of position solution (Up Positive)
double	dNS_DHOR	Horizontal distance to a reference point of position solution
double	dGPS_SEC	GPS Time of week of position solution [seconds] (Min: 0.0, Max: 604800.0)
double	dNS_X	Cartesian Geocentric X-coordinate of position solution
double	dNS_Y	Cartesian Geocentric Y-coordinate of position solution
double	dNS_Z	Cartesian Geocentric Z-coordinate of position solution

The GNSS-based guidance system resends the computed approach coordinates, deviation values, maximum lateral and vertical values for properly control the simulator aircraft CDI gauge. In this way, the pilot is able to control aircraft to the runway approach. ESP simulator view during the virtual flight is shown in Fig 2. The debug mode for SimAI view is presented in Fig.3. The SimAI application establishes connection to the Microsoft ESP Fight Simulator and receives data about the aircraft position in the virtual world. In experiments, the ESP simulator for this task was set to the approach performed in Al Hoceima (GMTA) airport. The Pildo company made prior flight tests with GNSS EGNOS receivers over few airports and all GPS receiver and aircraft flight data were recorded. During our tests the GMTA airport waypoints data were set into the ESP virtual world for GNSS-based guidance software computation and the test version of the CDI gauge data were presented to the pilot.

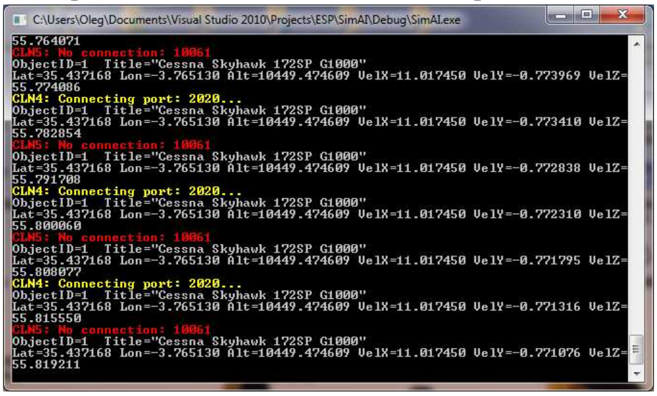

Fig. 2 SimAI Debug Mode

Fig. 3 ESP during GMTA approach flight

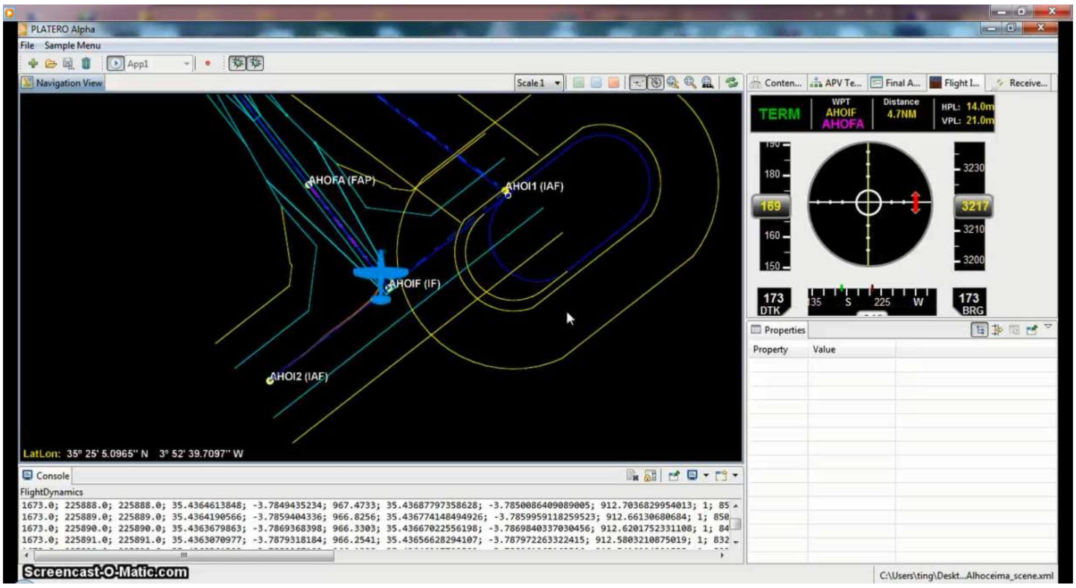

Fig. 4 GNSS-based guidance using Pildo's Platero application during virtual flight tests

