

INTEGRATING UAV INTO CONTROLLED AIR SPACE USING COOPERATIVE MULTIAGENT NEGOTIATION

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Abstract

Developed countries have made significant efforts to integrate UAV operations into controlled aerial space due to the rising of interest of using Unmanned Aerial Vehicles (UAV) for civilian purposes. This study focuses the usage of multi-agent architecture to distribute the workload of detecting and solving conflicts between the aircraft and the UAV with no intervention from ground-based facilities. Midair collision risk was the main unsafe situation evaluated in the paper using an aircraft collision model based on air traffic density data.

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1. INTRODUCTION

The development of the civilian usage of the UAV (Unmanned Aircraft Vehicles) is still on its initial phase, but it has shown a quite promising future when comes to the spawn of new navigational control technologies.

In order to develop a civilian market, the cost-benefit analysis recommends the UAV usage, replacing everyday procedures, in addition to the accomplishment of currently impracticable missions. Nevertheless, safety factor must be evaluated and taken into account.

Serious safety paradigms are raised when crewless and civilian passenger aircrafts or non-passenger carrier UAV would share airspace with conventional passenger-carrier aircrafts.

Therefore to operate UAVs in international airspace would require the observance of two closely related conditions (Sullivan, 2005): the UAV has to be safe and reliable enough to fly over densely populated areas and must be safely operated through all airspace zones. In this study we assume that UAVs are fit for being used in air traffic system areas. These safety issues for operating different types of UAVs in densely populated areas shall be in accordance to the safety rules of the International Civilian Aviation Organization (ICAO).

Solutions involving artificial intelligence

software or multi-agent systems have been researched, aimed to the development of decision-making systems capable of avoiding aircraft collisions in airspace zones (Sullivan (2005).

These automated systems require well-designed and well-defined implementation assuring a safe and reliable usage in the entire current air traffic control scenario. In order to make an UAV operation truly safe in airspace avoiding midair collisions, an UAV should take heed of mobile obstacles (as adverse weather or other aircrafts) independently of being another UAV.

CNS/ATM (Communications, Navigation, Surveillance/Air Traffic Management) enables technological progress in this field since communication may be conducted by means of data link. In addition, signal losses could cause critical situations due to general failures of the ATC (Air Traffic Control), weather interferences or failures in the UAV's avionics. Multi Agents Systems can be used to control the UAV automation.

Section 2 presents the main concepts about UAVs while in section 3 are presented the basics on multiagent systems. Section 4 introduces the subject of conflict detection and resolution systems. The main focus of section 5 is to solve such matter through the use of Monotonic Concession Protocol.

Besides that, section 6 briefly describes and analyzes the question of safety analysis of UAVs. Finally, section 7 details the main experiments and results obtained and section 8 closes with main conclusion of this paper.

2. UAV CATEGORIZATION

The description and categorization of Unmanned Aerial Vehicle can be made according to many criteria, such as flight altitude, endurance, observability and size, among others. For aeronautics, endurance is a jargon that includes concepts of Ruggedness, Reliability and Availability for a given period (Lax, 1996).

There are some international attempts on grouping them in "Tiers", but there is such a wide assortment of them that category overlapping is nearly unavoidable. Intending on minimizing such an inconvenience, International Forum on UAV, UAV (2006) proposed a set of descriptors based on flight characteristics, size/weight and functionality, given below:

- "Endurance" UAV: aircrafts with over 24-hour flight autonomy, may be sub-classified as: : operational (medium altitude) and strategic (high altitude).
- Micro UAV: Small vehicles, usually limited to short-range missions. Operate at low altitudes and weigh less than 1 kg.

- Mini UAV: Greater autonomy vehicles, operate at intermediate altitudes. May reach controlled airspace limits (around 18.000 ft). Most weigh from 1 kg to 20 kg.
- "Tactical" UAV: Military vehicles, can fly at intermediate altitudes. Typically weigh from 28 kg to 450 kg and have extended autonomy (many hours).

