AIR TRAFFIC CONTROL AND THE CHALLENGES GENERATED FOR THE FUTURE COMPUTATIONAL SYSTEMS

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Abstract

This paper presents some research works on air traffic control conducted by the Safety Analysis Group (GAS) of the Polytechnic School of the University of São Paulo (USP), Brazil, related to the CNS/ATM (Communication, Navigation, Surveillance/Air Traffic Management) context. These research works aim to highlight the new challenges that will be adopted by computational systems that will automate the air traffic control process, or support collaborative decisions. These new challenges make sense due to the growing demand on air traffic and aim to maintain the safety levels compatible to those used nowadays, or even to increase them. The new air traffic control systems will depend more and more on computational systems, for control, decision support and risk assessment. These researches have as new focus to certify that the risk levels are equal to or even smaller than the current ones, in an environment of increasing demand. Interdisciplinary concerns will have a very important role in this context, because computer and aeronautic engineering must work together, seeking to attain this new automation paradigms and a harmonious control of future needs, having in mind the human agents involved in this process: pilot and air traffic controller.

Keywords: Safety Analysis, Certification, Air Traffic Control, Risk Assessment, Automation

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1. INTRODUCTION

This paper aims to provide an overview of the researches being conducted by the Safety Analysis Group (GAS), associated to the Department of Computer and Digital Systems Engineering (PCS) of the Polytechnic School of the University of Sao Paulo (Poli-USP). The presented overview allows for further consideration with respect to the trends in the air traffic control and its impacts, which can be seen as challenges to be faced in the development of future computer systems that will support critical decisions.

The new air traffic control systems will depend more heavily on computer systems, both for control and decision support, and for the evaluation of the new risks involved. The main focus will be the proof that the new systems present risk levels equal or smaller than the existing systems, considering them in an environment of increasing demand. The interdisciplinary concerns will represent a key role as aeronautical engineers and computer engineers should have a broad debate in order to achieve a paradigm of automation and control harmonious with the future needs. They have to list the human actors involved in the process: the pilot and the air traffic controller.

2. THE CNS/ATM CONTEXT

The International Civil Aviation Organization (ICAO), by means of a special committee, called the Future Air Navigation Systems (FANS), from the early 1980s, identified serious limitations in the traditional systems of air navigation. The same committee also had to study, identify, analyze and evaluate new concepts and technologies, in order to increase the safety and efficiency levels in air operations worldwide, and to introduce the required improvements to support civil aviation of the XXI century. The work of the committee led to the design of a new system, free of most of the intrinsic limitations existing so far.

The design recommended by ICAO, known as CNS/ATM System, enables to adequately combine communication and navigation technologies based on satellites with optical elements installed on land. By means of the integration with the air traffic systems management, and considering the increasing use of automation, it is expected to achieve the required results. The key features of the new systems and their application principles, specific goals, and restrictions are already relatively well known. However, the development and implementation of new features and concepts that provide the basis for the implementation actions are the responsibility of the countries in a scope of regional planning and overall coordination.

The ATM system provides the Air Traffic Management by means of cooperative integration of human resources, information, technology, facilities and services, for all the ATM community. One of the major goals is the establishment of a single global and inter-functional ATM system during all flight phases, for the whole ATM Community that: meets the standards of operational safety established, provides optimized operations, is sustainable in relation to the environment and satisfies the national security requirements (Pequeno, 2007).

Considering this context, it is important to highlight the major functions of ATM:

- Air Traffic Organization and Management;
- Airports Operation;
- Demand and Capacity Balance;
- Traffic Synchronization;
- User Traffic Operations;
- Conflicts Management, and
- Management of ATM Service Deliveries.

The researches performed by the Safety Analysis Group are within this approach and are briefly described in the next item.

3. RESEARCHES PERFORMED BY THE SAFETY ANALYSIS GROUP

The purpose of this section is to describe the researches in the ATM area, conducted by master and doctoral students of the Safety Analysis Group, including both the work already completed, and those still in progress. The works are described in correlation with the ATM major functions, seeking to support collaborative decisions.

Depending on the action line of the Safety Analysis Group, much of the research fall under Air Traffic Organization and Management, Demand and Capacity Balance, Traffic Synchronization and Conflict Managing/Management. Other researches have been conducted, considering the Unmanned Aerial Vehicles (UAVs).

3.1. RESEARCHES IN AIR TRAFFIC MANAGEMENT AND ORGANIZATION

a) Availability Evaluation of Critical Computational Systems for Airspace Control using Analytical Models of Queuing Theory (Pizzo and Cugnasca, 2006).