3.2 SimAI Reply Mode

The general view of the GNSS-based guidance application during the virtual flight test is shown in Fig.4 on the example of Pildo's Platero application. In the reply mode the SimAI application transfers flight positioning data recorded in real flight to the ESP simulator to make virtual tour of the test flight. During this simulation, the user is able to observe and verify the LPV guidance procedure and fix possible errors. This mode is useful to boost the procedure design time and to provide measurable cost savings of the process. Table 2 shows the set of variables send to the SimAI program for ESP aircraft flight positioning For full aircraft simulation the pitch and heading must be calculated inside the

ISBN: 978-1-61804-141-8

SimAI application from known two closest position coordinates. The mathematical algorithms [5] are using the functions **GetPitch** for pitch and **GetAzimuth** for heading computation.

Table 2 Protocol variables description for PLATERO to ESP communication link

VAR TYPE	VAR NAME	COMMENT
int	nRX_WEEK	GPS Week of receiver epoch [week]
int	nRX_TOM	Receiver Epoch of navigation solution in receiver time
double	dGPS_SEC	GPS Time of week of position solution [seconds] (Min: 0.0, Max: 604800.0)
double	dNSFP_LAT	Latitude of the Navigation System Flight Path position solution [degrees]
double	dNSFP_LON	Longitude of the Navigation System Flight Path position solution [degrees]
double	dNSFP_ALT	Altitude of the Navigation System Flight Path position solution [meters]
double	dDFP_LAT	Latitude of Desired Flight Path in WGS84 Coordinates [degrees]
double	dDFP_LON	Longitude of Desired Flight Path DFP in WGS84 Coordinates [degrees]
double	dDFP_ALT	Altitude of Desired Flight Path DFP in WGS84 Coordinates [meters]

```
double GetAzimuth (double lat1, double lon1, double lat2, double lon2) {
  double lat1rad = lat1 * DEG2RAD;
  double lon1rad = lon1 * DEG2RAD;
  double lat2rad = lat2 * DEG2RAD;
  double lon2rad = lon2 * DEG2RAD;

  if (lat1rad == lat2rad && lon1rad == lon2rad) return 0.0;
  if (lon1rad == lon2rad) return lat1rad > lat2rad ? 180.0 : 0.0;

  double y = cos(lat2rad) * sin(lon2rad - lon1rad);
  double x = cos(lat1rad) * sin(lat2rad) - sin(lat1rad) * cos(lat2rad) * cos(lon2rad - lon1rad);
  double azimuthRadians = atan2(y, x);
  double azimuthDegs    = RAD2DEG*azimuthRadians;
  return azimuthDegs;
} // End of GetAzimuth


double GetPitch (double lat1, double lon1, double alt2, double lat2, double lon2, double alt1) {
  double R    = 6371000.0; // m
  double dLat = (lat2-lat1)* DEG2RAD;
  double dLon = (lon2-lon1)* DEG2RAD;
  double dPitch;

  lat1 = lat1* DEG2RAD;
  lat2 = lat2* DEG2RAD;

  double a = sin(dLat/2) * sin(dLat/2) + sin(dLon/2) * sin(dLon/2) * cos(lat1) * cos(lat2);
  double c = 2 * atan2(sqrt(a), sqrt(1-a));
  double distance = R * c;

  double dAlt = alt2 - alt1;
  if (distance > 0.0)
    dPitch = (-tan (dAlt/distance) * RAD2DEG)/2.0;

  return dPitch;
} // End of GetPitch
```

