MONITORING AND MANAGEMENT AEROSPACE SYSTEMS

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MULTIPLE-CHOICE CLASSIFICATION IN AIR NAVIGATION SYSTEM

In this article a multi-choice approach for aircraft deviation control from the flight-planned trajectory has been represented. Nine air-situation classes are considered as optimal number for guarantied required safety level. Bayesian classifier has been used for air-situation classification.

Розглянуто багатоальтернативний підхід до контролю відхилення повітряного корабля від запланованої траєкторії польоту. Дев’ять класів повітряних ситуацій забезпечують необхідний рівень безпеки авіаційних перевезень. Для класифікації стану використано критерій Баєса.

Introduction

The number of aircraft in the airspace is increasing every year. Nowadays airlines are constantly overloaded. The little altitude deviation can lead to a conflict situation between airplanes. Modern airborne collision avoidance systems (ACAS) are unable to operate in the congested airspace. The system generates a new flight trajectory for the both involved airplanes if ACAS reveals a potential conflict. This flight trajectory might produce new conflict situations with other aircraft within congested airspace. Air traffic controllers (ATC) and pilots work under high psychological pressure.

Therefore the flight safety level is reduced. This problem is very actual today.

Every air navigation parameter of flight has some deviation from its real valuations. It is the result of some errors influencing. Every measurement device introduces errors of measurement as well. These errors depend on operation life of measuring equipment. The real flight trajectory usually differs from the flight-planned trajectory. It might be the result of pilot’s mistakes as well. The summary of all these errors produces a very significant deviation from the light-planned trajectory and the conflict situation between the airplanes as the result. Therefore the purpose of modern navigation equipment is to control position of an aircraft in the congested airspace.

Multiple-choice classification can be used for the real-flight trajectory observation [1]. This classification shows a pilot and ATC the class of air situation. Each class depends on deviation value from the flight-planned trajectory.

Air situation classes

The airspace between two flight levels is divided into nine air situation classes. If the situation is normal (NS), the airplane is at the flight-planned level (H_{FL}).

If the airplane deviates from the cleared flight level the air situation degrades (DS) and it leads to a complicated situation (CS). If the aircraft intrudes into the adjacent flight level (H_{FL-1} or H_{FL+1}), it stipulates an emergency situation (ES). It results in a catastrophic situation (CTS) if the airplane crosses the centerline of the adjacent flight level. The aircraft deviation from the cleared flight level up generates one of four classes which are marked as DS^+, CS^+, ES^+, CTS^+. Analogies for deviation down are DS^-, CS^-, ES^-, CTS^- (fig.1).

Tab.1 contains formulae for calculation of air situation classes boundaries.

The air situations classification

There are many methods available for classification. The Bayesian averaging model can be used for combining the outputs of multiple classifiers [2; 3].

Bayesian decision-making theory is a statistical approach that quantifies the tradeoffs between various decisions using probabilities and costs that accompany such decisions. This theory is a fundamental statistical approach to the problem of pattern classification.

There are nine different classifiers (A_j, $j=\overline{1,9}$).

Bayesian averaging model starts with a prior over the classifiers, $p(A_j)$ for the j classifier. This is the mean value the (prior) belief in each classifier. Then we observe some altitude data h, and compute the marginal likelihood or model evidence for each j (that can involve integrating out the parameters of the classifier).