The use of the airspace is growing, considering civil aviation (expansions in aerial movements, airports and number of passengers and volume of cargo) and military aviation, increasing the diversity of the activities to be accomplished in the airspace control activities. There is an increasing technical complexity, considering the introduction of new features into the existing automation systems or even the introduction of additional resources to automate some functions previously performed by human operators, using manual procedures. This situation has increased the dependence upon the overall availability of the computer systems involved in the services provided by aeronautical authorities. Project directives and operational procedures are established in order to maintain the safety integrity levels of the systems, in case of any failure events. However, the availability becomes a critical parameter, since the occurrence of failure events can force an undesirable state of degraded operation, jeopardizing the nominal capacity of the services being performed through any controlled air space.

Therefore, this work presents availability models for the computer systems used in airspace control centers, based on modeling analysis provided by the queuing theory. A general model is first presented, referencing a case study that describes the use of queuing models to access availability of a generic data center operation. Further considerations are introduced to extend this general model in order to propose its application for the specific computer systems used in airspace control centers, where the operational control relies on the human controller's activities. In this case, the process control requires intensive use of human-machine interfaces (HMI), both for the regular activities performed by controllers and for the additional activities, occasionally imposed to their workload, when some automation function becomes momentarily unavailable.

3.2. Researches on Demand and Capacity Balance

a) Demand Optimization Model in Aeronautic Infrastructure (Naufal, 2005).

This work of doctoral research, already finished, presents a proposal for an optimization model for a problem of high complexity and hard safety requirements found in the Brazilian and world aeronautic infrastructure. This problem is related to the imbalance between capacity and demand in aeronautical infrastructure systems in air transport. Thus, the work proposes a Demand Optimization Model in aeronautic infrastructure, through the artificial intelligence technique called Genetic Algorithms. The research analyzes the efficiency of the proposed model in terms of the resolution of the problem as well as on the quality of the responses obtained. Additionally, the importance of each optimization model parameter is evaluated through its flexibility.

b) Impact Analysis of the Dynamic Resectorization in the Workload of the Air Traffic Controller by means of Computational Simulations (Teixeira *et al*, 2007)

The growing demand for air transportation has caused an increase in the density of aircraft flow in the airspace. The overload of aircraft in airspace sectors, which are under the air traffic controllers' responsibility, causes a permanent alert state in the air traffic management. A single controller's fault with monitoring and controlling a sector may endanger hundreds of people's lives. The air traffic controller has to perform many activities in order to ensure safety to the air space, being exposed to a certain workload. The Dynamic Resectorization can aim to balance the workload of the air traffic controllers. The goal of this research work is to investigate the behavior of the air traffic controller workload through the use of Dynamic Resectorization, having as a case study a Brazilian air space with high aircraft density.

3.3. Researches in Traffic Synchronization

a) Risk Analysis of Airborne Temporal Spacing by means of Stochastically and Dynamically Colored Petri Net (Oliveira, 2007)

Airspace safety can be considerably increased with the use of airborne spacing and separation operations. Under this paradigm, the task of maintaining a safe distance between aircraft is delegated to the pilots, which will be supported by the Airborne Separation Assistance System (ASAS). With this system, which is still in experimental phase, pilots become aware of the surrounding air traffic risks with up to 15 minutes in advance, without the help of air traffic controllers on the ground. This antecedence is much greater than the one provided by the current Traffic Collision Avoidance System (TCAS). ASAS uses a more advanced communication technology than Mode-C transponder, broadly used in the current civil aviation for collision avoidance purposes. The development of ASAS is being carried out intensively in Eurocontrol and in other initiatives in the United States of America, and this novel system is intended to work in parallel with the current collision avoidance systems, acting as safety nets. The present study approaches the ASAS application to improve the precision of spacing between aircraft that sequentially arrive at an airport, using the so called mathematical formalism "Stochastically and Dynamically Colored Petri Net", for evaluating quantitative data about accident risks. These data indicate that the accident risk is significantly smaller when aircraft pairs use ASAS Spacing than when aircraft pairs do not use ASAS Spacing.

3.4. Researches on Conflict Management

a) Hazard Evaluation of Collision between Aircrafts in Approaches Operation in Parallel Runways (Ogata, 2004).

In this master's research, already finished, the modeling of a decision-making aid tool is proposed based on the assessment of the hazard level of collision between two aircraft in operation UCSPA - Ultra Closely Spaced Parallel Approaches, supported by the CNS/ATM scenario. This tool shows promising results in terms of the analysis of distance minimization between parallel runways, according to the minimum hazard level regulated by the authorities. This tool is based on a dynamic model of two aircraft in UCSPA approach operation scenarios under adverse weather conditions. The prediction of the position of a possible aircraft "intruder" is shaped by uncertainty translated in terms of probability distributions, the distributions of which represent the uncertainties in the bow, lateral position, longitudinal position and speed. The tool used in the computational simulation and in obtaining the numerical data is based on the Monte Carlo method.

