Development of an interaction concept for knowledge based decision making processes in a future pilot assistance demonstrator
Declaration of authorship

Hereby I state that I composed the bachelor project of aeronautical engineering with the topic:

“Development of an interaction concept for knowledge based decision making processes in a future pilot assistance demonstrator”

completely on my own without using any other sources or aids than those indicated and I also marked any quotes.

Maribel Hernández Dalmau

Braunschweig, 15.03.2011
Overview

A Pilot assistance system is an integrated and on-board system, where all required functions under a single human machine interface take place.

Since now, the assistance systems have been designed to solve individual tasks, but this approach is reaching its limits, because of the continuous growth of civil air traffic as well as the new air traffic management procedures which put new demands on the services of the aircrews.

Pilot assistance systems help the cabin crew to maintain a high level of safety in air traffic. To facilitate the required increase of capacity in the following years, these kind of systems in manned vehicles will be introduced and are analysed in this project.

The other main objective of the project is to focus on the decision making process of the actions.

It is crucial for aviation safety, especially in critical situations (when the aircrew is facing technical problems) then the logic, the priority and the principles of the processes will be also studied.

Finally, a practical demonstration for a display for one scenario will be given as an example.

In the cockpit display, the information will allow the pilot to easily monitor and get a better vision of the aerial traffic surroundings, improving the security and the efficiency of the flight operations.
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ACRONYMS

A/P AutoPilot System

ACARS Aircraft Communications Addressing and Reporting System

ACAS Airborne Collision Avoidance System

ADM Aeronautical Decision Making

ADI Attitude Display Indicator

ADS-B Automatic Dependent Surveillance - Broadcast

AFGS Automatic Flight Guidance System

HMI Human Machine Interface

ALICIA All Condition Operations And Innovative Cockpit Infrastructure

ATC Air Traffic Control

ATIS Automatic Terminal Information Service

ATM Air Traffic Management

CNS Communication Navigation Surveillance

CPDLC Controller Pilot Data Link Communications

DME Distance Measuring Equipment

EFB Electronic Flight Bag

EFIS Electronic Flight Instrument System

EGPWS Enhanced Ground-Proximity Warning System
<table>
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<td>FANS</td>
<td>Future Air Navigation System</td>
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<tr>
<td>FBW</td>
<td>Fly By Wire</td>
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<td>FE</td>
<td>Flight Envelope</td>
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<td>FLYSAFE</td>
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<td>FM</td>
<td>Flight Management</td>
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<td>FMC</td>
<td>Flight Management Computer</td>
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<td>FMGC</td>
<td>Flight Management Guidance and envelope Computers</td>
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<td>FMS</td>
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<tr>
<td>HF</td>
<td>High Frequency</td>
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<td>Horizontal Situation Indicator</td>
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</table>
JAA  Joint Aviation Authorities

MCDU  Multi-Function Control Display Unit

MLS  Microwave Landing System

ND  Navigation Display

NextGen  Next Generation Air Transportation System

NDB  Non-Directional (radio) Beacon

PAT  Pilot Assistance Technology

PFD  Primary Flight Display

SARP  Standards and Recommended Practices

SELCAL  Selective Calling System

SES  Single European Sky

SESAR  Single European Sky Air Traffic Management

TAWS  Terrain Awareness Warning System

TCAS  Traffic Collision Avoidance System

RA  Resolution advisory

RNAV  Area Navigation

VFR  Visual Flight Rules

VHF  Very High Frequency

VOR  VHF omnidirectional radio range
INTRODUCTION

Piloting an aircraft used to be a very physical and sensory oriented task. First aircraft generations were highly unstable, and demanded constant physical control inputs.

Most facets of the flying task have become less sensory oriented than in the past. As aircraft evolved, flying became physically easier as parts of control task were automated, and automated systems began to perform many of the flight task previously accomplished by the pilot.

But, in the early 60s, the increasing amount of information presented to pilots on the instruments, instead of easing their task, made it more difficult by increasing the scan and increasing the processing time necessary in order to make use of all the information.

Therefore, the need of new systems under a single human machine, able to deal with all the amount of information, are demanded.

The objective of this project is to make a study of the pilot assistance technologies focused on manned vehicles, in order to find a solution to the increasing number of instruments in the cockpit. A list of available pilot assistance technologies and the limitations of these systems will be discussed too, as well as a list of the new incoming systems with the advantages they can contribute with.

The aeronautical decision making process will be introduced too in order to understand the human machine interface and finally, an example of an interactive multitask display prototype will be developed.

The principle used tool for the research has been a literature review and for the simulation the Justinmind Prototyper, a software able to create high interactive wireframes.
CHAPTER 1. PILOT ASSISTANCE TECHNOLOGIES

The chapter "Pilot assistance technologies" will lead into the subject. An introduction to understand why these systems are so important and a classification of them will be done.

After that, a research of the new systems is be named.

1.1. Introduction to manned vehicles

A manned vehicle is an aerial vehicle that requires a human operator to fly, although it can be also operated automatically by the AutoPilot (A/P).

Since the first commercial flights started operating, it has been more important to reduce the most as possible the workload of the pilot in order to make her or his job easier.

A pilot assistance system is an integrated system used to maintain a higher level of safety and to facilitate the pilot's work.

Nowadays, the used systems are focused in a specific area of flight, so their mission is to have the control of a single task, but to facilitate the required increase of capacity in the upcoming years, new solutions have to be developed.

These new solutions are referred to systems, which are capable to combine all required tasks at the same time and to manage and control several hazardous and critical situations under a single human machine interface.

1.2. Difference between on-board and ground manned systems

Solutions to ensure the safe of the flights are the on-board and ground systems. The implementation of on-board and ground systems would increase benefits for safety and security of air transportation, as well as a good opportunity to improve the efficiency and the economic conduct.

The main objective of an on-board system is to monitor and control the variations of flights, the equipment and systems, and to provide a good solution in case of technical problems or failure.

Another important function of the on-board systems is to record the data and information from the aircraft systems: engine temperature, flight speed, take-off parameters, Global Positioning System (GPS) data, Navigation information, etc.

This is an important function, because the recorded data malfunctions and alerts can be transmitted and analysed at the ground stations.

