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EXPERT SYSTEMS IN ATC

EKSPERTU SISTĒMAS GAISA SATIKSMES VADĪBĀ

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Keywords: Air traffic Control, expert systems, conflict detection and resolution, aircraft point-mass model

***Abstract* – Despite the fact that there is unimaginable technological achievement in communication, navigation, surveillance, computation and control, the Air Traffic Management (ATM) system suffers from the lack of automation abilities. Almost all main processes of ATM are based on a rigidly structured airspace and centralised human-operated system architecture, but increasing the level of automation we could improve the efficiency of ATM and the human-operator tasks could be simplified. The core objective of any ATM is to guarantee safety and efficiency.**

The main purpose of this work is to provide theoretical investigation of serious questions in ATC and to construct proper mathematical model for accurate simulation. Using appropriate knowledge in ATC physics, procedures and technology processes the ways to increase efficiency of Air Traffic Control (ATC) are found that do not destroy the safety level of whole ATM. The analysis of conflict characteristics that are modelled by mathematical probabilistic approach is processed by logical expert system.

Logical expert systems are similar to human operators that are using own knowledge bases, not mathematical functions, and are flexible for solving different typical problems of normal life.

Introduction

Recent technological, economical and social advances cause serious increase of air travels in the world. From the one hand great development of technical aids such as on-board computers that are called as Flight Management System (FMS) and Global Positioning System (GPS) gives new and more flexible abilities for air traffic operations. Even commercial air traffic carriers consider that a major component of the future air traffic control system will be the "free flight" concept. Consequently, separate aircraft or the whole air traffic flow would have more efficient routes in response to changing conditions. But from the other hand the loss of an airway structure may make the process of detecting and resolving conflicts between aircraft more complex. Consequently, high technology automated conflict or collision detection, avoidance and resolution tools will be required to support aircraft or ground staff in providing safe separation.

Nowadays the Air Traffic Management (ATM) system is built around a rigidly structured airspace. The core gear in the ATM service is human operator. And the rising demand for air travel is stressing ATM and following serving ground staff. Accordingly, increasing workload of the air traffic control officer (ATCO) cause the risk of occurrence of safety problems caused by human factor.

A number of different modelling approaches have been developed and applied in the past for aerospace operations. These models include a wide variety of mathematical techniques for different steps of air travel, but almost all of them were separate products and hardly connectable among themselves.

The aim of the current research is to find new ways of developing automated systems in ATM, which could be base for future ATC. The core purpose is to investigate all air traffic control operation stages and construct proper and accurate mathematical model.

Model of designed automated system

Any air traffic management system has basic functional requirements. The major and simplified design of planned system is shown in Fig.1, and will be explained step by stem in this paper.

First of all the traffic environment should be observed and all received traffic data must be adopted for technical use in computer technologies. It could be done by different types of surveillance and communication techniques. This paper does not provide wide discussion about technical specification of monitoring aids but way how to use them and what kind of parameters and algorithms we involve in model. Consequently, we get crude data about aircraft position — time label, x and y coordinates and altitude. So that it is 4D motion model.

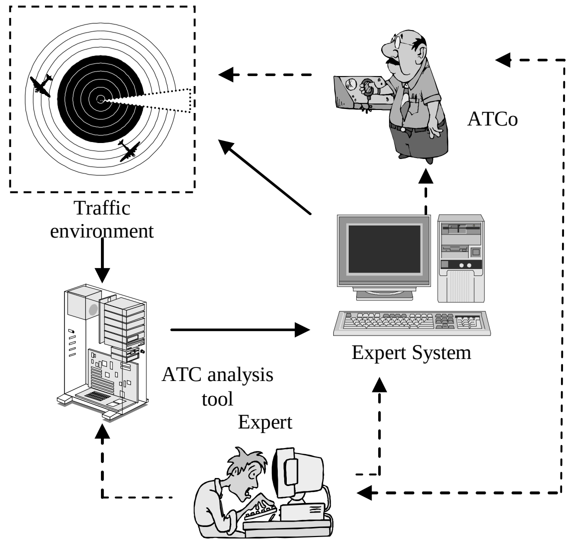

Fig.1. Automated ATM system

All collected traffic state information is used by traffic analyzing tool as shown in Fig.2. Received aircraft parameters are processed and it is possible to get aircraft velocity and direction of motion in x, y and z planes. Due to the errors of sensors and some stochastic weather conditions there are uncertainties in the values of states.