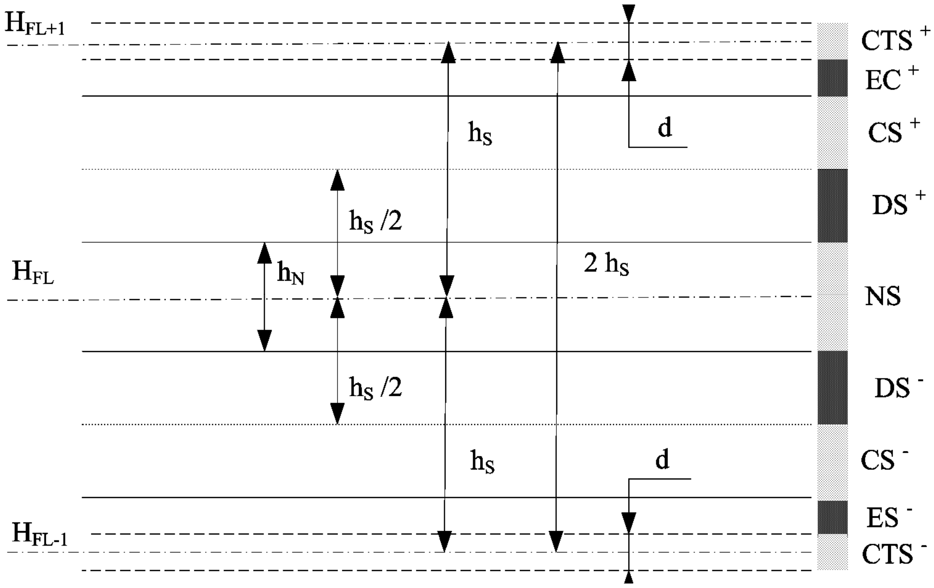

Fig.1. The multiple-choice classification structure

Table 1

Boundaries of air situation classes

Names of situation classes	Direction of deviation	Bottom boundary	Top boundary
NS	-	$H_{FL} – h_N / 2$	$H_{FL} + h_N / 2$
DS^-	Down	$H_{FL} - h_N / 2$	$H_{FL} - h_S / 2$
DS^+	Up	$H_{FL} + h_N / 2$	$H_{FL} + h_S / 2$
CS^-	Down	$H_{FL} - h_S / 2$	$H_{FL} - h_S + h_N / 2$
CS^+	Up	$H_{FL} + h_S / 2$	$H_{FL} + h_S - h_N / 2$
ES^-	Down	$H_{FL} - h_S + h_N / 2$	$H_{FL} - h_S + d / 2$
ES^+	Up	$H_{FL} + h_S - h_N / 2$	$H_{FL} + h_S – d / 2$
CTS^-	Down	$H_{FL} - h_S + d / 2$	$H_{FL} - h_S - d / 2$
CTS^+	Up	$H_{FL} + h_S – d / 2$	$H_{FL} + h_S + d / 2$

Explanation of symbols given in tab.1:
h_S is the altitude between two flight levels;
h_N is the normal situation size;
d is the vertical aircraft size.

Bayesian model uses posteriors:

$$\hat{P}(A_j/h)=\frac{p(A_j)\hat{\rho}(h/\grave{A}_j)}{\sum_{u=1}^{N} p(A_j)\hat{\rho}(h/\grave{A}_j)},$$

where

A_j are the state of flight;

$\hat{\rho}(h/\grave{A}_j)$ are the class-conditional density,

$p(A_j)$ are prior probabilities;

$\sum_{u=1}^{N} p(A_j)\cdot\hat{\rho}(h/\grave{A}_j)$ are the evidence.

The class A_i will be classified if the weight of posterior $\hat{P}(A_i/h)$ is maximum [4]. Then, current air class posterior is:

$$\hat{P}(A_i/h)=\frac{\max\limits_{1\le j\le 9}\left(p(A_j)\hat{\rho}(h/\grave{A}_j)\right)}{\sum_{u=1}^{9} p(A_u)\hat{\rho}(h/\grave{A}_u)}.$$

Deviation probability density of aircraft from the flight-planned trajectory

Deviations of aircraft from the flight-planned trajectory have been researched. Special radiolocation system has tracked the aircraft deviation. The data of size deviation have been used for probability density estimation of aircraft's deviation from the flight-planned trajectory. Double Laplace distribution has been chosen for estimation of probability density:

$$f(h)=(1-\alpha_1)\frac{1}{2a_1b_1\Gamma(b_1)}\exp\left(-\left|\frac{h-\mu}{a_1}\right|^{1/b_1}\right)+$$

$$+\alpha_1\frac{1}{2a_2b_2\Gamma(b_2)}\exp\left(-\left|\frac{h-\mu}{a_2}\right|^{1/b_2}\right),$$

where

a_1, a_2 are scale of coefficients;

b_1, b_2 are shape of coefficients;

μ is the mean of distribution;

$\Gamma(b)=\int_0^\infty e^{-t}t^{b-1}dt$ is the Gamma function.