Ground systems work in a pretty similar way the on-board systems do. The differences are the parameters they work with. Ground systems provide basically position data signals to determine the exact position of the vehicle. These systems are very useful in critical manoeuvres, like landing.
1.3. The aim of the Pilot assistance systems

Even in the lowest technology aircraft, problems associated with the scan, interpretation and analysis of the information became more and more apparent.

Various efforts were made to rationalise the process with the aims of:

- **Reducing scan**

In reducing the scan, it was recognised that the primary requirement was to provide the pilot with attitude and related aircraft handling information. A secondary requirement was to provide a navigation display. Effectively, a need for two indicators was identified:

- A primary or attitude display indicator.
- A secondary or navigation display (ND).

The primary display is variously known as the Primary Flight Display (PFD) or Attitude Display Indicator (ADI). The secondary display is variously known as the ND, Horizontal Situation Indicator (HSI) or (on an electronic unit) the MAP display.

- **Simplifying interpretation**

To simplify interpretation, clear presentations were utilised. These use colour (as and where beneficial), clear markings and symbology.

- **Simplifying/removing the need to analyse**

To simplify or remove the need to analyse information, a computer is employed to process all the necessary inputs.

1.4. On-board pilot assistance systems: Introduction and History

Extreme requirements of ergonomics, the need for enhancement of situational awareness in complex environments and the hard workload of the pilots during the flight (systems monitoring, control and navigation) led to increased levels of integration in the cockpit.

Prior to the 70s, cockpits were not equipped with electronic instruments or displays and there were lots of different distributions depending on the type of aircraft. But since the twenty first century, the cockpit’s distribution started to be equivalent in most of all commercial aircraft.

The modern flight deck automation also flourished driven by the rapid development of the microprocessor.
The improvements in computer technology and the rapid growth of commercial air transportation are the responsibility of the new era of cockpits, which design is made only for two pilots, reducing the economical operation costs and eliminating the role of the flight engineer.

One of the determining results of the new cockpit is the Glass Cockpit, also known as the Electronic Flight Instrument System (EFIS), firstly introduced by Airbus and then spread to the other companies.

The Glass Cockpit is an aircraft cockpit that features electronic instrument displays, where cathode ray indicators replaced the traditional mechanics indicators. The Glass Cockpit is a result of the Fly-by-wire (FBW) implementation, where the movements of flight controls are converted to electronic signals transmitted by wires. [6]

![Figure 1.1: FBW][7]

Some of the most important improvements are the weight save, the reliability increase, and the new alert systems for the crew (multicolour displays, intermittent lights...).

Another important feature is the Dark cockpit.

The Dark cockpit is a cockpit designed to fly without lit-up switches and warnings so as to allow the pilots to have a maximum night vision for scanning the sky. If something goes wrong with a system, a light comes on and then the pilot is prepared to fix the problem.

Often, the cockpit remains dark as the aircraft recognizes a fault. The systems fix the problem, and only tell the pilots at the end of the flight when the fault list is checked for maintenance.
Concluding, the five points that define the actual cockpit are:

1. The Fly by wire technology
2. The Glass Cockpit
3. The Dark Cockpit
4. A Common Cockpit for all the aircraft
5. Few indicators
Finally, this means an increase in safety due to the workload pilot’s reduction. We can differentiate five important elements in a cockpit depending on the task they manage:

- Instruments
- Controls
- Warnings
- Emergency equipment
- General equipment

In this part we are going to focus in the instruments and controls that are already implanted in the aircraft of nowadays, specifically in:

- Navigation systems
- Communication systems
- Surveillance and Collision avoidance systems
- Management systems
- Others

1.5. Existing On-board Pilot Assistance Systems

A separation between Primary and Assistance on-board assistance systems will be done.

- A **Primary system** is a system needed for current operation.

- A **Pilot Assistance system or technology** (PAT) is a system that provides an additional benefit to the pilot.

We will consider an Instrumental Flight Rule (IFR)\(^1\) flight to make the classification, as well as commercial flight of an A320 or B737.

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\(^1\) IFR - a classification in Visual Flight Rules (VFR) would be meaningless because the pilot needs to operate the aircraft with the only help of visual observation
### Primary Systems [7]

<table>
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<th>SYSTEM</th>
<th>DESCRIPTION</th>
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| **Area Navigation (RNAV)**    | Navigation method that allows an aircraft to choose any course within a network of navigation beacons, rather than navigating directly to and from the beacons. It takes the information from:  <ul> • VHF omnidirectional radio range (VOR)  
• Distance measuring equipment (DME)  
• Non-Directional Beacon (NDB) </ul> As well as GPS in modern equipments. |
| **HF and VHF radio equipment** | Radio transmitters and receivers are needed to make possible the communication between pilot/Air Traffic Control (ATC).                           |
| **ILS/ MLS**                  | • The Instrumental Landing System (ILS) system provides the pilot with instrument indications which, when utilised in conjunction with the normal flight instruments, enables the aircraft to be manoeuvred along a precise, predetermined, final approach path.  
• Microwave Landing System (MLS) was originally intended to replace or supplement the ILS. It has more advantages, like multiple approximation paths. |
| **ACAS/TCAS**                 | Systems designed to reduce collisions between aircraft. They are based on secondary surveillance radar transponder signals, which operates independently of ground-based equipment. TCAS and its variants are only able to interact with aircraft that have a correctly operating mode C or mode S transponder. |
| **GPWS/EGPWS/TAWS**          | System that provides the pilot with warning of potential collision with terrain in sufficient time for effective avoiding action to be taken. It provides aural alerts or warnings and illumination. The TAWS is an airborne safety net designed to overcome the shortcomings of the original GPWS. |

Table 1.1: Primary existing on-board PAT[17]

### Equipment Requirement

In Europe, as of 1 January 2005 all civil fixed-wing turbine-engined aircraft with a maximum take-off mass over 5,700 kg, or capable of carrying more than 19 passengers, must be equipped with TCAS II. [17]

ICAO Annex 6 Part 2 (International General Aviation) SARPs require carriage of either TAWS Class A or TAWS Class B in all aircraft with a Maximum Take Off Mass greater than 5700kg or authorised to carry 10 or more passengers.
## Assistance Systems