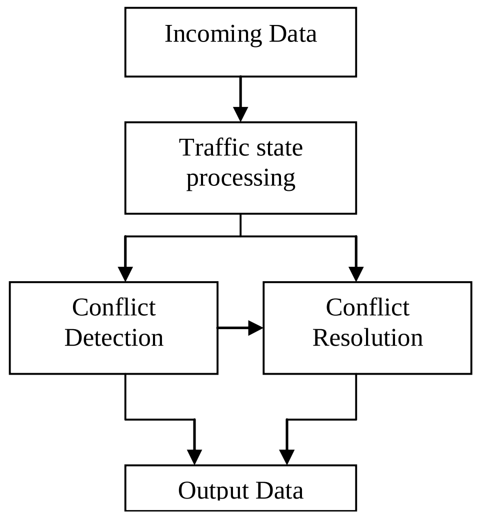

Fig.2. Design of ATC analyzing tool

That is why aircraft could be in the current position with some probability. This stochastic process influences all calculations. All aircraft motions and estimated positions must be observed as probability functions. Traffic state processing could not be imaginable without procedural information like constant aircraft flight plans.

Given traffic possible motions and flight plans are checked by conflict detection and resolution algorithms. Afterwards, we receive advice for appropriate action for following decision as output data. There could be situations when just standard ATC procedures should be applied for normal cases.

Following expert system is transition between final resolution and ATC system's offered facts. In general expert system could be replaced by air traffic control officer or even supplemented by human operator.

Moreover it is important to understand that development of all ATM automated systems could not be imaginable without correct coordination of ATCOs and producers. In some cases experts that produce appropriate software and systems and customers who use those products are the same people.

Air traffic control

The major concern of each advanced ATM system is to guarantee safety. The safety of air traffic is the result of interactions between multiple human operators, local or global procedures and technical systems. Safety is defined in terms of critical situations. Critical situations could be called as conflicts that are defined as the situations of loss of minimum safe separation between at least two aircraft. For present work a conflict is defined as a situation where any two aircraft come within 5 nautical miles (NM) of one another in horizontal plane (Fig.3.a)), which is called as longitudinal or lateral separation, and within 1000 or 2000 feet (ft) vertically (Fig.3.b)).

Briefly all flights could be divided in instrumental (Instrumental flight rules — IFR) and visual flights (Visual Flight Rules — VFR). VFR are set of regulations which allow a pilot to operate an aircraft in weather conditions generally clear enough to allow the pilot to see where the aircraft is going. VFR rules require a pilot to be able to see outside the cockpit, to control the aircraft's altitude, navigate and avoid obstacles and other aircraft. Opposite IFR are regulations and procedures for flying aircraft by referring only to the aircraft instrument panel for navigation. Even if nothing can be seen outside the cockpit windows, pilot can fly while looking only to instruments and following ATCO's

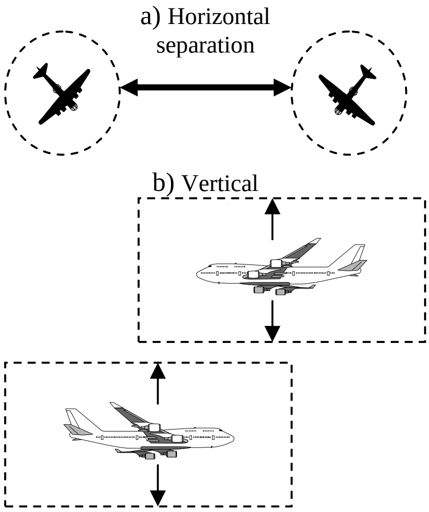

Fig.3. Aircraft separation

instructions for navigation and separation from other aircraft. There is variety of previously mentioned aerospace structures. Difference is in appropriate requirements for aircraft equipment, allowed types of flight and provided air traffic control service in this region.

