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FLIGHT PLAN BASED AIRCRAFT CONFLICT DETECTION METHOD

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Abstract- ***Early detection of conflicts between aircraft is the main purpose of air traffic management. This article provides an algorithm for calculating future aircraft geographical coordinates and conflict detection based on flight plans using the Vincenty formula. Finally, the experimental results are listed in tabular form.***

Keywords- *Conflict detection; flight plan; geographical coordinate; Vincenty formula*

I. INTRODUCTION

Improvements to air traffic control (ATC) systems could help prevent aircraft to aircraft and aircraft to other obstacles conflict. To achieve this goal, the ATC systems provide information indicating aircraft's coordinates, process and manage flight plans, detect conflicts, and implement controller requests. The increased amount of air traffic requires more effective conflict detection methods. Conflict prediction accuracy allows for optimal maneuvering. Investigations of different aircraft conflict prediction and resolution methods [1, 2 and 3] show that the main factor for an accurate resolution algorithm is accurate calculation of predicted aircraft coordinates. A mathematical model of the aircraft flight [4] and the algorithms for medium-term conflict detection [5, 6] are accurate for short-term predicted states of an aircraft, and these algorithms are better used for short-term conflict detection[7]. In medium-term conflict detection [8], forecasting aircraft flight for 20 minutes using these methods leads to certain errors because aircraft will fly long distances and aircraft trajectory is parallel to the curvature of the earth. Thus, the geodetic (or geographical) coordinate system is more suitable for determining coordinates. In [9] is given the method for calculating aircraft trajectory in a geodetic coordinate system. For calculation using the Vincenty formula [10]. Investigations show that the Vincenty formula is more accurate [11]. In this article, we will provide the algorithm for calculating future geographical aircraft coordinates and conflict detection based on flight plans using the Vincenty formula.

II. FLIGHT PLAN BASED AIRCRAFT CONFLICT DETECTION ALGORITHM

Let's look at a simple model to solve the problem. For this, we can use any flight. Let's suppose that, aircraft A1's trajectory, according to the flight plan, passes through points B1, B2, and B5, and aircraft A2's trajectory passes through points B3, B2, and B4 in sector S (Fig. 1). These points are fixed points and their geographical coordinates are known in advance [12].

Let's calculate coordinates for aircraft A1 between points B1 and B2 and for aircraft A2 between points B3 and B2 and use the conflict detection algorithm for these aircraft.

First, we must extract information about the flights for both aircraft from their flight plans [13]. We take cruising speed, altitude, and aircraft route information from flight plans.

Let's use the following for calculation:

V_{A1}, V_{A2} – the speed of aircrafts A1 and A2 according to flight plan;

H_{A1}, H_{A2} – the altitude of aircrafts A1 and A2 according to flight plan;

$B1(\varphi_{B1},\lambda_{B1})$, $B2(\varphi_{B2},\lambda_{B2})$, $B3(\varphi_{B3},\lambda_{B3})$, $B4(\varphi_{B4},\lambda_{B4})$, $B5(\varphi_{B5},\lambda_{B5})$ – geographical coordinates of points according to flight plan.

t_{A1} –aircraft A1's entry time into S sector from point B1. This is given in advance from the neighboring sector.

t_{A2} –aircraft A2's entry time into S sector from point B3. This is given in advance from the neighboring sector.

$A1(\varphi_{A1},\lambda_{A1})$, $A2(\varphi_{A2},\lambda_{A2})$ – geographical coordinates of aircrafts A1 and A2.

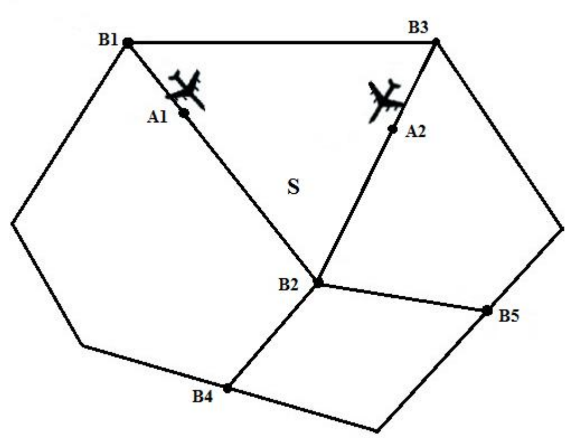

Fig 1. ATC sector

As mentioned, we will use the Vincenty formula for calculations. This formula is intended for calculations on the surface of earth. Thus, we will add aircraft altitude to the earth radius. To simplify calculations, we will separately describe Vincenty's direct and inverse methods and give dependence to output parameters from input parameters.

