Abstract
In the paper a prototype of a system for automatic landing of aircrafts and helicopters is proposed. The key requirement is to develop a completely autonomous system that does not depend on any kind of infrastructure or equipment, located outside the aircraft (like GPS, ILS, etc.). The idea is to control and navigate the aircraft using images, acquired by the camera, installed on the aircraft. The paper describes the structure and the properties of the proposed system and gives the overview of the international project within which the system is developed.

Keywords
Aircraft guidance and control, automatic landing systems, computer vision, image recognition, automatic control.

INTRODUCTION

In this paper an overview of an international project Pegase from the sixth framework is described. The main task of the project is the feasibility study and the development of the early prototype of a system for automatic landing of airplanes and helicopters. Systems for automatic or assisted landing are in service for many years, but they are either "ground based" or "satellite based". This means that they are based on a special equipment and infrastructure installed on airports or on satellites. Equipment typically emits radio signals to provide the guidance of the aircraft. On the aircraft a receiving instrument is installed, which indicates the aircraft position with respect to the beams of radios signals. Several systems of the described class are in service today, e.g. Instrument Landing System (ILS). The common property of all these systems is that their operation depends strongly on the infrastructure on the airports. This may be a drawback, since the ground infrastructure can be a subject of random or intentional failure (attacks), which is a threat to the safety. The motivation of the Pegase project is to design a new and completely autonomous system for automatic landing that does not depend on any kind of equipment or infrastructure of the airport, neither on systems like Global Positioning System (GPS). The system should be based exclusively on the procedures and equipment located on the aircraft. The system may be used as a back-up when the ground based landing system is out of service or it can be used as a primary system during landing to the airports without ground based landing system. The key idea is to navigate the aircraft using images, acquired by the camera installed on the aircraft itself. The position and orientation of the aircraft can then be estimated by comparing the acquired images and the geographical database, which is a part of the system.

The goal of the Pegase project is to conduct a feasibility study of the proposed system and to develop an early prototype of the system. In this early stage of the development the prototype will be implemented and tested using computer simulation rather than testing on real aircraft. In computer simulation all system components including the aircraft and image sequence taken from the aircraft will be simulated using mathematical models and numerical simulation techniques. Thus, providing the mathematical models for all system components is also a part of the project.

The paper is organised as follows. Introduction will be followed by the section, describing the structure of the proposed system and the subsystems. The next section will be devoted to the simulation environment, which is a key tool for the development and testing. This will be followed by the section, describing the role of Jozef Stefan Institute within the project. The paper will be concluded by the information about the current status and the progress of the project.

PROJECT DESCRIPTION

Pegase is an international European project, financed within the sixth RTD Framework programme. Furthermore, it is a Specific Targeted Research Project (STREP) that complies with the research area of the aeronautics research work program of the thematic priority 1.4 "Aeronautics and Space". The project is coordinated by the Dassault Aviation and involves 6 other companies and 7 academic institutions, as follows from the table 1. The budget of the project is 5,13 millions Euros. The project is divided into several thematically separated but also highly integrated workpackages that closely reflect the architecture of the system under development, which
will be briefly described. Further details can be found at the project internet homepage [1].