Traffic Environment

The focus of the present modeling methodology is on development of new air traffic control tools that is based on expert system. To develop current model it is important to find the source of data for ATC processing tool. The traffic simulation is used to produce incoming data and is slightly involved in traffic state processing. We do not need collect data from sensors, recognize and decode signals. Simply it is possible to use traffic simulator. The point-mass aircraft model could offer cheaper and more obvious object with appropriate dynamical effects. Such kind of models is very popular and useful for theoretical use in aircraft operation and performance evaluation work.

The current model shown in Fig.4 assumes that the thrust is directed along the velocity vector and that the earth is flat.

For current simulations it is possible to describe normal flight with several equations that show

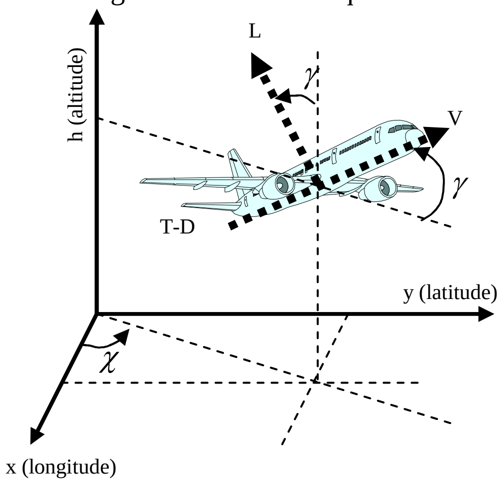

Fig.4. Aircraft coordinate system

the full dynamic motion of point-mass objects:

$$\dot{x} = V\cos\gamma\cos\chi \qquad (1)$$

$$\dot{y} = V\cos\gamma\sin\chi \qquad (2)$$

$$\dot{h} = V\sin\gamma \qquad (3)$$

$$\dot{\gamma} = \frac{g}{V}(n\cos\varphi - \cos\gamma) \qquad (4)$$

$$\dot{\chi} = \frac{g}{V}\frac{n\sin\phi}{\cos\gamma} \qquad (5)$$

$$\dot{V} = \frac{(T-D)}{m} - g\cdot\sin\gamma \qquad (6)$$

$$\dot{n} = \frac{L}{gm} \qquad (7)$$

$$m = -Q \qquad (8)$$

Each aircraft has own ground speed V that is assumed to be the same as airspeed to simplify source data model. Current x, y and h are the components of the position of the centre of gravity of the aircraft in a ground-based reference frame. x is the down range, y is a cross range. All angles are defined with respect to the same frame. From the Fig.4 it is clear that bank angle is φ, the heading angle is χ and γ is the flight-path angle. T is the thrust that is produced by aircraft's engine. Opposite force to the thrust is the aerodynamic drag D. g is the acceleration that is caused by gravity. And opposite gravity of the Earth is vehicle's lift L. The important parameter of point-mass object is current object's mass m. It is important to understand that the thrust depends on the altitude h and Mach number M. Q is the fuel flow rate that depends on engine thrust and altitude of flight.

The control variables for each separate aircraft are the bank angle, which is produced by rudder and ailerons trims, the thrust that is caused by the engine throttle and the load factor n is controlled by elevators. It is the basic point-mass object that could be adapted and simplified for any simulation needs.

Basics of the expert systems

The largest area of applications of artificial intelligence is in expert systems. Expert systems use human knowledge to solve problems that normally would require human intelligence. These expert systems represent the expertise knowledge as data or rules within the computer. All collected rules and data can be called to solve problems and this system could be called as rule-based expert system. The basic idea of the whole designed expert system is shown in Fig.1. It describes the main components and phases of conflict detection and resolution processes.

The core idea of the expert system is to use programmed software - "shell" that uses separate list of knowledge. This list might be changed without software correction.

There are several advantages of the expert systems: ability to capture and preserve irreplaceable human skills and ability to develop a system more consistent than human experts; minimize human expertise needed at a number of locations at the same time; solutions can be developed faster than human experts.