Estimated results of main parameters (scale and shape) of double Laplace distribution are represented in tab.2.

Table 2

Main parameters of double Laplace distribution

Parameter	Japan	USA	Europe
α	0,15	0,0005	0,014
a_1	163,2	26,4	107,0
b_1	0,5	1,1	0,7
a_2	102,4	205,4	111,3
b_2	1,0	1,0	1,0

These parameters are different for different Earth regions.

Prior probability of air classes

The prior probability of air classes are the area under deviation probability density within some altitude interval.

These altitude intervals are limited by the bottom n_k and the top m_k boundaries (tab. 1):

$$p_k=p_k\{\xi\in[n_k,m_k]\}=\int_{n_k}^{m_k}f(h)dh\ ,\ k=\overline{1,5},$$

$$p_k=\frac{p_k}{\sum_{r=1}^{9}p_r}.$$

The class-conditional density

Each of air situation classes is described by class-conditional density $\hat{\rho}(h/\grave{A}_j)$. Normal Gaussian law is usually used to define classes in the pattern recognition theory.

Let's compare each of the situation classes with Normal Gaussian law as in the fig. 2.

The distribution mean m_k and the mean-square distance σ_k^2 determine rate of Gaussian curve. These two parameters are connected with a deviation probability density. Therefore class-conditional densities have been controlled by a prior information about the aircraft deviation from the flight-planned trajectory:

$$m_k=\frac{\int_J xf_k(x)dx}{\int_J f_k(x)dx};$$

$$\sigma_k^2=\frac{\int_J (x-m_k)^2 f_k(x)dx}{\int_J f_k(x)dx}.$$

The measurements of the barometric altimeter contain an errors. Thus we use other formula for mean-square distance which contains an error value:

$$\sigma_{k\_rez}^2=\sigma_k^2+\sigma_{error}^2.$$

Posterior error

As the class-conditional density $\hat{\rho}(h/\grave{A}_j)$ is the statistical estimate, the posterior probability contains an error [5; 6]:

$$P(A_i/h)=\hat{P}(A_i/h)-R.$$

The maximum error size can be calculated as:

$$|R|\le\sum_{k=1}^{9}\left[p_k\ \max\varphi(\delta_1(n),\delta_2(n))\right]+\left[1-(1-\alpha)^9\right],$$

where

$$\varphi(a,b)=2\Phi\left(-\frac{a}{b}\right)-1+e^{a+\frac{b^2}{2}}\left(1-2\Phi\left(-b-\frac{a}{b}\right)\right);$$

$$\delta_1(n)=-\frac{n}{2}\left(\frac{\sqrt{2}n_{\alpha/2}}{\sqrt{m}}+\ln\left(1-\frac{\sqrt{2}n_{\alpha/2}}{\sqrt{m}}\right)\right);$$

$$\delta_2(n)=\frac{\sqrt{n}\sqrt{3}n_{\alpha/2}}{\sqrt{m}};$$

m is the size of learning measurements;

n is the number of measurements [7];

α is the confidence level;

$n_{\alpha/2}$ is normal law fractile.