There are already some civilian UAV usage either operating or in developmental stage, namely those related to surveillance and access to risky areas such as nuclear facilities, power transmission line maintenance and others (Civilian, 1999). These usage do not have significant influence on the air traffic system, since their flight routes are over clearly defined areas at low altitudes and low speed.

But, in order to the aeronautics industry integrate the civilian UAV usage to the system, some issues must be dealt with: technical (aircraft control technology), political (border control issues) or legal (liabilities in case of accidents).

One can see that categories still cling to a military heritage, since the military are still involved in most of the current UAV developments. The main military feature is avoiding human crews at all, in spite of severe

critics against armed military operation, such as what criteria should an algorithm assess in order to open fire? (Sullivan , 2005).

Opposing to this, crewless, civilian passenger aircraft raise a completely diverse paradigm in terms of reliability, compared to military usage. Because of this, new hurdles come in the way of a future categorization of passenger carrying UAVs, as well as of non-passenger carrying UAVs sharing airspace with conventional passenger carrying aircrafts.

Then, operating an UAV on international airspace must observe two closely related conditions (Allouche, 2000): the UAV must be safe and reliable enough to fly over densely populated areas and must be safely operated through airspace. Although both requirements are defined generically, they should account for the widest possible range of unsafe situations both for the airplane itself and its surrounding environs.

From such general safety requirements, arise research subjects such as risks on collision to the ground and midair collision. Both relate primarily to integrating UAV operation to the current system, which demands appropriate rules that enforce fulfillment of those requisites. In this paper we assume that UAVs are fit for use in the traffic system, and building on this hypothesis

present ground collision and midair collision related safety issues.

3. MULTIAGENT SYSTEMS

An agent is a piece of code or a program that is capable of analyzing inputs from its environment to make decisions and then to take proper actions. This concept of rational agents was developed in the field of artificial intelligence being used to solve problems involving individuals when making decisions and taking actions as presented in studies of M. J. Mataric (1995) e P. Ciancarini, A. Omicini, and F. Zambonelli (2000).

The combination of several agents creates a multi-agent system in which complex interactions and behaviors are possible. Agents can communicate, collaborate, and compete with each other to achieve their goals. Some multi-agent systems feature a team of agents with a common goal.

The UAV operation can surely be considered a multi-agent system in which every aircraft is an agent with its own goals (destination, time frame of arrival, service standards, etc) and is independent of the goals of any other aircraft. With this approach, it is possible to apply negotiation techniques that have been developed for such systems. These techniques will allow the aircraft to cooperate in solving airspace conflicts and, doing so, it will also be able to efficiently solve its own conflicts.

The possibility of cooperative negotiation is one of the powerful features of the multi-agent systems. Agents are free to solve their conflicts by developing and implementing solutions together in a more efficient way than when pursuing the solution individually.

Agents will be free to communicate with one another and to negotiate among themselves, using a simple negotiation protocol known as the MCP - Monotonic Concession Protocol, to find safe and efficient solutions to conflicts, and to mitigate possible risks. Once the agents have agreed upon a resolution, the agents shall automatically conduct the negotiation process themselves, excluding the participation of pilots or ground controllers.

4. CONFLICT DETECTION AND RESOLUTION SYSTEMS

There has been a great deal of research in the last few years focusing on CD&R - Conflict Detection and Resolution process automation. Kuchar and Yang (2000) have provided an overview of a number of these systems. While many methods have been proposed, few have applied the techniques of distributed artificial intelligence and multi-agent systems to the problem, and even fewer have applied cooperative methods.

Wangermann and Stengel (1999) have presented a solution that considers aircrafts as

negotiating agents, however, the agents negotiate indirectly through a centralized controller.