Knowledge-based expert systems collect the small fragments of human mental skills into knowledge base that is used to reason through a problem. The major problem in ATC is to provide all aircraft with safe separation minima. Expert system could use "User interface" to advice ATCo to issue clearance to change parameters of the conflicting aircraft. Otherwise the expert system by it self could issue appropriate clearances based on knowledge list. It could be provided by different ground-air data communication systems like CPDLC (Controller Pilot Data Link Communication).

Conclusion

In this paper was described the major idea of the modelled expert system that could be used as future ATM component. Simplified air traffic control functions and aircraft dynamic model were discussed in this text. Proposed design could be used as basic stages of producing appropriate real ATC expert system.

Future work on this topic will be conducted with each separate processing phases of the automated ATM model. It is important to find out effective algorithms and strategies for conflict detection and solution process. Furthermore, it is quite important to choose the correct expert system software. That is serious investigation plan for development of real expert system for future air traffic control, where safety and automation level be increased by using intelligent computer technologies.

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I.Siņuks. Ekspertu sistēmas Gaisa Satiksmes Vadībā

Mūsdienu pasaule ir pārpildīta ar dažādām tehnoloģijām, taču gaisa satiksmes vadības (GSV) sistēma cieš no automātikas tehnoloģiju trūkuma. Lielākoties GSV balstās uz stingru gaisa telpas sadalījumu, ar atbilstošām procedūrām un pienākumiem, kas pilnībā ir cilvēka kā satiksmes vadības operatora uzdevumi. Paplašinot automatizācijas līmeni, mēs varam paaugstināt GSV efektivitāti un drošību. Tas var būt panākts atvieglojot cilvēka-operatora darbu un minimizējot cilvēka kļūdas faktoru.

Galvenais šī darba mērķis ir veikt GSV darba apstākļu un uzdevumu izpēti ar turpmāku to iesaistīšanu nākamo darbu realizācijā. Svarīgi ir zināt patiesa matemātiskā modeļa struktūru, lai vēlāk to varētu korekti izveidot. Iegūstot papildus teorētiskās zināšanas GSV sfērā, ir svarīgi izdalīt jaunas satiksmes konfliktu noteikšanas un atrisināšanas metodes, izmantojot cilvēka prāta spēju līdzīgās tehnoloģijas, piemēram, eksperta sistēmas. Loģiskās eksperta sistēmas veic lēmumu pieņemšanu, lai izvirzītu vai nu rekomendāciju, vai arī gatavu uzdevuma atrisinājumu. Modelētā sistēma izmanto zināšanu datu bāzes un darbībā balstās uz matemātiskajām funkcijām, tādējādi radot sistēmu, kas pielāgojas situācijai, kas patstāvīgi mainās gaisa satiksmē.

I.Sinuks. Expert systems in ATC

Despite the fact that there is unimaginable technological achievement in communication, navigation, surveillance, computation and control, the Air Traffic Management (ATM) system suffers from the lack of automation abilities. Almost all main processes of ATM are based on a rigidly structured airspace and centralised human-operated system architecture, but increasing the level of automation we could improve the efficiency of ATM and the human-operator tasks could be simplified. The core objective of any ATM is to guarantee safety and efficiency.

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И.Синюк. Экспертные системы в управлении воздушного движения

В наше время мир переполнен различными технологиями из разных сфер. Тем не менее, системы управления воздушным движением (СУВД) испытывают недостаток в технологиях автоматики. Большинство СУВД опирается на жесткое разделение воздушного пространства с соответствующими ему процедурами, выполняемыми человеком (оператором). Увеличив уровень автоматизации, мы можем повысить эффективность и безопасность УВД, одновременно облегчив работу оператора и уменьшив его фактор ошибок.

Главная задача этой работы – произвести изучение условий работы и задач УВД и применение полученного материала в последующей работе. Важно знать реальную структуру математической модели и позже правильно ее воссоздать. Получив дополнительные теоретические знания в области УВД, важно выделить новые методы в нахождении и разрешении конфликтов воздушного движения, используя технологии схожие с возможностями человека, например, экспертные системы (ЭС). Логические ЭС способны принимать решения и давать рекомендации или производить готовое разрешение ситуации. Данная ЭС использует базы данных и в своем вычислении опирается на математические функции, впоследствии подстраиваясь под постоянно меняющуюся ситуацию в воздушном пространстве.