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Vincenty's inverse method: Vincenty's inverse method calculates geodesic distance and start and final azimuths for two points using geodesic coordinates.

The algorithm of Vincenty's inverse method:

1. **Included:** φ_1, φ_2, λ_1, λ_2, H input parameters. {φ_1, φ_2 – geodesic latitude, λ_1, λ_2 – geodesic longitude, H - aircraft altitude}.
2. **Included:** a1, b1, ε {Earth ellipsoid major and minor radius and calculating error }
3. **Calculates**:
   a=a1+H; b=b1+H;
   f = (a−b)/a; {flattening}
   $L = \lambda_1 - \lambda_2$; {longitude difference}
   U_1 = atan((1−f) · tanφ_1);
   U_2 = atan((1−f) · tanφ_2);
   λ = L; {first approximation}
4. **Beginning of the period**
5. **Calculates:**
   $\sin\sigma = \sqrt{(\cos U_2 \cdot \sin\lambda)^2 + (\cos U_1 \cdot \sin U_2 - \sin U_1 \cdot \cos U_2 \cdot \cos\lambda)^2}$
   $\cos\sigma = \sin U_1 \cdot \sin U_2 + \cos U_1 \cdot \cos U_2 \cdot \cos\lambda$;
   σ = atan2(sinσ, cosσ);
   $\sin\alpha = \cos U_1 \cdot \cos U_2 \cdot \sin\lambda / \sin\sigma$;
   $\cos^2\alpha = 1 - \sin^2\alpha$;
   $\cos 2\sigma_m = \cos\sigma - 2 \cdot \sin U_1 \cdot \sin U_2 / \cos^2\alpha$;
   $C = f/16 \cdot \cos^2\alpha \cdot [4+f \cdot (4-3 \cdot \cos^2\alpha)]$;
   $\lambda' = L + (1-C) \cdot f \cdot \sin\alpha \cdot [\sigma + C \cdot \sin\sigma \cdot [\cos 2\sigma_m + C \cdot \cos\sigma \cdot (-1+2 \cdot \cos^2 2\sigma_m)]]$;
6. **End of the period**
7. **If** $(|\lambda' - \lambda| > \varepsilon)$ **then** accept $\lambda = \lambda'$ do step 5;
8. **Else**
9. **Calculates:**
   $u^2 = \cos^2\alpha \cdot (a^2 - b^2)/b^2$;
   $A = 1 + u^2/16384 \cdot [4096 + u^2 \cdot [-768 + u^2 \cdot (320 - 175 \cdot u^2)]]$;
   $B = u^2/1024 \cdot [256 + u^2 \cdot [-128 + u^2 \cdot (74 - 47 \cdot u^2)]]$;
   $\Delta\sigma = B \cdot \sin\sigma \cdot [\cos 2\sigma_m + B/4 \cdot [\cos \cdot (-1+2 \cdot \cos^2 2\sigma_m) - B/6 \cdot \cos 2\sigma_m \cdot (-3+4 \cdot \sin^2\sigma) \cdot (-3+4 \cdot \cos^2 2\sigma_m)]]$;
10. **Calculates output parameters:**
   $S = b \cdot A \cdot (\sigma - \Delta\sigma)$; {S – distance}
   α_1 = atan2($\cos U_2 \cdot \sin\lambda$, $\cos U_1 \cdot \sin U_2 - \sin U_1 \cdot \cos U_2 \cdot \cos\lambda$); {$\alpha_1$ – start azimuth}
   α_2 = atan2($\cos U_1 \cdot \sin\lambda$, $-\sin U_1 \cdot \cos U_2 + \cos U_1 \cdot \sin U_2 \cdot \cos\lambda$); {$\alpha_2$ – final azimuth}
11. **End of algorithm.**

Vincenty's direct method: Vincenty's direct method calculates final point coordinates and azimuth using start point coordinate and azimuth and distance between starting and final points.