Table 1: Project partners

<table>
<thead>
<tr>
<th>Company</th>
<th>Acronym / Nation</th>
<th>Logo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dassault Aviation</td>
<td>DASSAV / FR</td>
<td><img src="image1" alt="DASSAV Logo" /></td>
</tr>
<tr>
<td>Alenia Aeronautica</td>
<td>ALA / IT</td>
<td><img src="image2" alt="Alenia Logo" /></td>
</tr>
<tr>
<td>Eurocopter France</td>
<td>ECI / FR</td>
<td><img src="image3" alt="Eurocopter Logo" /></td>
</tr>
<tr>
<td>Eurocopter Deutschland</td>
<td>ECd / GE</td>
<td><img src="image3" alt="Eurocopter Logo" /></td>
</tr>
<tr>
<td>European Aeronautic Defence and Space company</td>
<td>EADS / FR</td>
<td><img src="image4" alt="EADS Logo" /></td>
</tr>
<tr>
<td>Walphot S.A.</td>
<td>WAL / BE</td>
<td><img src="image5" alt="Walphot Logo" /></td>
</tr>
<tr>
<td>Elliniki Photogrammetriki</td>
<td>ELPHO / GR</td>
<td><img src="image6" alt="Elliniki Logo" /></td>
</tr>
<tr>
<td>Centre National de la Recherche Scientifique</td>
<td>CNRS / FR</td>
<td><img src="image7" alt="CNRS Logo" /></td>
</tr>
<tr>
<td>Consorzio Nazionale Interuniversitario per le Telecomunicazioni</td>
<td>CNIT / IT</td>
<td><img src="image8" alt="CNIT Logo" /></td>
</tr>
<tr>
<td>Institut National de Recherche en Informatique et Automatique</td>
<td>INRIA / FR</td>
<td><img src="image9" alt="INRIA Logo" /></td>
</tr>
<tr>
<td>Jozef Stefan Institute</td>
<td>JSI / SLO</td>
<td><img src="image10" alt="Jozef Stefan Institute Logo" /></td>
</tr>
<tr>
<td>Eidgenössische Technische Hochschule Zürich</td>
<td>ETHZ / CH</td>
<td><img src="image11" alt="ETHZ Logo" /></td>
</tr>
<tr>
<td>École Polytechnique Fédérale de Lausanne</td>
<td>EPFL / CH</td>
<td><img src="image12" alt="EPFL Logo" /></td>
</tr>
<tr>
<td>Instituto Superior Técnico</td>
<td>IST / PO</td>
<td><img src="image13" alt="IST Logo" /></td>
</tr>
</tbody>
</table>

PEGASE SYSTEM DESCRIPTION

The architecture of the Pegase system can be explained by the Figure 1. On the figure, one can identify the main subsystems described later in this section.

Figure 1: Architecture of Pegase system – a conceptual view

Imaging sensors

One of the crucial components of the Pegase systems is the equipment for image acquisition, i.e. camera or more precisely, imaging sensor(s). It is used to provide the image of the environment, taken from the aircraft. Image must be reliable and of sufficient quality and resolution in all weather conditions. The selection of imaging sensors is therefore very critical.

Figure 2: Components of Pegase control system

Figure 3: Examples of imaging sensor

Figure 4: Example of image, taken by IR sensor
There are several candidates that are readily available on the market today, e.g.: visual (CCD), infrared (IR), laser, radar and magnetic sensors. Their technical specifications (range, resolution, accuracy, etc.) should be collected and compared. It is expected that a combination of several sensors integrated by data fusion will give the best results. For the selected sensors real video sequences will be provided enabling final sensor validation, i.e. to see if they can fulfill the requirements of visual tracking and servoing algorithms. Video sequences will be taken from real aircraft during real landing procedure.

**Geographical database**

The basic principle of the localization of the aircraft using images is based on comparing the image acquired and the geographical database.

![Figure 5: Examples of geographical databases – a graphical representation](image1)

Simply speaking, the position and orientation of the aircraft is estimated from the point of the best match between the acquired image and the geographical database. The geographical database is therefore an important component of the Pegase system. In the first stage a state-of-the-art on geographical data representation will be studied and several products from the market will be evaluated. It will be checked if existing standard solution fulfill the needs of the Pegase system. It is expected that two forms of database will be needed, one to support wide range localization by describing the environment in wider range and the other to support close range localization by describing the details of the runway (terminal) area.

Pegase system will not only employ the database but it will also support the “online” creation or refinement of the existing database. This can be done by fusing the acquired images during flying and position coordinates gathered from the standard position sensors, e.g.: GPS or inertial sensors, which are normally installed on aircrafts.

Note, that "online" creation and refinement of the database is an extra feature of the Pegase system. Normally, the database is provided prior the use of Pegase system using "offline" procedures or existing sources. Therefore, for normal operation of Pegase system, when existing geographical database is employed for navigation and landing, the systems like GPS are not needed.

**Visual tracking**

The algorithms for visual tracking are the key functions of the Pegase system, used for estimation of aircraft position and orientation [2, 3].