<table>
<thead>
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<th>SYSTEM</th>
<th>DESCRIPTION</th>
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| Communication systems      | • Aircraft Communications, Addressing and Reporting System (ACARS): Digital data link system for the transmission of messages between aircraft and ground stations. There are three possible data link methods:  
  - VHF or VHF Data Link  
  - Satellite Communications  
  - HF or HF Data Link  
  • Automatic Dependent Surveillance-Broadcast (ADS-B): is a means by which aircraft, aerodrome vehicles and other objects can automatically transmit and/or receive data such as identification, position and additional data as appropriate in a broadcast mode via a data-link.  
  • Digital Automatic Terminal Information Service (D-ATIS): Continuous broadcast of recorded information in busier terminal areas. ATIS broadcasts contain essential information such which runways are active, available approaches, and any other information required by the pilots. Pilots can download and save D-ATIS messages at any time during the flight, opening up the critical approach phase for more important tasks.  
  • Controller Pilot Data Link Communications (CPDLC): it is a two-way data-link system by which controllers can transmit messages to the pilot without the use of voice communications.  
  • Selective Calling System (SELCAL): it is a signaling method which can alert an individual aircraft that a ground station wishes to communicate with it. SELCAL signals can be transmitted over either HF or VHF RTF. |
| Navigation systems         | Future Air Navigation System (FANS): direct data link communication between the pilot and the Air Traffic Controller. The communications include air traffic control clearances, pilot requests and position reporting. FANS plays a key role in supporting many of the evolving CNS/ATM strategies and mandates. |

Table 1.2: Assistance existing on-board PAT [17]
### SYSTEM | DESCRIPTION
--- | ---
Management systems | A management system is a computer that can store and process information typically contained in manuals, checklists, performance charts, flight plans, weather reports and documents of all sorts.

- **Electronic Flight Bag (EFB):** it is an electronic information management device, that can store and display a variety of aviation data or perform basic calculations for aircraft performance or fuel loading purposes, making the tasks more easily and efficiently with less.

- **Flight Management System (FMS):** on-board multi-purpose navigation, performance, and aircraft operations computer designed to provide virtual data and operational harmony between closed and open elements associated with a flight from pre-engine start to engine shut-down.

- **Flight Management and Guidance System (FMGS):** The FMGS provides predictions of flight time, mileage, speed, economy profiles and altitude. The interface to this system is the Multi-Function Control Display Unit (MCDU).

### Table 1.3: Assistance existing on-board PAT[17]

#### 1.5.1. Flight management systems

The flight management systems are nowadays the key to reduce the pilot’s workload (to the point that modern aircraft no longer carry flight engineers or navigators), therefore we will take a deeper look to them.

#### 1.5.1.1. FMS

The FMS is the Boeing version of the system (the first one introduced on the Boeing 767).

The four main components are:

- **Flight Management Computer (FMC):** computer system that uses a large data base to allow routes to be pre-programmed and fed into the system by means of a data loader. The system is constantly updated with aircraft position by reference to available navigation aids.

- **Automatic Flight Guidance System (AFGS):** receives sensor information from other aircraft systems. Dependent upon whether the aircraft is under A/P or manual control, mode selections made by the crew will either automatically move and control the aircraft flight control surfaces or display Flight Director commands for the pilot to follow to achieve the desired status.

- **Aircraft Navigation System:** integrated package which calculates continuously the aircraft position. It may include Inertial Reference System (IRS) and GPS inputs in addition to receivers for ground based aids.

- **EFIS (electromechanical instrumentation):** replaces conventional systems and flight deck displays. Is where the effect of FMS aircraft control is principally visible.

All FMS contain a navigation database (NDB). The NDB contains the elements from which the flight plan is constructed like: waypoints, airways, runways, Standard instrument departures, Standard terminal arrivals...
The flight plan is then entered into the FMS either by typing it in, selecting it from a saved library of common routes or via an ACARS datalink with the airline dispatch center.

During preflight, other information relevant to managing the flight plan is entered (gross weight, fuel weight, center of gravity, initial cruise altitudes...). After that, the FMS sends the flight plan information to the ND.

Once in flight, its principal task is to determine the aircraft’s position and the accuracy of that position. To measure it FMS are equipped with GPS, VORs, scanning DMEs or Inertial reference systems (IRS) like laser gyros. Some FMS use a Kalman filter to integrate the positions from the various sensors into a single position.

Fuel savings are possible in sophisticated aircraft with full performance in vertical navigation (VNAV), which purpose is to predict and optimize the vertical path, at the same time that guidance includes control of the pitch axis and control of the throttle. [17]

1.5.1.2. FMGS

The FMGS is the Airbus version of the system.

The FMGS is divided in four main parts:

- Two flight Management Guidance and envelope Computers (FMGC)
  Each FMGC is divided into four main parts:
  - Flight Management (FM): navigation, management flight planning, management of displays...
  - Flight Guidance (FG): A/P, Flight Director and Auto-thrust commands
  - Flight Envelope (FE): computation of data, monitoring of parameters ...
  - Fault Isolation and Detection System (FIDS): acquisition and concentration of maintenance data, interface with the Central Maintenance Computer...

- Three Multipurpose Control and Display Units (MCDU): The use of MCDU allows the flight crew to interface with the FMGC by selection of a flight plan for lateral and vertical trajectories and speed profiles.

- One Flight Control Unit (FCU): The FCU located on the glareshield, is the short-term interface between the crew and the FMGC. It is also used to select any flight parameter or modify those selected in the MCDU.

- One Flight Management source selection device: allows to switch the FMGC data to the offside MCDU and EFIS display in case of failure.

During cockpit preparation the pilot inserts a preplanned route from origin to destination via the MCDU. This route includes the departure, enroute waypoints, arrival, approach, missed approach and alternate route as selected from the navigation database.

Each FMGC has its own set of databases and the individual databases can be independently loaded into their respective FMGC, or independently copied from one FMGC to the other.