b) Safety Verification in Aircrafts Trajectory Confluence using Hybri Automata (Oliveira, 2003)

This research work presents the application of the Hybrid Automata mathematical language for verifying safety conditions in air traffic control systems. Among these systems, a specific case was chosen, which consists of a hypothetical system for conflict detection of aircraft trajectories in confluence, to be studied in more detail. To attain this aim, first the formal mathematical content is presented; next, the application context, that is constituted by the Air Traffic Service, observing its evolution in face of the CNS/ATM Project (Communication, Navigation, Surveillance/Air Traffic Management) is explained and, prior to approaching the specific case study, an overview of using Hybrid Automata in Air Traffic Control Systems is presented.

c) Aircraft Position Prevision Model for use in Airspace Surveillance Systems (Navarrete, 2006).

This research presents a contribution to the evaluation of the predicting aircraft future positions problem considering the Brazilian airspace. These predictions are very important for airspace surveillance systems, mainly for detecting conflict among aircraft. The problem is studied for en route flights, considering position predictions from 1 to 20 minutes. First, the problem is proposed, so that its application context to air traffic management automation can be cleared. Then, the necessary mathematical methods used to study en route aircraft future position prediction are shown. The proposed model employed to find the predictions makes use of linear regression of known aircraft positions, extrapolating its future positions. En route flight conditions permit this approach. Prediction results are then compared with real aircraft positions, so that position estimates quality can be evaluated. Finally, ways of practical application of the proposed model inside computational systems used for aircraft future position prediction are presented. This allows surveillance airspace systems to make use of the predictions.

d) Impact Assessment of the Use of New Surveillance Technologies on Air Traffic Control Safety (Vismari and Camargo, 2005).

The main purpose of this Master's research, already finished, is to propose and implement a new method, based on hybrid modeling techniques and accelerated simulation, assessing the impact of the use of new technologies, especially the Automatic Dependent Surveillance - ADS, on the air traffic system safety level . More specifically, this work aims to evaluate the possibility to use surveillance systems based on ADS as a way of reducing inaccuracies, to increase the surveillance coverage levels of Aeronautics and consequently reduce the values of minimum separation between aircraft, without penalizing the safety levels of the air traffic system. The reduction of the minimum values of applied separation between aircrafts is one of the ways to enable the increase in the air traffic system capacity. Considering its practical application, this work aims to contribute as a formal method to quantitatively evaluate the impact on safety levels of air traffic systems, considering changes in its conceptual architecture, improving the quality of its services and its capacity.

3.5. Researches on Air Traffic Control involving Unmanned Aerial Vehicles

a) Unmanned Aerial Vehicles modeling based on Multiagent Systems (Correa *et al*, 2006).

This PhD research proposes a modeling of an Unmanned Aerial Vehicle – UAV taking as its starting point the mobile robot concepts. The most relevant concepts involve the "intelligent function," which means making decisions, recognizing environments, adapting to or learning, as well as taking "actions similar to those of the human being" mean act in the air as a real pilot, considering the rules of a safety flight, to fulfill its tasks. Once the robotics nature of the UAVs is understood, they, in general, must deal with environments partially observed - stochastic, dynamic and ongoing. Thus, a UAV needs to incorporate all knowledge about itself, about previous missions and its environment and about the tasks it will perform, so the UAV can learn quickly, and perform its duties safely. Finally, a UAV should communicate and collaborate with other UAVs, civil aircrafts and air traffic controllers, all in accordance with the rules of the CNS / ATM. Therefore, a modeling from the point of view of multiagent systems is necessary to complete the robotic model.

b) Reliability and Safety of Unmanned Aerial Vehicles (UAVs) in Civil Aviation (Correa *et al*, 2006)

The pressure from the aviation airlines and the entire aviation market demands new technologies, allowing an increase in the number of aircraft in the controlled airspace. Considering this kind of application, many researches are being made in the area of Unmanned Aerial Vehicles (UAVs). However, this type of aircraft is still in a very preliminary development stage for use in commercial aviation. This doctoral research aims to assess solutions that employ UAVs, verifying and assuring their reliability and critical safety, since such automation solutions imply the replacement of pilots by computers.

Another consequence of this research is also the possibility of replacing air traffic controllers by another automated system, which would imply a fully automatic critical system, depending on a wide computer network distributed throughout the territory of the countries. Thus, the hazards such as an emergency landing without a proper runway, the lack of fuel at cruising altitude, and even the failure of any equipment inside the aircraft are critical situations that this study is proposing.

c) Challenges in Application of Sensor Fusion on Unmanned Aerial Vehicles - UAV (Furtado and Camargo, 2007)

Unmanned Aerial Vehicles (UAV) are becoming a reality in several countries, in the military and in the civil sphere areas. In Brazil, there are already several researches involving different aspects such as reliability, autonomy, communication and safety for the development and support of this new challenge to the aviation world. The sensor fusion can be an important contribution to make possible the implementation of these vehicles as a way of "feeling" the environment around the aircraft, bringing more precise data for the on board systems. This PhD research seeks to identify the problems involved, as well as the key issues to be explored and to propose appropriate methods using sensor fusion techniques, viewing their implementation in UAVs.

d) Assessment of Quantum Communication in Aeronautic Telecommunication Network (Costa and Camargo, 2006).