The algorithm of Vincenty's direct method:

1. **Included:** φ_1, λ_1, H, S, α_1 input parameters {φ_1– geodesic latitude, λ_1 – geodesic longitude, H- aircraft altitude, S –geodesic distance, α_1 – start azimuth}.
2. **Included:** a1, b1, ε {Earth ellipsoid major and minor radius and calculating error }
3. **Calculates**:
   a=a1+H; b=b1+H;
   f = (a−b)/a; {flattening}
   $\tan U_1 = (1-f) \cdot \tan\varphi_1$;
   $\cos U_1 = 1/\sqrt{(1+\tan^2 U_1)}$;
   $\sin U_1 = \tan U_1 \cdot \cos U_1$;
   σ_1 = atan2($\tan U_1$, $\cos\alpha_1$);
   $\sin\alpha = \cos U_1 \cdot \sin\alpha_1$;
   $\cos^2\alpha = 1 - \sin^2\alpha$;
   $u^2 = \cos^2\alpha \cdot (a^2 - b^2)/b^2$;
   $A = 1 + u^2/16384 \cdot [4096 + u^2 \cdot [-768 + u^2 \cdot (320 - 175 \cdot u^2)]]$;
   $B = u^2/1024 \cdot [256 + u^2 \cdot [-128 + u^2 \cdot (74 - 47 \cdot u^2)]]$;
   $\sigma = s / b \cdot A$; {first approximation}
4. **Start of the period**
5. **Calculates:**
   $\cos 2\sigma_m = \cos(2 \cdot \sigma_1 + \sigma)$;
   $\Delta\sigma = B \cdot \sin\sigma \cdot [\cos 2\sigma_m + B/4 \cdot [\cos\sigma \cdot (-1+2 \cdot \cos^2 2\sigma_m) - B/6 \cdot \cos 2\sigma_m \cdot (-3+4 \cdot \sin^2\sigma) \cdot (-3+4 \cdot \cos^2 2\sigma_m)]]$;
   $\sigma' = \sigma$;
   $\sigma = s / b \cdot A + \Delta\sigma$;
6. **End of period**
7. **If** $(|\sigma - \sigma'| > \varepsilon)$ **then** do step 5.
8. **Else**
9. **Calculates output parameters:**
   φ_2 = atan2($\sin U_1 \cdot \cos\sigma + \cos U_1 \cdot \sin\sigma \cdot \cos\alpha_1$, $(1-f) \cdot \sqrt{[\sin^2\alpha + (\sin U_1 \cdot \sin\sigma - \cos U_1 \cdot \cos\sigma \cdot \cos\alpha_1)^2]}$);
   λ = atan2($\sin\sigma \cdot \sin\alpha_1$, $\cos U_1 \cdot \cos\sigma - \sin U_1 \cdot \sin\sigma \cdot \cos\alpha_1$);
   $C = f/16 \cdot \cos^2\alpha \cdot [4+f \cdot (4-3 \cdot \cos^2\alpha)]$;
   $L = \lambda - (1-C) \cdot f \cdot \sin\alpha \cdot [\sigma + C \cdot \sin\sigma \cdot [\cos 2\sigma_m + C \cdot \cos\sigma \cdot (-1+2 \cdot \cos^2 2\sigma_m)]]$;
   α_2 = atan2($\sin\alpha$, $-\sin U_1 \cdot \sin\sigma + \cos U_1 \cdot \cos\sigma \cdot \cos\alpha_1$) ;
   $\lambda_2 = \lambda_1 + L$;
10. **End of algorithm**

For using Vincenty's direct and Vincenty's inverse methods mark dependence of output parameters from input parameters for Vincenty inverse methods

$S = S_{Vi}(\varphi_1, \varphi_2, \lambda_1, \lambda_2, H)$; $\alpha_1 = \alpha_{Vi1}(\varphi_1, \varphi_2, \lambda_1, \lambda_2, H)$;
$\alpha_2 = \alpha_{Vi2}(\varphi_1, \varphi_2, \lambda_1, \lambda_2, H)$;

For Vincenty's direct method

$\varphi_2 = \varphi_{VD2}(\varphi_1, \lambda_1, H, S, \alpha_1)$; $\lambda_2 = \lambda_{VD2}(\varphi_1, \lambda_1, H, S, \alpha_1)$;
$\alpha_2 = \alpha_{VD2}(\varphi_1, \lambda_1, H, S, \alpha_1)$;

Aircraft conflict detection algorithm will be as follows:

Step1. Included: Coordinates of points $B1(\varphi_{B1}, \lambda_{B1})$, $B2(\varphi_{B2}, \lambda_{B2})$, $B3(\varphi_{B3}, \lambda_{B3})$, aircraft altitudes H_{A1}, H_{A2} and aircraft speeds V_{A1}, V_{A2} takes from flight plan; t_{A1}, t_{A2} aircraft entry time to the sector S;
t current time takes from accurate time system;
$\Delta t = 5$ sec {Requirement updates information for detection aircraft coordinates maximum 5 second for flight aerodrome zone and maximum 8 second for enroute flight [14], thus we fulfill calculations every 5 second.}

Step2. Calculates:

$\alpha_{B1} = \alpha_{Vi1}(\varphi_{B1}, \varphi_{B2}, \lambda_{B1}, \lambda_{B2}, H_{A1})$,