In general, visual tracking of an object means continuously identifying its location when either the object or camera is moving. More specifically, 3D tracking aims at continuously recovering all six degrees of freedom that define the camera position and orientation relative to the scene, or, equivalently, the 3D displacement of an object relative to the camera. In our case the camera is installed on the aircraft and the runway is an object of tracking.

It is expected that two stages of tracking will be needed in Pegase system:

- **Wide range navigation (Localization)**, used when the aircraft is far away from the runway. The goal in this stage is to find (locate) the object of tracking, i.e. the runway. This is done by comparing the acquired image and the wide range geographical database. Here mainly the position of the runway is of interest, the shape of the runway is assumed not to be visible due to remote distances.

- **Close range navigation (Tracking)**, used when the aircraft is close to the runway and the runway has already been found. In this stage the tracking is typically based on the recognition and following of certain image features, e.g. edges, border lines or similar, see Figure 6 showing an image from the video sequence, where the border of the runway is being continuously tracked by the red rectangle.

![Figure 6: Tracking an image from the video sequence](image2)
Visual servoing

In general, visual servoing means the controlling the physical position of either object or camera \([4, 5, 6]\). In our case visual servoing is used to control the position of the aircraft, which should follow the prescribed path, called landing trajectory. Visual servoing is a set of control loops acting on the aircraft actuators (rudder, elevator, ailerons, throttle, etc.). A set of measured variables feed into visual servoing control loops represents the estimated aircraft position and orientation, which are estimated by visual tracking algorithm. The algorithms of visual servoing are closely related to the standard autopilot functions. They are organized as a cascaded structure with two main control layers, as follows from the Figure 2. On the figure, the following control layers can be identified:

- The first control layer ("Stabilisation") is used for aircraft stabilization by control of aircraft angles and angle rates (yaw, pitch roll) and the aircraft speed.
- The second control layer ("Path following") is responsible for following the prescribed path during flight. The algorithm monitors the deviation between the aircraft actual position and the demanded path and accordingly adjusts the command values for aircraft orientation and speed, which are then feed into the first control layer. The result of one early prototype algorithms can be seen on the figure 7 representing a 3D view, where the green line represents the demanded path and the black line is the actual path of the aircraft.

Aircraft types (platforms)

Pegase system will be able to navigate two different types of aircrafts: airplanes and helicopters. Consequently, two variants of the system will be developed, but they will share the majority of the technology. Main differences are expected to be found in units for control and guidance (visual servoing) due to different principle of operation and control of aircraft and helicopter.

SIMULATION ENVIRONMENT

As explained already in the introduction, the Pegase project is a feasibility study, which means that the prototype of the Pegase system will be tested using computer simulation. Therefore a common simulation environment is needed to integrate and simulate all subsystems that play the role in the operation of the of the Pegase system. Simulation environment specifies interfaces of subsystems.
and possible ways of implementation of subsystems. It also provides a common simulation engine, used for coordinated and synchronized simulation of all subsystems. All this should allow quick integration of the subsystems. Note that particular subsystems will be developed by different project partners, so quick and easy integration is very important. Therefore a simulation environment is one among first tasks of the project.

In the frame of simulation environment a set of test scenarios will be prepared, specifying the prescribed landing paths and other external influences (wind, disturbances, etc.). These scenarios will be used during the assessment and validation of the Pegase system.

In the simulation environment a set of test scenarios will be prepared, specifying the prescribed landing paths and other external influences (wind, disturbances, etc.). These scenarios will be used during the assessment and validation of the Pegase system.

Figure 8: Simulation environment

There are three elements that must be simulated during tests:

- the operation of the aircraft (airplane or helicopter),
- the image, seen by the imaging sensor, installed on the aircraft,
- the performance of the imaging sensor (i.e. the way that the sensor distorts the original ideal image).

Accordingly, the simulation environment must provide three basic mathematical models: a model of the aircraft, an image generator and a model of the imaging sensor. Figure 8 shows the integration of the Pegase system in the simulation environment.