The FMGC generates an optimum vertical and lateral flight profile and predicted progress along the entire flight path. [17]
1.6. Research Pilot Assistance Systems

Today’s safest way of traveling is flying. Air traffic is expected to triple growth world-wide within the next 20 years. With the existing on-board systems, aircraft accidents would lead in the same, or a higher proportion. [9]

To keep flying safe, new powerful safety systems must be developed to provide optimal information to the cockpit crew. Also, the rapidly growing air traffic and the wish to keep a high level of safety, are the cause of a research and development of new pilot assistance systems.

The prediction of aircraft trajectories as a way of ensuring efficient and conflict free flights from gate to gate is also an important fact. Several projects are conducted to assess 4D trajectory concepts and capabilities from both air and ground perspectives.

It is not a priority to find some new modern or sophisticated navigation, communication or anti-collision systems. The most important is to develop a system designed to alleviate the problem of pilots spending too much time looking and monitoring inside the cockpit.

So the new systems must be developed to help alleviate the demands of pilots presented by an increasing amount of technology in modern aircraft cockpits.

That means, to monitor all the systems is a very stressful task; therefore, a system able to gather several systems would be the key to reduce the pilot's workload.

Some new research projects will be listed as follows.

1.6.1. SESAR-NextGen

SESAR/NextGen objective is to make aviation a more accessible mode of transport. Provided that there is a growing industry of low cost flight sport aircraft, the number of general aviation pilots will assuredly increase.

One of the consequences of making flight more easily available is that there will be an increase in less experienced pilots flying.

In one sense SESAR/NextGen systems are designed to improve commercial flight especially in busy traffic areas. But in the sense of increase availability, the SESAR/NextGen system also has to account for this new generation of pilots.

It is already common for light sport aircraft to come equipped with modern displays, but near-future additions of a SESAR/NextGen system will also have to accommodate growth in general aviation as well.

Both projects, include a shared situational awareness for more collaborative decision making and trajectory based operations for a safer and more efficient airspace utilization.

The Single European Sky Air Traffic Management (SESAR) Research programme is one of the most ambitious research and development projects ever launched by the European Community. The programme is the technological and operational dimension of the SES initiative to meet future capacity and air safety needs.
Supporting the entire ATM system, and essential to its efficient operation, is a netcentric System Wide Information Management (SWIM) environment that includes the aircraft as well as all ground facilities.

It will support collaborative decision making processes, using efficient end-user applications to exploit the power of shared information.

The main objectives of the SESAR project are:

- To manage and control an augmentation more of the triple of the current volume of air traffic.
- To reduce a 10% of the contamination per flight.
- To reduce a 50% of management air traffic costs.
- Multiply per 10 the air traffic safety.

NextGen is the American project, which moves away from ground-based surveillance and navigation to new and more dynamic satellite-based systems and procedures, and also introduces new technological innovations in areas such as weather forecast, digital communications and networking.

When fully implemented, NextGen will safely allow more aircraft to fly more closely together on more direct routes, reducing delays, and providing unprecedented benefits for the environment and the economy through reductions in carbon emissions, fuel consumption and noise. [6]

SESAR and NextGen differ in their implementation frameworks because of the very different European and US industry structures.

NextGen tends to be closely tied to the government in a hierarchical framework whereas SESAR appears to be a more collaborative approach including but not limited to, ATM ground activities.

ICAO’s role is to ensure that they are compatible with each other and the rest of the world. [7]

### 1.6.2. All Condition Operations And Innovative Cockpit Infrastructure

All Condition Operations And Innovative Cockpit Infrastructure (ALICIA) is a new project centered at developing new and scalable cockpit applications which can extend operations of aircraft in all degraded conditions. It is funded by European Commission under the Seventh Framework Programme.

ALICIA aims to enhance the safety and the efficiency of flights, developing a new and scalable cockpit application enabling aircraft to operate in:
• Degraded weather conditions: rain, snow, fog...
• Several challenging scenarios: alpine search and rescue operations, medical services on mountains and cities...
• Different phases of flight: taxing in crowded airports with low visibility, landing in bad weather conditions...

![Image: ALICIA overall concepts](image)

Figure 1.5: ALICIA overall concepts [3]

So, the main objective of ALICIA is the development of an All Condition Operations capability to reduce weather-related delays by 20% and a new cockpit architecture facilitating the introduction of new technologies and applications. [3]

1.6.3. **QinetiQ’s Direct Voice Input (DVI) and NAS Voice System (NVS)**

According to the Joint Aviation Authorities (JAA), the current switch bases are old with supportability problems.

A new technology that allows pilots to control aircraft systems by voice command is the key to the Future air traffic operations.

QinetiQ’s DVI and NVS systems incorporate speech recognition technology, with an independent speaker system, meaning that it does not need to be trained to recognise a specific pilot or user. It also permits the direct voice control of avionics equipment using standard aircrew helmet microphones and intercom.
It gives aircrew the ability to control aircraft systems using voice commands and access information without removing their hands from the flight controls or being distracted from what is happening outside the aircraft.

The main problem could happen in an emergency operation, when there are a few crew members that give conflicting commands to the voice recognition system. [5][14]

1.6.4. PHARE- The Programme for Harmonised ATM Research in Eurocontrol

The Phare Programme is an Eurocontrol research programme within Europe focused to the ATM of the future.

The main objective is to organise, coordinate and conduct the development of an integrated air traffic management system in all phases of flight.

The investigation of the integrated air/ground environment is made using advanced ATM tools (Data Link) and Human Machine Interfaces (HMI), which would provide an increased airspace capacity.

The Experimental Flight Management System includes:

- Prediction of 4D trajectories.
- Negotiating the "user preferred" trajectory with ATC via data link.
- Guidance of the aircraft to that trajectory in space and time.

The Human Machine Interface includes:

- 4D flight planning: from the aircraft current position to the last planned position.
- 4D flight negotiation.
- 4D flight progress monitoring and alerting.
- EFMS system.

The Airborne Human Machine Interface (AHMI) components will include a Liquid crystal display (LCD) flat-panel with touchscreen overlay for the Experimental Flight Management System (EFMS) control, an EFIS and ND using a cursor control device (rollerball or touchpad) to carry out route editing. [13]

1.6.5. FLYSAFE-Airborne Integrated Systems For Safety Improvement, Flight Hazard Protection And All Weather Operations

Airborne Integrated Systems For Safety Improvement, Flight Hazard Protection And All Weather Operations (FLYSAFE) is a project aimed to design, develop, implement, test and validate a Next Generation Integrated Surveillance System (NG ISS).