$\alpha_{B3} = \alpha_{Vi1}(\varphi_{B3}, \varphi_{B2}, \lambda_{B3}, \lambda_{B2}, H_{A2})$

{ α_{B1} – azimuth for flying from point B1 to point B2, α_{B3} – azimuth for flying from point B3 to point B2 }.

n=0 {initial value of calculation step number for aircraft A1},

$\varphi_{A1n} = \varphi_{B1}, \lambda_{A1n} = \lambda_{B1}$ {start coordinates for aircraft A1}

$\alpha_{A1n} = \alpha_{B1}$ {start azimuth for aircraft A1}

m=0 {initial value of calculation step number for aircraft A2}

$\varphi_{A2n} = \varphi_{B3}, \lambda_{A2n} = \lambda_{B3}$ {start coordinates for aircraft A2}

$\alpha_{A2n} = \alpha_{B3}$ {start azimuth for aircraft A2}

k=1 {initial value for forecast time step number}

$t_{pk} = t$ {initial value of forecast time taken equal the current time}

Step3. Start the period.

Step4. If $(t_{A1} \le t_{pk})$ **then** {this statement shows that the aircraft A1 is entered sector S or not}

[$g_{A1} = 1$; Do step5 ;] { g_{A1} - indicator aircraft A1 coordinate calculations}

Else [$g_{A1} = 0$; Do step 7 ;]

Step5. n=n+1; $S_{A1(n-1)A1n} = V \cdot \Delta t$; {aircraft A1 flight distance during the Δt time}

Step6. Calculates: {calculates coordinates and azimuth for aircraft A1 in time t_{pk} }

$\varphi_{A1n} = \varphi_{VD2}(\varphi_{A1(n-1)}, \lambda_{A1(n-1)}, H_{A1}, S_{A1(n-1)A1n}, \alpha_{A1(n-1)})$;

$\lambda_{A1n} = \lambda_{VD2}(\varphi_{A1(n-1)}, \lambda_{A1(n-1)}, H_{A1}, S_{A1(n-1)A1n}, \alpha_{A1(n-1)})$;

$\alpha_{A1n} = \alpha_{VD2}(\varphi_{A1(n-1)}, \lambda_{A1(n-1)}, H_{A1}, S_{A1(n-1)A1n}, \alpha_{A1(n-1)})$;

Step7. If $(t_{A2} \le t_{pk})$ **then** {this statement shows that the aircraft A2 is entered sector S or not}

[$g_{A2} = 1$; Do step 8;] { g_{A2} - indicator aircraft A2 coordinate calculations}

Else [$g_{A2} = 0$; Do step 10;]

Step8. m=m+1; $S_{A2(m-1)A2m} = V \cdot \Delta t$; {aircraft A2 flight distance during the Δt time}

Step9.Calculates: {calculates coordinates and azimuth for aircraft A2 in time t_{pk} }

$\varphi_{A2m} = \varphi_{VD2}(\varphi_{A2(m-1)}, \lambda_{A2(m-1)}, H_{A2}, S_{A2(m-1)A2m}, \alpha_{A2(m-1)})$;

$\lambda_{A2m} = \lambda_{VD2}(\varphi_{A2(m-1)}, \lambda_{A2(m-1)}, H_{A2}, S_{A2(m-1)A2m}, \alpha_{A2(m-1)})$;

$\alpha_{A2m} = \alpha_{VD2}(\varphi_{A2(m-1)}, \lambda_{A2(m-1)}, H_{A2}, S_{A2(m-1)A2m}, \alpha_{A2(m-1)})$;

Step10. If $((g_{A1} = 1) and (g_{A2} = 1))$ **then** do step 11;

Else do step 13;

Step 11. If $(|H_{A1} - H_{A2}| < H_l)$ **then** {If altitude difference between aircrafts is low allowable limit} do step 12;

Else do step 13;

Step 12. Calculates:

$S_{A1A2} = S_{Vi}(\varphi_{A1n}, \varphi_{A2m}, \lambda_{A1n}, \lambda_{A2m}, H_{A1})$;

{Calculates distance between A1 and A2 aircraft. During the calculations for altitude value we can take aircraft A1 altitude or aircraft A2 altitude because this calculations after step 12 and altitude difference between aircrafts is negligible.}

If $(S_{A1A2} < S_l)$ **then [**Given the conflict warning between aircraft A1 and A2 after t_{pk} time]

Else do step 13;

Step13. $k = k + 1$, $t_{pk} = t_{p(k-1)} + \Delta t$;

Step14. If $(t_{pk} - t \ge 20 \text{ min})$ **then** end of period;

Else do step 3.