The technological impact represented by the transition from current silicon classical technology to new technologies that make use of quantum phenomena has motivated intense research worldwide on development of devices capable of processing quantum information. Despite several issues still not completely settled in this area, it has already been shown that quantum computers have their own computational complexity rules, being able to treat certain classes of classic problems much more efficiently. Among the various impacts arising from the processing of quantum information, those related to information security are gaining great attention. This is because the main cryptographic methods currently used are becoming vulnerable. This scenario does not arise with respect to the quantum cryptographic algorithms, which are more robust even in scenarios of greater computational capacity.

In the current context, in which traffic data are gaining increasing importance, being responsible for several critical functions, the security maintenance in data transmission has become a strategic aspect. This Master's research aims to assess the impact of this new technology in the context of aeronautical telecommunications, in which aspects of information security are closely related to the non-occurrence of accidents. Considering the current trend of joint operation of Manned Air Vehicles and Unmanned Aerial Vehicles (UAVs) using a unified data network, it is very important and significant to formally evaluate the benefits and feasibility of the implementation of quantum cryptographic algorithms in a future context of air traffic control.

e) Safety Analysis of the use of UAV on the Brazilian Air Space (Oliveira and Cugnasca, 2006).

This research is being developed and focuses the analysis of reliability and safety levels for operation of Unmanned Aerial Vehicles (UAVs) together with manned vehicles in the Brazilian airspace. The evaluation of these reliability and safety levels involves the aircraft, including its dimensions and reached speeds, when it is over dense populated regions. So far, there is no specific legislation for operating UAVs, be it in Brazil or in other countries and the release for operation and flights are examined case by case by ANAC (National Agency of Civil Aviation) in Brazil, and the corresponding organizations, in the case of other countries, such as USA, Britain and Australia.

4. CHALENGES FOR THE COMPUTATIONAL SYSTEMS

The evolution of air traffic control systems is an ever increasing need in the light of a growing demand. Considering the CNS/ATM paradigm, new management and control forms should be investigated with special attention to the decision support systems. Pilots and air traffic controllers should be advised by support systems. Without such systems, it will be very difficult to meet the huge demand.

These decision support systems are directly related to the distribution of intelligence between the various elements of the air traffic control system. At first, some tasks can be transferred from the air traffic controller to the pilots. At a second moment, however, many of the tasks performed by the controllers and pilots may be supported by automated systems, which will support the decisions of the human beings involved.

Therefore, there should be a greater distribution of decisions, providing the creation of fault tolerant distributed systems with high availability and safety level. These systems should be fully integrated, promoting collaborative decision-making in real time. Thus, the computer systems tend to acquire a growing responsibility. This implies that one must bear in mind the enormous complexity of these systems and the need to ensure its safety and reliability.

Following this trend, enormous challenges will be imposed to the computer systems; among them, the following can be emphasized: computational modeling of artificial complex systems, the transition from the traditional silicon technologies to other ones, and development of quality systems, considering their availability, accuracy, safety, scalability, persistency and ubiquity.

Computation is becoming increasingly ubiquitous, i.e., it is everywhere. Therefore, there is a great challenge, that is, the way of checking the safety of complex critical systems, bearing in mind the emergence of new technologies such as quantum computing, which may endanger the safety aspects guaranteed by classical cryptography. Considering the huge complexity of critical systems and also new forms of threats that are emerging because of new technologies, other risk analysis methods must be rethought in order to obtain a greater confidence in the analysis performed. Taking into consideration that the absence of failures can not be guaranteed, the most adequate is to work with robust and fault tolerant systems, able to self-correct, or even able to continue generating safe services despite having less capacity or functionality (degraded operation).

5. CONCLUSION

This paper has presented some research lines of the Safety Analysis Group, seeking to identify new challenges, considering the future trends in air traffic control, specially with regard to ATM. As already mentioned, the new air traffic control systems will depend more heavily on computer systems, considering the functions of control and decision support. A very important aspect is the evaluation of the new risks, in which the main focus will be the proof that the new systems will present risk levels equal to or smaller than the already existing systems, always viewing a growing demand. The interdisciplinary concern will represent a key role as aeronautical engineers and computer engineers should have a broad debate in order to achieve an automation and control paradigm harmonious with the future needs, while listening to the human agents involved in the process, to the pilot and to the air traffic controller.

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