The Research and Development of the Key Technologies for Runway Intrusion System

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Abstract. With the rapid development of the aviation market and the capacity limitations of aviation systems, runway intrusion has received increasing attention from the aviation community. Through the analysis of the possibility of runway incursions during the operation of Wuhan Tianhe International Airport, an algorithm for effectively preventing runway intrusion has been studied. Aiming at the many influencing factors of runway incursion, an improved runway intrusion algorithm has been proposed. Improved runway intrusion algorithm, applying flight performance and planning related knowledge to establish mathematical model, the physical properties of aircraft, such as type, wake, braking time, braking time after braking, as well as conflicting multiple zones, the slope of runway, pilot judgment reaction time, etc., these factors are all included in the consideration, so that the accuracy can be improved by setting different speed functions for different models. The simulation of the operation of the aircraft at Wuhan Tianhe International Airport has been carried out. The simulation results show that the model can give the alarm of runway intrusion and the reasonable solutions in time, which can effectively provide the assistants with decision-making.

1. Preface
In recent years, China's civil aviation has developed rapidly. The number of civil aviation flights is growing at a rate of nearly 20% per year, and the airport is getting more and more busy. Solving the problem of runway incursions has become a top priority for civil aviation in China. Runway [1] is the bottleneck of airport traffic. With the large increase in the number of aircrafts at various airports, the problem of runway intrusion has become more and more serious, and the research and application of runway intrusion prevention systems has become more and more extensive. In order to solve the problem of runway intrusion, domestic and foreign flight safety organizations have done a lot of research. Since China introduced the concept in 2003, it started late. At this stage, most airports rely on the introduction of runway usage specifications and controller operation guidelines to regulate operations and processes. At present, China's research on runway incursion mainly starts from analyzing the causes of runway incursions [2-4], technical means [5-6], risk assessment [7-8] etc, the algorithm research on runway intrusion detection is not very deep.

In this paper, an improved runway intrusion algorithm is proposed for the influencing factors of runway incursion. Improved runway intrusion algorithm, applying flight
performance and planning related knowledge to establish mathematical model, physical properties such as aircraft type, wake, braking time, braking time after braking, as well as conflicting multiple zones, runway slope, pilot judgment reaction time, etc. The factors are included in the consideration, so that the accuracy can be improved by setting different speed functions for different models. At the same time, the simulation experiment was carried out by taking the operation of the aircraft at Wuhan Tianhe International Airport as an example. The simulation results show that the model can give the runway intrusion alarm and reasonable solution in time, and can effectively provide the assistants with decision-making.

2. Runway incursion problem

2.1. Runway intrusion definition

According to the ICAO definition, runway incursions refer to the intrusion of any aircraft, vehicle or person at an airport into a ground protected area designated for aircraft landing and take-off [9].

According to the FAA definition, runway intrusion means any occurrence on the runway and its scope, an event in which a certain aircraft, ground vehicle, personnel and ground obstacles collide with a landing/lowering aircraft or an aircraft intended to start/drop or cause a minimum safety interval to be lost [9].

2.2. Division of the risk level of runway incurs by the International Civil Aviation Organization

International research on runway incursions has been carried out internationally and necessary measures have been taken to not only strengthen the education of relevant personnel, but also accelerate the research and development of various equipment and related technical means. According to the relevant regulations of the International Civil Aviation Organization and the Federal Aviation Administration, the runway incursion hazard level can be divided into five levels, A, B, C, D and E, as shown in Table 1 [10]. The classification of runway intrusion severity is shown in Figure 1.

| Levels of danger | International civil aviation organization |
|------------------|------------------------------------------|
| Class A          | A very serious incident in which reluctance to avoid collisions. |
| Class B          | A larger event in which the interval is reduced and there is a high probability of collision, which may result in an emergency correction/escape response to avoid collisions. |
| Class C          | A very small event, characterized by plenty of time and/or distance to avoid collisions. |
| Class D          | The event conforms to the definition of run-to-intrusion, for example, a single vehicle/person/aircraft erroneously appears in the ground protection zone designated for landing and take-off aircraft, but without direct safety consequences. |
| Class E          | Severity assessment is not possible due to insufficient information, inconclusive or contradictory evidence. |
2.3. Factors affecting runway incursions

(1) Physical properties of the aircraft

In previous studies, aircraft were often studied as a mass point. In fact, when a conflict occurs, the aircraft is a real object with a certain volume, and its wings, fuselage and other factors play a certain role in the occurrence of conflict. The role of simply using the aircraft as a particle not only weakens the role of these related factors in the research, but also increases the error in the study, thus affecting the system to make a correct judgment. Therefore, the various physical properties (type, volume, wake and speed, etc.) of the aircraft are taken into consideration.