FLYSAFE is project funded by the European Commission as part of the 6th Framework Programme. [17]

Its main goal is to define innovative and affordable new means that will contribute to guarantee the highest level of air traffic safety by 2020.
The project is structured upon the three “threats” which play a major role in accidents:

- Collision with terrain and obstacles
- Collision with other aircraft
- Adverse atmospheric conditions

1.6.6. SMARC - Multi-Agent System For Conflict Resolution

This project, explores the introduction of automatic tools for conflict resolution in a Free Flight environment.

Free Flight, by delegating more freedom to pilots and advocating a less centralised control over aircraft, opens a wide range of possibilities to make air traffic management safer, more scalable and more efficient.

However, such improvements cannot be achieved without the introduction of sophisticated automatic tools to support the activity of pilots and controllers.

Conflict resolution for a Free Flight environment stands out as an ideal domain of application for this approach, which has reached technological maturity and has already proven effective in dealing with several real-world problems.

In particular, an algorithm based on Multi-agent systems and game theory is applied, which allows pilots to condition their own preferences over the preference of others, therefore enabling a truly collaborative approach to conflict resolution. [18]
1.7. Limitations of the Pilot Assistance Systems

The limitations of a PAT depend on every different aircraft. Each aircraft shall be provided with a flight manual and other documents stating the limitations of the vehicle.

The limitations can be produced by different causes:

- Regulation requirements/limitations
- Incompatibility with other systems
- Technology limitations: Hardware/software

1.7.1. Regulation requirements/limitations

The different aviation authorities are the ones who codify the principles and techniques of international air navigation.

Depending on the type of aircraft and the type of flight (number of passengers, cargo, military...) the limitations are different.

The main authorities in Europe are:

**ICAO, Annex 6**: International Standards and Recommended Practices for aeroplanes used in international commercial air transport operations carrying passengers or freight.

The Annex addresses flight operations: aeroplane instruments, equipment and flight documents, aeroplane communication and navigation equipment...

**JAA, JAR**: Comprehensive and detailed aviation requirements that are present in the JAA countries.

- **JAR-OPS**: Joint Aviation Requirement for the operation of commercial air transport
- **JAR-25**: Joint Aviation Requirements for Large Aeroplanes
- **JAR-TSO**: Flight instruments certification

**EASA**: Agency of the European Union which is taking functions of the JAA
1.7.2. Incompatibility with other systems

One of the problems of having too many systems in the cockpit is the incompatibility between them. Some examples of incompatibility are:

1.7.2.1. TCAS

The TCAS does not take into account terrain and ground clearance or obstacle awareness. This means that a system capable to manage with the TCAS and TAWS tasks will be the better solution.

1.7.2.2. Communications

Modern aircraft employ complex electronic systems for navigation, control and internal communications, all of which must be kept immune from high-intensity radiated fields as to prevent the occurrence of critical flight incidents due to electromagnetic interference.

The most common problem is the loss of communication.

Loss of communication incidents usually occurs in one of three circumstances:

- **Radio Interference**: Situations in which transmissions other than those from authorised users of an RTF frequency interfere with radio reception.
- **Changing the frequency**: many possibilities of communication failure if the pilot selects the wrong frequency accidentally.
- **Malfunction of communications equipment**

1.7.3. Technology limitations: Hardware/software

Some problems come from the lack of invented hardware or the lack of programs capable to give the demanded activities.

1.7.3.1. Example of Hardware Limitations

- An A/P consists of servos that actuate the flight controls. The **number of these servos** depends on the complexity of the system.
  
  More advanced systems may include a vertical speed and/or indicated airspeed hold mode, but not all of them.

- TCAS is not fitted to many smaller aircraft due to the absence of any legal requirement to do so and the **high costs** involved in installing the system.

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2 Radio interference - disturbance that often comes from commercial stations on the ground
1.7.3.2. Example of Software Limitations

- TCAS uses extrapolations to predict future flight paths based on flight path history rather than utilising actual aircraft routing (flight plan information) and relevant ATC instructions.
- TCAS Current implementations do not support horizontal separation advisories.
- TCAS is primarily range based however in some situations a time based representation may be of more assistance.
- GPS: Data Programming. GPS relies on correct data input, with effective cross checking against a map position to verify accuracy.
- Use of the GO TO Function in GPS. Following a deviation from track, care must be taken in using the go to function to ensure that the new track does not infringe controlled airspace.
- Excessive reliance on GPS. Large navigational errors can arise where GPS is used as the sole navigation aid.
  
  GPS navigation should be augmented by reference to map-reading and/or radio navigation aids. [17]
CHAPTER 2. DECISION MAKING PROCESS

The following sections will discuss the decision making process of the pilot assistance system and its requirements.

The introduction to the topic will be followed by the description of the two main ways of decision making process; the "perceive-process-perform" model and the "DECIDE" model.

After that, the "aviate, navigate and communicate" concept will be presented as well as a decision making process scenario and its several options to solve the incoming warnings.

2.1. Introduction to the decision making process

In aviation, the transition of cockpit display technology is continuing. In the past, the cockpit was a marvel of large, crowded instrument panels filled with an array of interrelated gauges.

The implementation of current display technology has reduced the expanse of critical flight information into a minimal number of electronic displays, more closely to a computer monitor than a mechanical gyroscope.

The technological advances since the early days of flight have significantly transformed the aircraft cockpit, and have altered the relationships among the human pilot, the aircraft, and the environment.

Consistent with technological advances in aviation, the role of the pilot has evolved from one characterised by sensory, perceptual, memory, and motor skills to one characterised primarily by cognitive skills.

In contrast to earlier aviators, glass cockpit pilot can relatively spend little of their time looking out the window or manipulating flight controls, and most to all of it focused on integrating, updating, and utilising technology generated information inside the cockpit.

Then, the development and introduction of modern automation technology has led to new cognitive demands, resulting a new knowledge requirements, new communication tasks, new management tasks and new attentional demands.