Menon, et al. (1999) have developed a method that uses cost-related functions, similar to those found in agent-based systems. However, their system is based on quasi-linearity optimization methods rather than agent-to-agent negotiation system. Through their system, aircraft trajectories are defined as sequences of four-dimensional waypoints (three spatial dimensions and one time dimension) and various parameterization methods. Optimal trajectories are computed using the parameterized representation of initial aircraft trajectories, appropriate cost-related functions and the sequential quadratic programming method. These new trajectories minimize the overall cost of the system providing that the aircraft do not violate protected zones of other aircrafts. This method can handle a wide range of risking conflicts of aircrafts.

5. APPLYING THE MCP TO UAV AND AIR TRAFFIC CONFLICT RESOLUTION

The Monotonic Concession Protocol captures the basic ideas of a bargaining process and involves relatively simple computation. The usage of this protocol leads to the selection of the deal from NS - Negotiating Set, which maximizes the system utility. Additionally,

and most importantly, it was shown that the protocol could not be manipulated by any of the agents to obtain unfair advantages through false information or by changing negotiation strategies. (Zeuthen 1930; Rosenschein, 1994).

In order to apply the MCP to the air traffic conflict resolution problem, many issues must be resolved including details pertaining to utility functions for aircraft, conflict detection, negotiation set generation, and others. We have developed a simple air traffic conflict resolution model addressing these concerns.

Figure 1 provides an overview of the CD&R process described in the following sections. The process with agents, constantly monitors traffic situation in their own areas and uses nominal state propagation check, therefore impending conflicts. The agents look 20 minutes ahead, when predicting conflicts. When an agent determines that a conflict is going to occur, the UAV agent starts to negotiate with that aircraft.

The agent starts the negotiation by sending a message to the other aircraft informing that an impending has been detected. The agent uses a prescribed procedure to generate a number of possible trajectories and Fly Levels (FL). Each of these trajectories and FL are evaluated using the risk measuring function for determining the risk level and for

comparing it to the risk of the trajectory fallback through utility scores.

Each alternative trajectory and its associated utility score are then sent to the aircraft, showing the impending conditions. At the same time, the agent receives the other aircraft's possible trajectory alternative utility functions. Each of these trajectories is paired with one of the agent's own trajectories to produce potential deals.

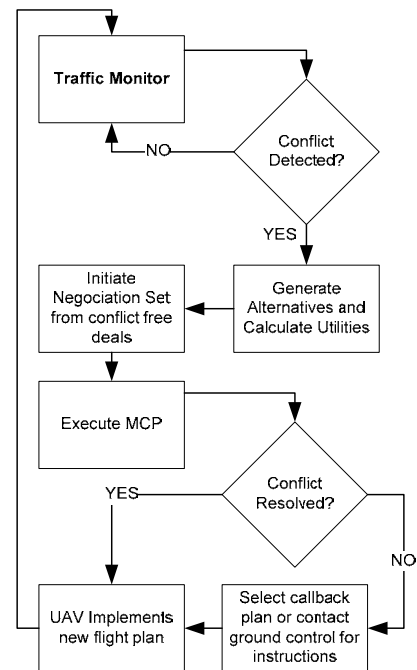


Figure 1: Overview of the Conflict Resolution Process

It is possible that some or all of these deals will not be conflict free. Therefore, each deal is to use a nominal state propagation method assuring that no conflict will arise from it. Every deal that is not conflict free is rejected. Once this process is completed, the

negotiation set is generated.

After the negotiation set is concluded, the agents execute the Monotonic Concession Protocol to select the deals from the negotiation set. If no deal can be agreed upon, the conflict deal will be selected. Finally, the UAV agents will take the selected flight plan for proper approval and implementation.

5.1. Conflict Detection

This proposed model uses a simple conflict prediction tool. Nominal state propagation is used to determine the future location of aircraft using current state information and the conflict probability map derived from Monte Carlo simulations. The update cycle of each agent will inform current positions, speed, and heading routes of each aircraft, within an area, ten minutes ahead of the imminent conflict.