(2) Operational reality factors

More realistic factors (safety margins) are included in the considerations of previous studies, such as: radar error, aircraft type, interval time, system operation processing time, braking time, braking time after braking, pilot Judgment reaction time and pilot operation time, conflict zone, runway slope, etc.

(3) Conflict resolution

In the event of a runway incursion, the crew on the aircraft does not know the speed of the other aircraft or even the measures taken by the other party to resolve the conflict, so the avoidance of both sides is blind. In the case that the two aircraft could not communicate with each other, the two crews could hardly avoid conflicts or even collisions. Therefore, through the improvement of the algorithm, the system can give the advice of avoiding both the intruding aircraft and the normal running aircraft through calculation, so that the intruding aircraft and the normal running aircraft can get clear instructions, thereby avoiding the blind manipulation of the crew when the intrusion occurs.

3. Research on key technologies of runway intrusion system

3.1. Establishment of mathematical model

If an aircraft is on the ground and the aircraft is ready to take off over the taxiway waiting position into the runway intrusion detection zone, the system begins a collision detection of the aircraft as it enters the detection zone. Only aircraft located near the boundary of the
runway intrusion detection area are considered “potentially invading aircraft”. The system detects the speed of the potentially invading aircraft at the aircraft that is about to reach the taxiway waiting position. The algorithm filters out outliers through the filtering module and uses the correct and valid data to simulate the aircraft speed. The collision detection of the aircraft is not stopped until the aircraft leaves the ground or leaves the runway intrusion detection area.

First, according to the takeoff run distance $s_3$ and the takeoff taxi time $t_3$ of each aircraft, the "s-t function coefficient $a_i$" corresponding to each aircraft is calculated by the formula (1).

$$ S_i = a_i \cdot t_3^{\frac{3}{2}} $$

(1)

Then, according to the average taxi speed $v_{4i}$ of each aircraft on the taxiway and the time $t_{4i}$ required for the maximum efficiency brake, the "brake v-t function coefficient $b_i$" corresponding to each aircraft is calculated by the formula (2).

$$ b_i = \frac{v_{4i}}{t_{4i}} $$

(2)

Finally, according to the take-off taxi time $t_3$ in the formula (1), the time $t_4$ required for the airplane to reach the taxiway is calculated by the formula (3).

$$ t_i = t_3 + \frac{3.6L_i}{V_i} $$

(3)

Where $V_i$ is the "average taxi speed $v_{4i}$ (m/s) on the taxiway" of the intruding aircraft and $L_i$ is the length of the taxiway.
3.2. Runway intrusion detection process

![Runway Intrusion Detection Flow Chart]

Figure 2. Runway intrusion detection flow chart.

Where \( h_i \) is the “maximum efficiency braking time \( t_{i1} \)” of the intruding aircraft; \( V_i \) is the “average taxiing speed \( v_{i1} \) (m/s) on the taxiway”; \( B_i \) is the “brake \( v-t \) function coefficient \( b_i \)” of the intruding aircraft; \( L_i \) For the taxiway where the intruding aircraft is located (for example, if it is on taxiway \( a \), it is marked as \( L_a \)); \( h_s \) is the "maximum efficiency brake time required for normal operation aircraft \( t_{s1} \)”; \( V_s \) is the average taxi on the taxiway for normal operation aircraft Speed \( v_{s1} \) (m/s)”; \( B_s \) is the "brake \( v-t \) function coefficient \( b_s \)” of the normal operating aircraft; \( A \) is the \( s-t \) function coefficient \( a_s \) of the normal operating aircraft.