III. EXPERIMENTAL RESULTS

This article provides an algorithm for aircraft conflict detection based on flight plans using the Vincenty formula. The experimental results are given in Figure 2 and Table1 using the Delphi programming language [15, 16]. In the program the input parameters, point B1 (LatB1 and LonB1), point B2(LatB2 and LonB2), and point B3(LatB3, LonB3) are the geographical coordinates (degree); tA1 and tA2 are entry times in to sector S (hour:min:sec) for aircrafts A1 and A2; HA1 and HA2 are altitude (meter) for aircrafts A1 and A2; VA1 and VA2 are speeds (meter/sec) for aircrafts A1 and A2; Delta t is the calculation step(sec); and Current t is the current time (hour:min:sec). During the calculations, a1=6378137m (semi-major axis), b1=6356752m (semi-minor axis) [17]; and $\varepsilon = 1E-10$ (meter). Output parameters LatA1, LonA1, and DisA1 are aircraft A1's geographical coordinates and flying distance; LatA2, LonA2, and DisA2 are aircraft A2's geographical coordinates and flying distance. It is possible to improve the conflict detection algorithm by including all fixed points for the aircraft and increasing accuracy by calculating aircraft coordinates using radar information.

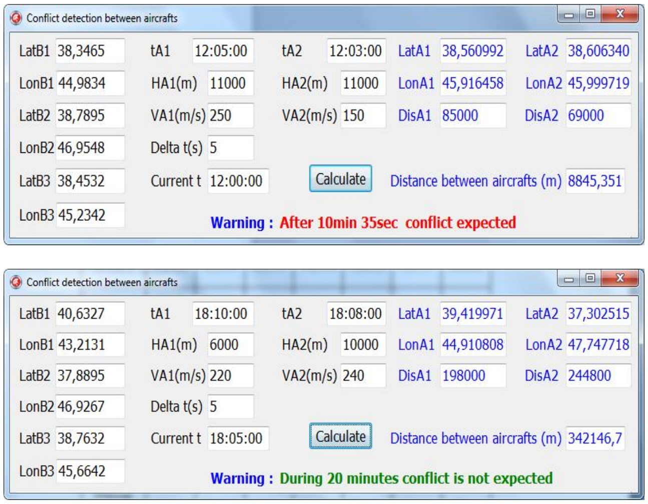

Fig 2 Simulation results.

	1	2	3	4	5	6	7
LatB1(°)	38,3465	38,9465	39,1327	40,6327	39,0865	12,0865	23,4535
LonB1(°)	44,9834	45,0231	45,2131	43,2131	44,9834	14,8249	29,3449
LatB2(°)	38,7895	38,7895	37,8895	37,8895	38,7895	13,8105	22,4498
LonB2(°)	46,9548	46,4567	46,9267	46,9267	46,9548	15,5532	31,5532
LatB3(°)	38,4532	38,2532	38,7632	38,7632	38,4532	11,4614	21,4614
LonB3(°)	45,2342	46,2342	45,6642	45,6642	45,2342	15,1142	30,1142
tA1(time)	12:05:00	15:35:00	10:29:00	18:10:00	00:25:00	17:28:00	21:56:00
tA2(time)	12:03:00	15:43:30	10:32:30	18:08:00	00:23:00	17:31:00	22:01:00
HA1(m)	11000	8000	8000	6000	11000	6000	10000
HA2(m)	10900	11000	8100	10000	11000	6100	10100
VA1(m/sec)	250	230	220	220	120	160	260
VA2(m/sec)	150	190	200	240	150	215	230
Current t (time)	12:00:00	15:40:00	10:30:00	18:05:00	00:30:00	17:30:00	21:58:00
LatA1(°)	38,5609	38,5790	37,9719	39,4199	38,8436	13,6283	22,4779
LonA1(°)	45,9164	48,1599	46,8159	44,9108	46,6126	15,4757	31,4926
DistA1(m)	85000	276000	190300	198000	144000	184800	245700
LatA2(°)	38,6063	39,8600	37,9142	37,3025	38,8421	13,5525	22,4023
LonA2(°)	45,9997	46,9116	46,8916	47,7477	47,2379	15,5045	31,4832
DistA2(m)	69000	188100	143000	244800	180000	235425	175950
Dist. 2 aircraft(m)	8846	178754	9248	342146	54379	8956	8435
Conflict situation	After 10min 35sec	Not expected	After 14min 20sec	Not expected	Not expected	After 19min 10sec	After 15min 40sec

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