If the protected zone of another aircraft is overlapped with that of the agent (Figure 2) during a period, then a conflict resolution process will be started. The model defines a conflict when any overlap is detected in the protected zones of both aircraft and the UAV. The protected zone is a cylinder of 1.5 nautical mile radii, and a height of 1000 feet, centered on the aircraft itself. Observe that the UAV is considered an intruder aircraft. The model uses all three dimensions of the state information.

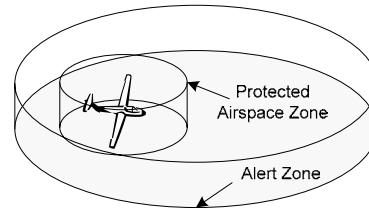


Figure 2: Protected and Alert Zones.

During the process of state propagation and conflict detection, the times for beginning and ending the impending conflict are stored. The first time and last time the protected zone is overlapped are used in the process for generating the alternative trajectories comprising the negotiation set.

5.2. Negotiation Set Generation

When the agent detects that a conflict is going to occur involving another aircraft, it uses a predefined process to generate six alternative trajectories. The six prescribed possibilities are deviations toward its left, right, up, down, and slow down or increase up its speed. A given process generates each pair of opposite trajectories. In terms of the taxonomy outlined by Kuchar and Yang (2000), this resolution process allows climbing, turns, and speed changes, but not a combination of them.

The generation of the left-turn/right-turn pair (see Figure 3) is based upon the predicted times concerning the beginning and the end of the conflict. The agent determines the conflict location at the time protected zones are first overlapped. This point is used to generate two

temporary waypoints; lines of right angle projection, to the left and to the right, of three nautical miles each from the aircraft current heading line, at the point where the conflict would start. A similar procedure is used to generate two waypoints, using the position the agent aircraft would be at the end of the conflict. Finally, a fifth temporary point is created on its original path route, several minutes after the conflict would have ended.

This point is called the rejoining point and the agent will use it to return to its original path after the conflict evasion maneuver has been completed. These five waypoints, two to the left of its original path, two toward its right side, and the rejoining point, allow two new trajectories to be defined. The left alternative involves an immediate turn to fly towards the first left waypoint, then to the second left waypoint, and finally rejoining it to its original path at the rejoining point. Similarly, the right turn alternative is the path from the current position to the first right waypoint, then to the second right waypoint, and finally to the rejoining point.

Climbing and descending alternatives (Figure 4) also consider recorded conflicting times, during the step of predicting the conflict. The climbing alternative refers to the immediate climb to an altitude of 500 feet above its current altitude. The agent continues

to fly its original course at the new altitude until it passes the point at which the conflict is over, when then, it returns to its original altitude. The descending option follows similar procedures; however it would descend to 500 feet. It maintains that altitude until crossing the end of the predicted conflicting point, when then it climbs back to its original altitude.

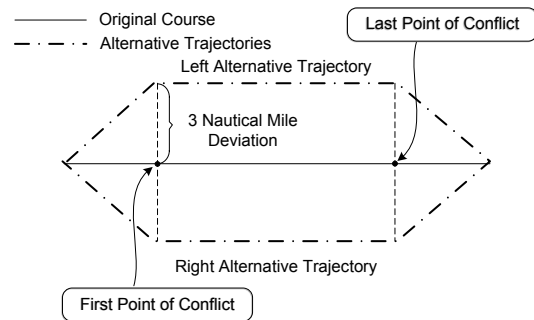


Figure 3: Generation of left and right alternative trajectories (top view).

Finally, the speeding up or slowing down options are generated. They are less complicated and simply require the agent to fly its previously intended path in slightly faster or slower speeds. No other course or altitude changes are required. A value of 50 knots was arbitrarily chosen for the amount of speed increasing or decreasing for this model, but this value could easily be altered. It is likely that in a real world application of this process, this value will consider the class of the aircraft involved.