The runway intrusion detection flow chart is shown in Figure 2. When a normally functioning aircraft enters the runway, there is a tendency for runway incursions to occur once the aircraft is about to cross the taxiway waiting position. If the system operation results in less than a safe interval between the trajectory of the normally operating aircraft and the potentially invading aircraft, then the conclusion is “consistent with the runway incursion”, and the system issues the alarm information at this time and gives the controller a proper avoidance suggestion.
4. Simulation experiment

4.1. Simulation data and environment
The simulation data used in this paper uses part of the aircraft data operated by Wuhan Tianhe International Airport, as shown in Table 2. The implementation of this algorithm uses Java programming language, combined with mysql database, to verify the simulation.

Table 2. Partial data of some aircraft operated by Wuhan Tianhe International Airport.

| Number | 1   | 2   | 3   | 4   | 5   | 6   | 7   |
|--------|-----|-----|-----|-----|-----|-----|-----|
| Aircraft Type | ERJ-190 | B737 | B747 | A320 | A321 | A330 | A380 |
| Wingspan (m)    | 28.72 | 28.9 | 64.4 | 34.09 | 34.1 | 60.3 | 79.8 |
| Apron           | Apron1, 2, 3, 5 | Apron1, 2, 3, 5 | Apron1, 2, 5 | Apron1, 2, 5 | Apron1, 2, 5 | Apron1 |
| Taxiway         | C1, D2, P3, P9 | C1, D2, P3, P9 | P9 | C1, D2, P3, P9 | C1, D2, P3, P9 | P9 | P9 |
| Takeoff run distance s_{3i}(m) | 2305 | 1950 | 2900 | 1850 | 1850 | 2990 | 2800 |
| Takeoff taxi time t_{3i}(s)    | 38 | 32 | 45 | 31 | 31 | 50 | 47 |
| Average taxi speed on the taxiway v_{4i} (m/s) | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| Maximum efficiency brake time t_{4i} | 4.5 | 4 | 10 | 5 | 5.5 | 7 | 12 |

4.2. Analysis of simulation results
The setting of the runway of Wuhan Tianhe International Airport is shown in Figure 3.

![Figure 3. Wuhan Tianhe International Airport Runway Setting.](image)

According to the flow of the runway intrusion detection process (Fig. 2), the algorithm calculates the “s-t function coefficient a_{i}” and “brake v-t function coefficient b_{i}” corresponding to each aircraft through the corresponding formula until the end of the algorithm. Where L represents the length of the taxiway and L varies with the taxiway. The distance between a solid red line on the runway in Figure 4 and the orange short line on the
taxiway is the set value of the radar error. For example, when the radar error is set to 20m, the red line is a distance below the orange short line on the taxiway, as shown in Figure 3.

![Figure 4](image)

**Figure 4.** Shows the display when the radar error is 20m.

Where,

\[ L_a = L_c = L_e = L_f = (150 + 20)m \]
\[ L_b = L_d = \sqrt{2}L_a = 240m \]

\( L_a, L_b, L_c, L_d, L_e, \) and \( L_f \) represent the lengths of the taxiways a, b, c, d, e, and f, respectively, as shown in Figure 3.

In this simulation, a B747 takes off and a runway incursion occurs at random time \( t \) (this time \( t=38s \)). At this point, the routes of the two aircrafts cross conflict, and the type of aircraft invaded at this time is A320. In the process of radar detecting potential intruding aircraft and performing functions, the alarms and conflict relief measures given after the operation are shown in Figure 5.

![Figure 5](image)

**Figure 5.** Alarm and conflict resolution interface.

5. **Summary**

As flight traffic increases, incentives such as capacity expansion and expansion of various airports and the surge in environmental pressure from controllers have led to an increase in the risk of runway incursions, which is a serious threat to flight safety. The algorithm proposed in this paper to improve the runway intrusion has higher efficiency and obvious advantages. The simulation test shows that the algorithm can detect the intrusion alarm of the airport scene in time, reduce the controller's workload properly, and give the controllers the conflict resolution guide to increase the safety margin of the runway. There is a good push to reduce or avoid aircraft intrusion events in the runway intrusion detection area and improve the operational efficiency of the airport.
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