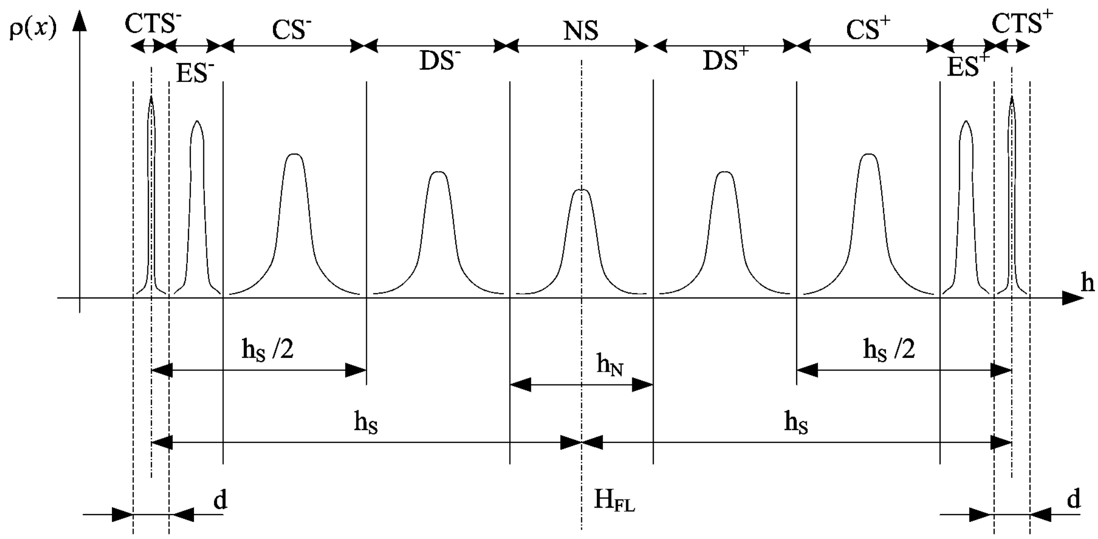

Fig.2. The class-conditional density

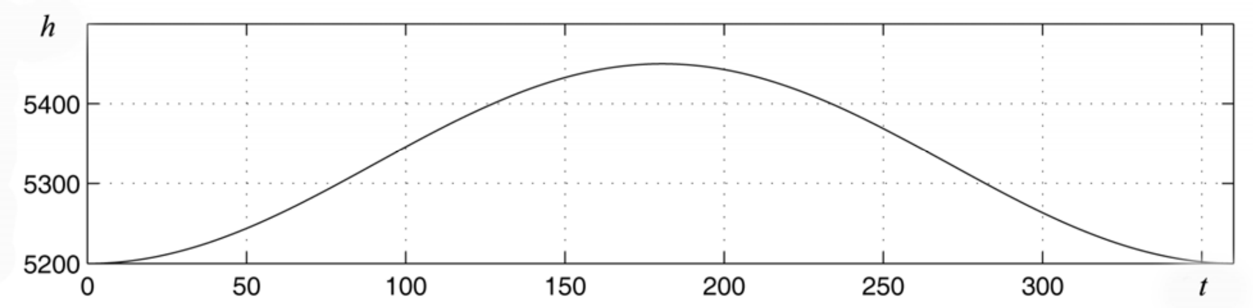

Fig.3. Simulation of altitude flight

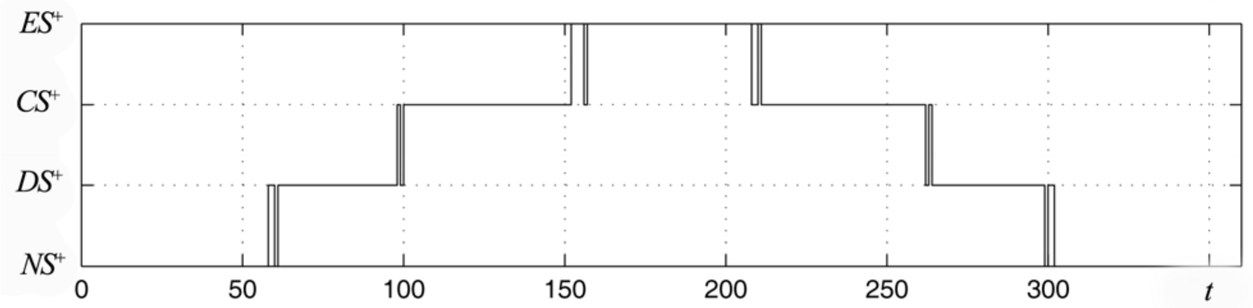

Fig.4. Air situation classes

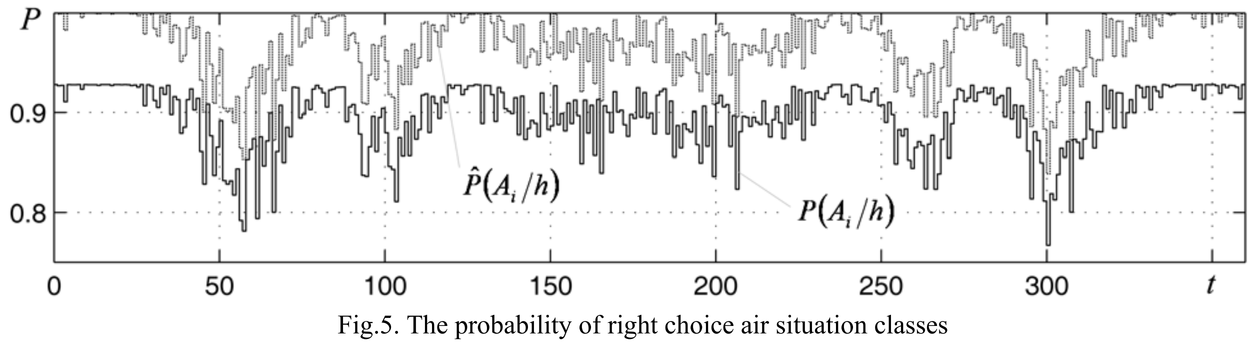

Fig.5. The probability of right choice air situation classes

Simulation

The operation of Bayesian classifier has been explored by math simulation. Special mathematic software (MathLAB) has been used for the process of simulation. This software is appropriate for modeling environment for investigation of the pattern recognition problem.

The AN-140 airplane has been chosen for simulation. At first the statistical manipulation of real flight data has been done. Records of flight emergency recorder have been used for the real flight trajectory investigation. There are unknown parameters of the aircraft deviation probability density from the flight-planned trajectory. These parameters have been found by statistical manipulation of the real-flight altitude data.

The aircraft deviation probability density has been used for prior probability estimation of air classes and some parameters of class-conditional density. Thus we have enough input parameters to build a math Bayesian classifier model.

The simple aircraft model is used for simulation altitude deviation from the flight-planned trajectory.

Altitude simulation model can be written as:

$$h(i+1) = h(i) + V\sin(\beta),$$

where

V is the speed of flight ($V_{AN\text{-}140}$=540 km/h);

β is the angle of pitch;

i is the iteration step.

Track simulation model:

$$d(i+1) = d(i) + V\cos(\beta).$$

Time simulation model:

$$t(i+1) = d(i+1)/V.$$

The pitch angle variation has been used for producing different deviations from the flight-planned trajectory. The result of simulation deviation from the flight-planned trajectory you can find in fig.3. The results of Bayesian classifier work is represented in fig.4. Fig.5 shows the probability of right choice air situation classes.

Conclusion

The congested airspace is going to be a big problem for aviation in the near future. A multi-choice approach for deviation control should help pilots and ATC to operate in the congested airspace. This classification can be used for different aircraft models.

Multi-choice classification marks ever class of air situation as a “step” (fig.4). The stairs (fig.4) show increasing deviation size, at the beginning and decreasing at the end of the curve.

The graphic of right choice probability represents good probabilistic recognition characteristics.

Therefore it is possible to use this approach on the real aircraft.

For example this math algorithm can be used in the Flight management systems (FMS) or in the special module. The last one is more important because a lot of light airplanes are not equipped with expensive FMS or ACAS.

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