4. Conclusions

During the EGALITE project, the goal of efficient exchange of the aircraft flight positioning data was achieved in order to integrate the PHS flight simulator with GNSS-based guidance. The developed within the project SimAI application interconnects two network systems: the ESP Flight Simulator installed in Virtual Flying Laboratory at SUT, with the GNSS-based guidance system implemented as the Pildo's Platero application. The SimAI application which controls the cockpit CDI gauge allows pilot to make full flight following selected LPV approach guidance procedure. This new ability added to the FNTP II simulators will increase interest to design and implement LPV procedures. Now it is possible to train pilots to use LPV guidance using FNTP II simulators and to learn them how to use the warning about electric field systems in virtual environment. Virtual Flying Laboratory at SUT, now will offer this new ability to civil aviation industry in Poland. This exceptional laboratory was established in 2011 as a result of professional interests of researchers in the Institute of Informatics at SUT in aviation [6,7]. However, at this initial stage the problems addressed in research concerned mainly the fast image recognition systems based on opto-electronic methods, proposed by collaborators from Military University of Technology in Warsaw, which were used jointly with computational intelligence approaches such as rough sets [8] and artificial neural networks [9]. After setting up the Virtual Flying Laboratory, the new research area were proposed. Results of the research activities performed in EGALITE project by authors in collaboration with their colleagues form Pildo Labs. in Barcelona, are described in this paper. These new horizons resulted in a common research in the field of GNSS in aviation, in particular with the use of capabilities offered by professional flight simulators installed at SUT. These results can be used to increase safety of the helicopter pilot operations in the proximity of ground, based not only on indications of smart sensors used for detection of electromagentic fields produced by power lines, but also by usage of electronic flight bag, displaying the warnings based on appropriate databases and current position detected by GNSS and course deviation indicators of the sort presented in the paper.

It is worth to note at this point, that this is only the first step of this collaboration. After successful implementation of LPV guidance procedures to the FNTP simulators, the next step will be performed. During execution of the EGALITE project, the new ideas have been proposed such for example the design of more sophisticated CDI gauges. The following task will be therefore performed in the next stage: to create new 3D looking CDI gauge for better exploit the LPV procedures approach flights. This will increase the safety of flights during landing procedures and close to ground flights.

5. Acknowledgements

The research leading to these results has received funding from the PEOPLE Programme (Marie Curie Actions) of the European Union’s Seventh Framework Programme FP7/2007-2013/ under REA grant agreement no 285462.

The authors would like also to acknowledge the fruitful collaboration with the group of Pildo Labs. (Barcelona Spain) employees, in particular Juan M. Romero, Silvio Semanjsky, and Santiago Soley, who participated in the project and supported us with functional description of their GNSS-guidance system called Platero and helped us to experiment at Pildo premises with integration of this system with the simplified version of the ESP flight simulator.

References:

[1] K.A. Cyran, D. Sokołowska, A. Zazula, B. Szady, O. Antemijczuk, Data gathering and 3D-visualization at OLEG multiconstellation station in EDCN system, Proc. 21st International Conference on Systems Engineering, Las Vegas, USA , 221-226, 2011

[2] O. Antemijczuk, B. Szady, K.A. Cyran, Integrity Events Analysis at OLEG GNSS Station in EGNOS Data Collection Network, in Man-Machine Interactions 2 (T. Czachorski et al. Eds.), Advances in Intelligent and Soft Computing 103, Springer, 95-103. 2011.

[3] O. Antemijczuk, K.A. Cyran, E. Wróbel, One and a half years of participation in the EDCN project – summary, in Transport Systems Telematics: Communications in Computer and Information Science 104: 320-326, Springer, 2011.

[4] Microsoft Corporation, *ESP 1.0 SDK Simulation Variables*, Microsoft MSDN, 200X.

[5] Synder, John P., Map Projections: A Working Manual 1987, *USGS Professional Paper: 1395*, pp. 30.

[6] L. R. Jaroszewicz, I. Merta, T. Podeszwa, K. A. Cyran, Airplane engine condition monitoring system based on artificial neural network, in: Quality, Reliability and Maintenance, G. J. McNulty (ed.), Bury St Edmunts London, Professional Engineering Publishing, 179-182, 2002.

[7] T. Podeszwa, L.R. Jaroszewicz, K. Cyran, Fiberscope based engine condition monitoring system, Proc. SPIE, 5124, 299-303, 2003.

[8] K. A. Cyran, A. Mrózek, Rough sets in hybrid methods for pattern recognition, Int. J. Intell. Syst., 16 (2), 149-168, 2001.

[9] K. A. Cyran, L. R. Jaroszewicz, T. Niedziela, Neural network based automatic diffraction pattern recognition, Opto-electronics Rev., 9 (3), 301-307, 2001.