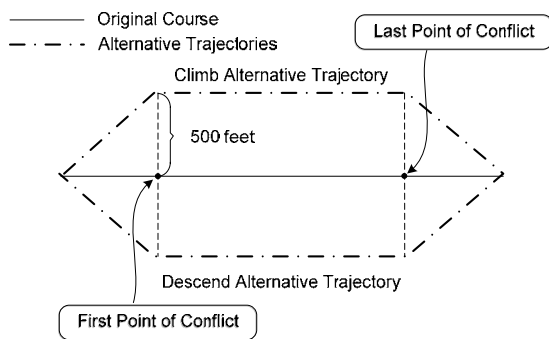


Figure 4: Generation of climbing and descending alternative trajectories (side view).

Once all six options have been generated, the agent processes each one of them using its utility function. In order to make use of the MCP, each agent must have its utility function. This function is used to encode the agent's preferences for certain flight plans. The power of the cooperative negotiation approach comes from these functions. By encoding preferences for certain flight plan attributes in a utility function, the agents are able to insert their options into the conflict resolution process, in a way that is not possible in most standard systems.

The agent produces a utility score for each potential conflict resolution. Then, the agent sends messages to the other aircraft involved in the potential conflict. Each message includes a request to initiate the negotiation process and informs all the flight-plan data required to completely describe the six alternative trajectories and their associated utility scores. The message concludes by

stating that all the information needed has been sent.

The process described above occurs simultaneously for both affected agents. Similarly, the following steps, after the agent receives the trajectory alternatives and their utilities, will also occur simultaneously for all parties. After receiving the trajectory alternatives, an agent will pair them up, generating its alternatives.

Each received trajectory is paired with one generated trajectory for a total of 36 potential solutions. In the MCP terminology, every one of these 36 trajectory pairs is considered a deal, and together they form a preliminary negotiation set.

6. SAFETY ANALYSIS METHODOLOGY

Besides the conflict detection and resolution, another very important question to be considered is to analyze safety issues arising from operating the different types of UAVs in densely populated areas, one should run a "Preliminary Hazard Analysis" - "PHA" -, according to the safety rules by the International Civilian Aviation Organization ICAO (2006).

A preliminary analysis can identify critical risks associated to UAV operations, allowing the prediction of values for each risk and also assess their implications on UAV systems design and operation. Risk identification is

done by means of an approximation based on event consequences. This approximation focuses on events classified as extremely harmful. Due to reliability demands for aviation systems, events with most grievous consequences should be the guide for the project of critical systems. Two UAV operation related events are of major interest for public safety: ground collisions and midair collisions (the latter involving other aircraft).

Granting that there are other potentially catastrophic risks, the aforementioned critical events have direct influence on integration of UAVs to the current controlled airspace. Finally, perceptions of risks and benefits of civilian operation of UAVs by the general public, together with interest on the system by investors, will have a deep influence on air traffic safety and management politics.

6.1. Ground Collisions

Statistics on aircraft accidents show that 15% of all accidents happen on take-off and initial climb and other 50% on descent (near landing) and landing (go-around included), Jump (2006). It is quite interesting to realize that main reasons behind such mishaps are lack of positional awareness in the air and inappropriate decision making. By one side, such failures may have a lesser incidence on the usage of automated crewless aircraft control. Such an example is CAT-IIIc landing,

for which few airports have qualified operators authorized to land in zero/zero conditions.

On the other hand, one should care about problems arising from the very use of avionics replacing human operators aboard an aircraft. Namely, criteria definition is needed to achieve acceptable safety and reliability levels for a totally automated aircraft control system.

Automation and avionics became unavoidable in every field of aviation, be it Fly By Wire flight control module, or be it a set of navigation aiding systems. In the realm of in-flight airplane, any maintenance operation becomes staggeringly complex, and components must follow the 'safe mission' criterion, for they do not allow for in-flight maintenance (Mean Time Between Failure - MTBF is made equal to Mean Time To Repair - MTTF). This implies that any project in avionics has special requirements on tolerance to failure (Boléat, 2005).