Despite of all these improvements, the information load on pilots has not decreased. As a result, the source of the overload that the pilots are experiencing is changing; high visual workload has changed to high cognitive workload. 3

The decision making process is the process where a person has to choose between two or more alternatives. There are different phases in the decision making process.

First, the problem and the reason of that should be identified and analysed in order to find a solution for that problem.

In the next phase a search for all alternative solutions should be conducted, because there can be many different solutions for the same problem.

---

3 High cognitive workload - the load related to the executive control of working memory
Then, identify the decision criteria and weigh the solutions in order to take the final decision selecting the best solution depending on that criteria.

To evaluate each solution a study in detail of advantages and disadvantages should be done, giving them a certain weight to choose the best solution in the end.

The last stage is the evaluation of the solution, which helps to find out if the solution will be working positively or not.

If this evaluation results negative means that the decision is wrong and the decision making process will start again without considering the previous results. [6]

### 2.2. Aeronautical Decision Making Process

Aeronautical decision making (ADM) is a systematic approach to the mental process used by airplane pilots to consistently determine the best course of action in response to a given set of circumstances.

ADM builds upon the foundation of conventional decision making process, but enhances the process to decrease the probability of pilot error.

Pilot error, is the most common cause of error, over 70% of the accidents are involved to pilot factors [1].

![Figure 2.1: Broad accident factors [1]](image)

The most common pilot factors are related to poor judgement and decision making (cp. section 2.1 and 2.2)
ADM provides a structured, systematic approach to analysing changes that occur during a flight and how these changes might affect a flight’s safe outcome. The ADM process addresses all aspects of decision making in the cockpit and identifies the steps involved in good decision making. There are two models for practicing ADM.

### 2.2.1. Perceive-Process-Perform (3P)

The (3P) offers a practical and simple system that can be used during all phases of flight:

- Perceive the give set of circumstances of flight.
- Evaluate the impact on flight safety
- Implement the best course of action
2.2.2. The DECIDE model

The DECIDE model is a six-step process that prove a logical way of approaching decision-making.

- Detect: identify that a change has occurred.
- Estimate: estimate the need to counter or react to the change.
- Choose: choose a desirable outcome for the flight.
- Identify: identify actions that can successfully control the change.
- Do: take the necessary action.
- Evaluate: evaluate the effectiveness of the action.

Figure 2.4: ADM DECIDE[6]
2.3. "Aviate, Navigate and Communicate" concept

One of the first concepts the pilots use to learn, is the useful and easy concept of "aviate, navigate and communicate".

These priorities are equally applicable for all aircraft, from small, single-engine training aircraft, right up to large transport jets, but it is more applicable than ever for the pilots of today’s automated aircraft.

Priorities

- **Aviation**: If the aviation is not possible, there won’t be enough time to navigate or communicate. The first need is to aviate with precise control of the airplane. Some of the first configurations the pilot must check are:
  - Attitude: pitch, bank...
  - Power and drag configuration
  - A/P

- **Navigation**: When the aircraft is ready to aviate, the next task is to head the aircraft to the desired direction.

  Depending on the type of aircraft, navigation can be an involved task of piecing together several pieces of information (DME, VOR etc.) into a meaningful mental picture.

  In a glass cockpit aircraft, it is a task of following some display information and make sure that the display is showing the right direction and that the aircraft is following the displayed information.

- **Communication**: Once aviation and navigation is achieved, the next task is communication (for example to ask for airport or weather information).
2.4. Decision Making Scenario

A decision making scenario will be provided in this part as an example of how a decision making process works.

First of all, the conditions of flight will be provided (where the situation happens, constrains, boundary conditions...) as well as the warnings that the aircraft will experiment and the possible warning solutions.

Finally, in chapter 3 a possible solution (options, preference, consequences...) in a non-real monitor/display interface will be showed.

2.4.1. Conditions of flight: SCENARIO

The conditions of the scenario are defined as follows:

2.4.1.1. Phase of flight

**APPROACH:** the chosen phase of flight is the approach. The approach is one of the most critical moments during flight. The margin of safety is minimal during this phase of flight (cp. figure 2.6), so at this point, an emergency or distraction could overtax pilot capabilities causing an accident.
2.4.1.2. Boundary conditions

Depending on the boundary conditions the situation can be better or worse. The external conditions of the scenario are:

- **Weather**: The weather conditions to the destiny airport are not good. Snow and de-icing process for the departing aircraft.
- **Airport terrain**: The airport is situated near a mountain.
- **Traffic**: The traffic is elevated, lots of aircraft are waiting to take off.

2.4.1.3. Constrains

There are not defined constrains in the scenario. We are going to suppose that the chosen aircraft is a regular commercial aircraft so the airplane is equipped with:

- **A/P**: in modern complex aircraft are three-axis and generally divide a flight into taxi, takeoff, ascent, level, descent, approach and landing phases. A/P exist that automate all of these flight phases except the taxiing, therefore the approach phase can be perfectly automated.
- **IFR**: the weather conditions are bad so IFR permit an aircraft to operate in instrument meteorological conditions, which have much lower weather minimums than VFR.

2.4.2. Warnings

Once the aircraft starts the approach phase, several warnings come up.

We suppose that the first and second warnings show up separately, but the third, forth and fifth appear almost simultaneously. This fact will obligate the management system an the proposed display to take a decision of which warning must be fixed first.

Some extra information about the warnings in this particular case are:

- The "**Too low, flaps**" warning (cp. figure 2.7) is considered as a pilot's oversight.
- The **communication loss** is transitory.
- There are two possibilities to fix the problems:
  
  - The aircraft solves the warnings and lands.
  - The aircraft aborts the landing and makes a new approach.