### Aircraft model

A mathematical model of the aircraft is a set of dynamic and static relations that describe the response of the aircraft to the command signals (rudder, elevator ailerons and throttle commands) and external influences (height, wind speed, disturbances, etc.). Very accurate and realistic mathematical models will be used, which closely mimic the operation of the real aircraft. This is important in order to provide the credible validation of the entire system. It is clear that each particular aircraft has its own mathematical model with different parameters and possibly even different structure.

### Image generator

In a simulation environment, an image generator is needed, which provides the image sequence of artificial environment substituting the imaging sensors aiming at the real environment. Image sequence should be generated according to the simulated signals of the position and the orientation of the aircraft. Therefore, image generator must contain its own 3D database of the environment. However, this database should be distinguished from the geographical database, which is a part of the Pegase system.

The development of image generator is not a goal of the Pegase project, rather one of the available software products will be used for this purpose. There are several such software products available, for example Flight-Gear, which an open source freeware.

### Imaging sensor model

Real imaging sensors produce non-ideal images, distorted by noise or similar disturbances, depending on the characteristic of particular sensor and the atmospheric conditions.

To provide the realistic simulation, the overall sensor characteristic should be taken into account. The characteristic is described by the model of imaging sensor. During computer simulation sensor model will convert the ideal artificial image, provided by the image generator, into the non-ideal image that a real sensor would produce. Sensor model is a mathematical transformation that converts a sequence of ideal images into sequence of images that match the output of the sensor. Sensor models will be provided based on real video sequences, taken during real landing procedures.
Jozef Stefan Institute, Department of Systems and Control is one among three project partners working on the topic of visual servoing algorithms. The role of Jozef Stefan Institute is to provide advanced visual servoing algorithms, including both low-level control (aircraft stabilisation) and high-level (path following). The goal here is to enhance the existing autopilot functions and to adapt them to the special conditions that appear due to use of visual tracking and localization:

- Jozef Stefan Institute, Department of Systems and Control, has expertise in advanced control methods, applied to various types of systems and processes. In this scope there are methods for multivariable and nonlinear processes, predictive control methods and others. These methods in general provide better results than traditional methods, especially when applied to demanding processes. The control of aircraft is a relatively demanding process, so the goal is to find out, how to enhance the visual servoing of the aircraft by utilizing the advanced control methods.

- The prescribed landing path is a trajectory that is known in advance. The algorithms for the control of aircraft must be able to employ this extra information in a way to achieve better results. Here the use of predictive control algorithms seems to be very promising, since these algorithms can take into account the future demanded values of the process outputs.

- In operation of visual tracking and servoing algorithms different types of distortions may occur in case of to extremely bad weather conditions. In this cases the signals of aircraft position and orientation may be corrupted with noise or may be temporarily (for a short interval) unavailable. To cope with this, the control algorithms must be enhanced by intelligent filtering of data.

- Visual tracking is based on algorithms for computer vision and image processing and they involve computationally intensive operation that may require certain time to complete. Consequently, there may be a certain lag time between the change of the position of the aircraft and the estimation of the position and orientation. Jozef Stefan institute will provide special control solutions based on predictive control techniques that are accommodated for the presence of lag time.

CONCLUSIONS

In the paper the technical overview of the system for automatic and autonomous landing of aircraft is presented. In the period of preparation of this article (i.e. the end of September 2007) the three year project is entering its second year and the progress of the project follows the plan. Results achieved up to now are very promising, basic technologies of all weather image acquisition and visual localization and tracking prove the system feasibility. The early results in the field of visual servoing and control of aircraft are also very encouraging and form a good base for future progress. In the following planed phases existing results will be refined and great part of attention will be focused to the integration of all system components within the simulation environment in order to perform final assessment of the system and the result of the feasibility questions.

ACKNOWLEDGMENTS

Authors and project partners are grateful to the European Commission for financial support of the project. The number of the contract is AST5-CT-2006-030839.