As an example on such concerns, accidents such as that involving a (currently) brand new Airbus A320, that was first effectively operating on Fly By Wire. It happened in 1988 under suspicion of Fly By Wire system failure, according to the airplane captain. Official version states that the aircraft operated properly, but since May 1998, it is proven that the Flight Data Recorder was

switched after the accident (Kilroy, 2006).

From the moment a given aircraft is defined as being an UAV, all of its control systems are run by electronic components that are held liable for all decision making required on flight. In such a case, redundant analogical equipments are not necessary, once there is no crew to use them. On this subject, one must also account for the different types of landing procedures, including emergency landing, both on airport runways and on inadequate terrain. In extreme cases, use of algorithms for decision making is still perceived as unreliable, since their capabilities are very limited as yet.

Another complex situation for decision making by an algorithm is the high speed approaching for engines-out emergency landing, as happened to a Boeing 767 that run out of fuel at 41,000 feet. Twelve kilometers above Manitoba countryside, the unthinkable happens: a brand new Air Canada Boeing 767 runs out of fuel dropping at over 600 meters per minute. Despite of the critical situation, the powerless plane makes a successful emergency landing on an abandoned airbase. This accident is understandable, if one keeps in mind that when it happened (1983), pilots as a whole didn't trust onboard computers and that airplane's crew didn't take heed of the alarms (Nelson, 1997).

6.2. Midair Collisions

The main task of air traffic controllers managing arrival traffic is to sequence, group and individuate aircrafts for landing. Unfortunately, the airborne counterpart of the arrival manager, which could help the flight crew to converge aircraft towards a fixed distance according to a constrained sequence, is not yet available. This kind of maneuver seems difficult to perform by humans, and may induce excessive increase in flight crew workload, thus requiring new on-board automated functions.

One may easily see the search for automation of several systems, both avionics and air traffic control related. This leads industry to search for aerial systems automation, envisaging optimizing maximum use of airspace. In this sense, a trend in new projects of large companies is the research on UAVs that manages flying in the airspace.

But to make an UAV operation in the airspace truly safe, it should minimize the unsafe states in take-offs and landings, in order to avoid midair collisions an UAV should take heed of mobile obstacles (such as adverse weather and other aircrafts) that may or may not be another UAV.

Answers involving artificial intelligence software or multi-agent systems have been researched on, in the search for decision-

making systems capable of avoiding aircraft encounters in a given airspace (Kuchar, 2005).

To make such automated systems safe and reliable, their implementation should be designed and defined for the entire current air traffic control scenario. And that because UAVs demand new communication methods and equipments for the air traffic control system, since voice command by ATC to a crewless aircraft is still a problem.

7. EXPERIMENTS AND RESULTS

The conflict detection and resolution model was preliminarily evaluated using randomly generated scenarios. Each scenario consisted of one aircraft and one UAV whose initial headings and speeds would cause a conflict. Random scenarios were created using this process. First, a conflict point was selected. It is the location where both, the aircraft and the UAV, would undergo a collision if an intervention were not provided. Random velocities were selected for the aircraft and UAV from a nominal range. Headings were also randomly generated for the aircraft and UAV, with the condition that they kept apart 30 minutes of one another. Finally, a conflict time was selected. This time represents in minutes, counted from the scenario starting point to the time the conflict would occur, considering the interval between 10 to 20

minutes they have to be drawn apart.

Selected headings, velocities, and time, aircraft and UAV starting positions were used to calculate it. Waypoints were then created for the aircrafts' headings considering one hour forward the starting position, therefore completing its flight plans.