The table 2.1 shows the warnings in order of appearance as well as a description of each one.
<table>
<thead>
<tr>
<th>WARNING</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCAS: Traffic Advisory Voice Alert: &quot;Traffic; Traffic&quot;</td>
<td>Intruder near both horizontally and vertically: Attempt visual contact, and be prepared to maneuver if an Resolution advisory (RA) occurs. The aircrew shall not maneuver their aircraft in response to traffic advisories (TA), only should prepare for appropriate action if an RA occurs; but as far as practicable, pilots should not request traffic information.</td>
</tr>
<tr>
<td>GPWS Alert: Too low, terrain</td>
<td>If the landing gear and flaps are retracted and GPWS defects that the aircraft is close to the ground it generates a &quot;Too low, terrain&quot; aural warning and the GPWS red lights illuminates. If speed is greater than 190kt up to 400kt then from 1000ft RA to 30ft RA it gives &quot;Too low terrain&quot;.</td>
</tr>
<tr>
<td>Loss of Communication</td>
<td>Loss of communication may be transitory or prolonged. It most often occurs because of inadvertent mismanagement of aircraft equipment by flight crew.</td>
</tr>
<tr>
<td>TCAS: Resolution advisory Voice Alert: &quot;Descend; Descend&quot;</td>
<td>Descend at the vertical speed indicated by the green area on PFD.</td>
</tr>
<tr>
<td>GPWS Alert: Too low, flaps</td>
<td>If the landing gear is down, but the flaps are not in landing configuration, the warning is &quot;Too low flaps&quot;. The problem can be produced by a mechanical failure or just an oversight.</td>
</tr>
<tr>
<td>TCAS: Clear of conflict</td>
<td>Range is increasing and separation is adequate.</td>
</tr>
</tbody>
</table>

Table 2.1: Warnings

2.4.3. Possible warning solutions

First of all, the solutions of the warnings are shown (cp. table 2.2). The next step is to decide the order of applying the possible solution, as well as its consequences.

![Figure 2.7: Unsafe Terrain Clearance With The Flaps Not In Landing Position [2]](image-url)
## Decision Making Process

### WARNING

<table>
<thead>
<tr>
<th>WARNING</th>
<th>ACTION</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TCAS: Traffic Advisory Voice Alert:</strong> &quot;Traffic; Traffic&quot;</td>
<td><strong>VISUAL CONTACT:</strong> Intruder near both horizontally and vertically. The pilot must attempt visual contact, and be ready to maneuver if an RA occurs.</td>
</tr>
<tr>
<td><strong>GPWS Alert: Too low, terrain</strong></td>
<td>The pilot has to <strong>ASCEND</strong> in order to avoid the terrain and a worse alert, like &quot;pull up&quot;.</td>
</tr>
</tbody>
</table>
| **Loss of Communication** | Some actions the Pilot must do are:  
- Do not switch immediately to the next sector frequency following read back of controller’s instruction.  
- Check radio equipment settings and audio panel settings and carry out a radio check.  
- If a message is unclear, request confirmation or clarification.  
- If the squelch control is adjusted to reduce the effect of interference, take care to ensure that transmissions from ATC or other aircraft are not cut out.  
- Make use of other aircraft to relay messages when operating at extreme range or when poor propagation is suspected.  
- If there is no suitable frequency on which to initially re-establish communications, then 121.5 MHz can be used. |
| **TCAS: Resolution advisory Voice Alert:** "Descend; Descend" | **Start DESCENDING at 1500 - 2000 ft/min** or descend at the vertical speed indicated by the green area on PFD. |
| **GPWS Alert: Too low, flaps** | If the landing gear is down, but the flaps are not in landing configuration, the warning is "Too low flaps". The pilot must **EXTEND FLAPS to maximum position**. In figure 2.7 is it possible to see when this alarm appears. |
| **TCAS: Clear of conflict** | **TCAS warning is solved:** Range is increasing and separation is adequate. |

Table 2.2: Warnings Solution
2.4.4. Resolution scenarios

Decision making in aircraft crews becomes most pertinent when abnormal situations occur, such as system malfunctions, or bad weather conditions. In these circumstances, workload is high: Crews have to determine the nature of their problem, and what course of action they should take.

There are several ways to resolve the warnings. Three different scenarios are presented in the next sections for the proposed warning scenario.

The consequences and advantages of using every different option are described as well.

2.4.4.1. SCENARIO 1: Order of appearance

The warnings are resolved in the order of when they appeared in the display. First warning to appear is the first one to be fixed.

1. TCAS "Traffic, Traffic": the Pilot establishes Visual contact and sees an aircraft ascending.
2. GPWS "Too low, terrain": the pilot checks if everything is how it is supposed to be, and realises that the aircraft it is pretty close to a mountain, therefore the pilot goes up and changes the direction of flight in order to avoid the obstacle.
3. Loss of communication: the loss of communication is in that case transitory and it is because of some interferences. The pilot starts to check what could be the problem.
4. The TCAS alerts again, this time with a "descend, descend". The reason is that another aircraft is taking off and both aircraft are going to the same direction.
5. GPWS "Too low, flaps": The GPWS alerts that the flaps are not extended. The pilot checks if it is a mechanical problem or just an oversight.

Consequences

- The danger priority is not taken into account.
- To fix a problem could take a long a time, so other hazardous problems can come up and make the situation worse.
  
  For example, to try to figure out from where the communication loss comes, can take a long time, and it is not the biggest problem to solve, so it can make de situation worse.

Advantages

- It is the easiest way for the pilot to fix the warnings.
2.4.4.2. **SCENARIO 2: Go-around: aborted landing**

Initiation of a go-around procedure may be either ordered by the ATC (normally the local or 'tower' controller in a controlled field) or decided by the pilot in command of the aircraft.

In this scenario, the solution is to abort landing and start approach again, so the warnings are solved until the pilot decides it is too dangerous to keep going and decides to abort landing.

1. TCAS "Traffic, Traffic": the Pilot establishes Visual contact and sees an aircraft ascending.
2. GPWS "Too low, terrain": the pilot checks if everything is how it is supposed to be, and realises that the aircraft it is pretty close to a mountain, therefore the pilot goes up and changes the direction of flight in order to avoid the obstacle.
3. Loss of communication: the loss of communication is in that case transitory and it is because of some interferences. The pilot starts to check what could be the problem.

Once the pilot received the GPWS warning, as well as a communication loss, decides to abort the landing.

To avoid hitting the ground the pilot must initiate the following sequence of actions:

- Disconnect the A/P and Auto-throttle if engaged.
- Advance the Thrust or Power levers to the Take Off position.
- Rotate the aircraft to a pitch up angle (around 20 degrees pitch up for most aircraft) which reaches the margin of stick shaker activation.
- If the Landing Gear is selected down, do not raise it immediately.
- If speed brakes are deployed, retract them.
- If trailing edge flaps are deployed, do not retract them immediately.