REFERENCES

http://www.transslo.com
[1] Information about the project on the internet: http://dassault.ddo.net/pegase/


BIOGRAPHIE

Dr. Gregor Dolanc has received his Ph.D in electrical engineering at the University of Ljubljana, Faculty of Electrical Engineering in 2000. He is currently employed as a researcher at the Jozef Stefan Institute, Department of Systems and Control in Ljubljana, Slovenija. His research interest is focused on the design of advanced computer based control algorithms and their implementation in industrial practice. He has been involved in many industrial applied research and also turn-key projects of automatic control in various branches of industry (machine building and integration, metal industry, chemical industry, brick and tile industry) and he has also been participating in several projects financed by European commission. He is an author and co-author of several scientific papers from the field of advanced model based control.

Satja Lumbar, born in Ljubljana in 1980, received his B.Sc. in electrical engineering at the Faculty of Electrical Engineering, University of Ljubljana in 2005. Since 2005, he has been a researcher in the Department of Systems and Control. His research interests include PID control, predictive control, flight control systems, aerodynamics and related fields (modeling, simulation).
TransSLO WORKSHOP BOOK

Presentation papers

12. October 2007, Ljubljana, Slovenia

http://www.translo.com
TABLE OF CONTENT

1. PLENARY PRESENTATIONS
   WELCOME PRESENTATION, MR. SREČKO JANŠA, CHAIRMAN ................................................................. 4
   WELCOME SPEECH OF MR. RADOVAN ŽERJAV, M.SC., MINISTER OF TRANSPORT IN SLOVENIA ........... 5

2. TRANSPORT RESEARCH – NATIONAL AND EU LEVEL
   OVERVIEW OF TRANSPORT RESEARCH IN SLOVENIA .................................................................................. 12
   OVERVIEW OF TRANSPORT RESEARCH IN SLOVENIA, MR. PETER VERLIČ, PH.D................................. 14
   STRENGTHS AND PRIORITIES AT THE NATIONAL LEVEL, MR. DENNIS SCHUT .................................................. 19
   Transport Research areas of interest for Slovenia .................................................................................. 23
   Interactive session – Voting with Turning Point .................................................................................. 27
   TransSLO workshop – Sustainable transport research ........................................................................... 36
   Examples of industry/academia partnership to carry out research and development projects: National and EU levels, Mr DANIEL CADET, PH.D ................................................................. 42

3. CROSS – CUTTING ACTIVITY TO SUPPORT SURFACE TRANSPORT AND FRAMEWORK
   PROGRAMME 7 (FP7) ............................................................................................................................... 61
   Surface transport research in FP7 – A new approach towards an European transport system, Ms SUSANNA MARTINS ................................................................................................................. 62
   EU research programmes in Slovenia, Mr BOJAN JENKO, PH.D ................................................................. 76

4. RESEARCH EXCELLENCE - BEST PRACTICE ......................................................................................... 93
   Intermodal – BESTUFS project, Prof. STANE Božičnik ............................................................................. 94
   The efficiency of intelligent traffic signal control .................................................................................. 103
   Experiementing with intelligent traffic signal control, Ms ALENKA MALEJ, M.Sc ................................. 109
   Transport and environment an integrated analysis, Mr MILOŠ PREGLI, M.Sc ........................................ 117
   Position errors of aircraft future trajectory prediction ............................................................................ 130
   The concept of autonomous flight airspace ............................................................................................ 135
   Autonomous flight airspace concept, Mr TONE MAGISTER, PH.D ............................................................ 142
   PEGASE – helicopter and aeronef navigation airborne system experiments ....................................... 148
   PEGASE - helicopter and aeronef navigation airborne system experimentations, Mr GREGOR DOLANC, PH.D ..................................................................................................................... 155
   Slovenian contribution to maritime education, environment and safety ................................................. 166
   Slovenian contribution to maritime education, environment and safety, Mr MARKO PERKOVIČ, M.Sc ........................................................................................................................................ 174
   ETMS/ETCS system in the framework of EU process for introducing interoperability on the EU network ................................................................................................................................. 181
   Opportunity for the railway system – implementation of unique signaling system in the Republic Slovenia, Mr BENJAMIN STEINBACHER PUŠNJAK ........................................................................... 186

5. BRAKEOUT SESSIONS .......................................................................................................................... 191
   Proposal ideas from “Safety & Security” breakout session ........................................................................... 192

http://www.transslo.com