The most important function performed by any conflict detection and resolution model is the assurance of safe distance between the aircrafts involved (with "risk less" constrains). This was qualitatively verified by running several hundred trials of these randomly generated scenarios. In these trials, the agents were presented with different scenarios and had to negotiate case by case. Each resolution was analyzed to assure that no conflict would occur. Whenever there was a risk of conflict, it was avoided by the trial; the protocol, therefore, proved to meet the minimum safety standard.

The second goal of the model is to increase efficiency through cooperative conflict resolution. The efficiency of the model was evaluated using cost functions as previously described. A number of basic cost parameters (keeping in mind the risk mitigation) were defined and combined to create cost functions to be used in these tests. Equation 1 is the simplest cost function tested, in which the cost of the flight plan is equal to

the flown distance, in nautical miles. Equations 2, 3, and 4 add penalties for altitude and heading changes.

$$\begin{aligned} \text{Cost} &= D & (1) \\ \text{Cost} &= D + \Delta A & (2) \\ \text{Cost} &= D + \Delta H & (3) \\ \text{Cost} &= D + \Delta A + \Delta H & (4) \end{aligned}$$

Were:

$$\begin{aligned} D &= \text{total distance traveled} \\ \Delta A &= \text{total altitude changes during flight plan} \\ \Delta H &= \text{total heading changes during flight plan} \end{aligned}$$

The altitude penalty is equal to the gross altitude change over the entire flight plan. For example, a plan that includes a 500-foot climb and a 1000-foot descent will incur an altitude penalty of 1500. The heading change penalty is similarly defined. These penalties were idealized to minimize the payload hazards as well as to maximize passenger comfort.

Test 1 (see Table 1) shows the average results from 100 trials, in which both agents

use cost function 1. As expected, when both agents use the same utility function their results are very similar. Agent 1 had an average of 6.1% improvement and agent 2 showed an average of 9.3% improvement, when comparing their negotiated deals to their conflict deal.

However, in Test 2 (see Table 2), when agent 2 used cost function 4, which includes all three penalties, agent 1 showed an average improvement of 8.5%, which is not statistically different from what was obtained in test 1. On the other hand, agent 2 showed a much higher improvement. This demonstrates that when an agent has a strong preference for an option, the model allows that preference to be expressed. This is the primary difference between this model and any non-cooperative solution; the negotiation process allows agents to select their best suiting plan.

Table 1: Summary Results for Evaluation #1

Agent	Conflict Cost	Negotiated Cost	Average Improvement	Std. Deviation
1	156.31	146.00	6.1 %	5.4 %
2	160.04	144.65	9.3 %	5.6 %

Table 2: Summary Results for Evaluation #2

Agent	Conflict Cost	Negotiated Cost	Average Improvement	Std. Deviation
1	145.03	143.76	8.5 %	6.4 %
2	218.01	158.09	27.8 %	20.5 %

8. CONCLUSIONS

UAVs have been used for new military applications and civilian research, for instance on supporting surveillance mission. Aviation developments are directly related to the level of risk the society is prepared to assimilate. Therefore, this preliminary research shows important concerns and new fields to be studied. Ground and midair collision impacts are the two main concerns of the air traffic control system.

The investigation undertaken in this study is a first step to meet the air traffic safety and reliability requirements concerning these aforementioned critical risks. We proposed and implemented a simple conflict resolution model, based on multi-agent cooperation and negotiation. The system was tested to evaluate not only its safety but also its efficiency. In all tests, conflict was successfully avoided, showing that the system meets the minimum safety standards.

In addition, tests have confirmed the hypothesis that if agents are allowed to use cost functions to express preferences, they can reach better resolutions than those provided by non-cooperative methods. We have shown that, by considering the ATM (Air Traffic Management), a system of individual agents with differing goals and utility functions, those well-known cooperative negotiation techniques can be used in air traffic conflict

problems. These cooperative techniques will allow a group of aircrafts and UAVs to efficiently and safely solve their conflicts without constant interaction with the ground control.

Further studies shall be conducted and expanded to diagnose and to identify critical issues on the UAV usage and all the safety implications.

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