**Consequences**

- The danger priority is not taken into account.
- The go-around procedure can cause more overload to the ATC.
- Possibility of impact with other aircraft.

**Advantages**

- It is a way to prevent the appearance of other warnings and a way to have more time to resolve the existing warnings.
2.4.4.3. **SCENARIO 3: Aviate, Navigate and Communicate**

As it is described before (cp. section 2.3.) the order of solving the warnings follows the rule of "Aviate, Navigate, Communicate". This is a good way to solve the warnings because pilot's task is to make sure the possibility to aviate is higher than the possibility to navigate or communicate.

The warnings are solved first in order of appearance until three of them appear simultaneously and a hierarchy must be defined.

- **TCAS "Traffic, Traffic":** the Pilot establishes Visual contact and sees an aircraft ascending.
- **GPWS "Too low, terrain":** the pilot checks if everything is how it is supposed to be, and realises that the aircraft it is pretty close to a mountain, therefore the pilot goes up and changes the direction of flight in order to avoid the obstacle.
- **GPWS "Too low, flaps":** The GPWS alerts that the flaps are not extended. The pilot checks if it is a mechanical problem or just an oversight.
- **The TCAS alerts again, this time with a "descend, descent":** The reason is that another aircraft is taking off and both aircraft are going in the same direction.
- **Loss of communication:** the loss of communication is in that case transitory and it is because of some interferences. The pilot starts to check what could be the problem.

The GPWS warning is solved first, instead of the TCAS alert. The reason is that is easier to deal with other aircraft rather than with the terrain (the other aircraft have probably a TCAS systems on-board as well, so a new command will be sent if the first one is not accomplished.

If the other aircraft is not equipped with the TCAS, we can rely on the idea that the other aircraft does not want to crash so will take the necessary measures to avoid it.

**Consequences**

- Reliance on ATC instructions to other aircraft, or reliance on the maneuver of the other aircraft because the GPWS warnings are first solved rather than the TCAS ones.
- Possibility of impact with other aircraft.

**Advantages**

- While the important warnings are being solved, others like communication warnings could be also solved, then the ATC can give instructions to the pilot.
CHAPTER 3. DISPLAY DEMONSTRATION

Basing on the previous chapter, this chapter will develop an example of a possible solution to the warning scenario described in the section 2.4.2. The chosen scenario is the number 3 (cp. section 2.4.4.3.).

The chosen display consists in a multitouch LED Display, where the pilot interacts directly with the display.

3.1. Main menu

In figure 3.1 the main menu is showed. Two big parts are visible:

- **Main menu buttons**: where all the systems can be monitored and checked by clicking. Once the pilot clicks the button, the drop down menu with all the systems appears. There are 3 big groups, depending on the task of the system.
  - **Aviation**: the most critical systems or measures for flying are displayed here: engine data, flight controls...
  - **Navigation**: where the systems or data related to the navigation are displayed: GPS, TCAS...
  - **Communication**: where the communication systems are displayed: ACARS, CPDLC...

- **Scroll bar menu**: the scroll bar menu is placed in the right part of the screen. All the warnings that have come up are recorded in it. It is a good way to have control of what has been happening in the aircraft.

![Figure 3.1: Display Main Menu](image)

In figure 3.2, an example of the drop-down menu is showed.
3.2. Warnings

Once a warning shows up, an image related to the warning appears followed by the corresponding aural message.

In figure 3.3 a communication warning is displayed.

After that, an icon with the warning name will be displayed waiting to be solved (cp. figure 3.4).
The pilot must click on the warning to see the recommended options to fix the warning. Once the warning is solved, the warning message disappears.

In case of multiple warnings the display will show them in order of priority (cp. figure 3.5).

While a warning is displayed, the main menu and the drop-down menu are blocked. That forces the pilot to fix the warning first. If after trying, the warning can not be fixed, the pilot can skip the warning and try to fix the next one.
3.3. Warning Solutions

The warning solution will be showed as well as the warnings in order of priority to solve the most dangerous warnings first.

![Figure 3.6: Warning solution message](image)

Once the warning is solved, a notification to the scroll bar menu is sent in order to follow all the warnings during the flight.
CHAPTER 4. SUMMARY AND OUTLOOK

Beginning with an introduction to the pilot assistance technologies, a list of the current systems and its limitations are provided.

The pilot assistance technologies are a way to reduce the pilot's workload but more important, is the fact of facing the new demands of flying, which are every day more strict so are the biggest limitation right now.

The prediction of the future air navigation demands more accuracy and safety in order to satisfy the increasing necessities of flights, so new systems able to satisfy these requirements are needed, therefore a list of the new research systems is provided.

New regulations are every day implanted to fly too, so aircrafts without the appropriate systems will not be allowed to fly, basically because they will endanger other aircraft.

One other advantage of using the PAT is a decrease in accidents.

Most of the aviation accidents are caused due to human factors (cp. section 2.2.), therefore the PAT have incorporated a well studied decision making process in order to facilitate the pilot's task in hazardous situations.

For that reasons, new systems able to manage the most systems as possible in a single interface, are very important.

In order to develop these systems, the aeronautical decision making process of the systems must be investigated to try to find the best order of hierarchy to solve the incoming problems.

One important fact is to trust in the management systems, which biggest advantage is that they include less scanning time, more visual symbology and tend to use the minimum displays as possible.

A good example for the future, is a widescreen interactive multi-touch display (cp. chapter 3), where its functionality is extended by cooperative elements, which connect ground traffic planning to on-board flight planning systems (via new communication systems like CPDLC).

The biggest problem of these systems is the difficulty to fit them in a single system due to the different data they work with, and also an extra logical programming is needed to describe the hierarchy of the most critical systems.

But finally, a significant improvement in the efficiency and capacity of Air Traffic Management can be achieved integrating airborne (Flight Management Systems) and ground-based systems.


[10] Kehoe, Aidan; Neff, Flaithri; Russel, Gavin. Improvements to a Speech-Enabled User Assistance System Based on Pilot Study Result (University College Cork Ireland). pdf


