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Performance Visualization Method of Air Traffic Control Tasks for Educational Purpose with Utilizing Cognitive System Simulation

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In the dynamic and multi-task condition of air traffic control, an Air Traffic Controller (ATCO) must utilize effective strategies to control traffic to prevent potential collision of aircraft and also to reduce his cognitive workload. Therefore, the strategy building skill of an ATCO is quite important for aviation safety and efficiency. In the present research, for supporting education of strategy building, a function which can visualize the difference of task performance has been implemented into the Air Traffic Controller Cognitive Simulation (ATCCS). Using this function, the effect of ATCO’s control on air traffic flow has been successfully visualized, which helps trainee to understand the differences of the consequences of the different strategy. This result has strongly implied that ATCCS equipped with performance visualization function can be utilized as a supporting tool for education of ATCO trainees.

It is strongly required to achieve higher level of safety in aviation along with the rapid increase of the demand in air traffic recent years. The human factors in Air Traffic Control (ATC) area are one of the most important issues to be tackled for enhancing aviation safety.

The ATC tasks are characterized by multiple tasks under the time-pressure condition. ATCOs are sometimes required to control over 10 aircrafts which have multiple performance and different demands at the same time. It means that the task environment of ATC essentially involves potential causes of human errors such as cognitive overload and inappropriate attention allocation. However, our previous research of cognitive task analysis for ATCOs (Inoue, K. et.al. 2006, Inoue, S. et.al. 2005) has revealed that they have typical skill to develop effective air traffic strategies which can prevent potential conflict of aircraft well in advance and also can reduce their cognitive workload. Such strategy building skill of
ATCOs is definitely important for enhancing safety in the heavy traffic condition. Based on such recognition, our research group has explored possible application of computer simulation as a supporting tool for acquiring strategy building skill in the basic training process of ATCO by visualizing the possible consequences of various task plans. In the ATC area, Fast Time Simulations (FTS) have already been utilized as an effective supporting tool for prediction of ATCO’s workload and also for evaluation of airspace design. However, as conventional FTSs have mainly focused on generating discrete ATC events, their problem solving strategy tends to be somewhat different from that of human controllers in a specific situation. That is because the cognitive processes concerning the decision making by ATCOs have not been modeled properly in those conventional FTSs. Therefore, conventional FTSs have not been capable of being utilized for educational purposes. In our opinion, further elaboration of FTSs is definitely required in order to realize the realistic computer based simulation for the initial education of ATCOs.

In the present study, the cognitive system simulation including the detailed cognitive model of ATCO called Air Traffic Controller Cognitive Simulation (ATCCS) has been developed, which has been designed based on the results of cognitive task analyses of an ATCO performed with the help of ATCOs working regularly. The implementation of prototype supporting function for educational purpose and results of its preliminary evaluation are described in this paper.

Air Traffic Controller Cognitive Simulation (ATCCS)

Major Characteristics of ATCCS

The major characteristics of the proposed simulation framework are described in the following:

*Uncertainty.* According to the interviews with ATCOs conducted by our research group, uncertainty of an air situation is an important factor affecting ATCO’s cognitive strategy and workload. In

![Fig.1 Basic Structure of ATCCS](image1)

![Fig.2 Cognitive Process of Simulated ATCO](image2)
our ATCCS, the uncertainly concerning the future situation of aircraft (e.g. future trajectory and flight path of aircrafts, time delay of pilot’s reaction to ATCO’s instruction) has been taken into consideration. The proposed ATCCS can simulate ATCOs’ behavior when future situation cannot be determined exactly, which requires the extensive monitoring and the adjustment of strategies by the simulated ATCO according to the ongoing situation.

**Bounded rationality.** Cognitive activity of ATCO in the ATCCS is limited by multiple cognitive resources based on Wickens’s theory (Wickens, C. D. et.al. 1984); they are visual, auditory, cognitive and motor resources. In addition, ATCO in the ATCCS has the Internal Situation Model (ISM), which is separated from the Actual Situation Model (ASM). The ISM represents ATCO’s situation awareness, which may differ from the actual situation. In other words, it is ATCO’s mental representation concerning task environment involving temporal and spatial aspects. On the other hands, the ASM represents situation of the actual world. ATCO’s actions are determined based on the ISM which needs to be updated by information acquisition from the Radar Data Processing Unit (RDP) Model or predictions based on obtained external information and ATCO’s inherent knowledge. This architecture realizes a simulation taking the model of bounded rationality into consideration. It also enables ATCCS to simulate the situation in which chain of errors occurs resulting from the discrepancy between ISM and ASM caused by erroneous recognition of a parameter and inappropriate attention allocation.

**Schematic knowledge.** Our previous research has revealed that ATCOs have schematic knowledge defined as “routine” involving dynamic descriptions of typical situations which can serve as a significant basis for comprehension and prediction of situations (Inoue, S. et.al. 2005). It has also indicated that routines involve the packages of heuristics to handle the situations effectively. The routines represented in the developed ATCCS provide necessary knowledge for developing three-dimensional flight image in objective sector based on the destination and route of the focused aircraft. The routine is also utilized to detect and recognize related aircrafts among the number of aircrafts in the sector.

**Basic Cognitive Process of Simulated ATCO**

Cognitive Process of Simulated ATCO has been designed based on a cognitive process model of ATCOs constructed with the help of ATCO in our group working regularly. Fig.2 shows simple overview of the cognitive process of the simulated ATCO. In the ATCCS, ATCO’s cognitive functions are implemented as an assembly of various agents. Each agent has a specific cognitive function such as information acquisition from a radar screen, execution of communication with a pilot, storing a schematic knowledge, and so on. Those agents activate each other, and the activation levels of agents determine the overall behavior of the simulated ATCO.
Table 1  Definition of Task Levels  (proposed by Aoyama, H. et al.)

<table>
<thead>
<tr>
<th>Task Level</th>
<th>Situation</th>
<th>Display Color in ATCCS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No necessity of providing instruction without any requests from a pilot</td>
<td>Green</td>
</tr>
<tr>
<td>2</td>
<td>Typical tasks such as setting intrail, changing altitude are existed</td>
<td>Yellow</td>
</tr>
<tr>
<td>3</td>
<td>Typical tasks and conflict resolution tasks are existed</td>
<td>Orange</td>
</tr>
<tr>
<td>4</td>
<td>Task level 2 or 3 + Time pressured situation</td>
<td>Red</td>
</tr>
</tbody>
</table>

Fig. 3  Scenario of Simulation Experiment

Visualization of Task Levels

For educational purposes, ATCCS has a visualization function of task levels which are defined by actual ATCO in our research group. The definition of task levels is shown in Table 1. The transition of task levels depends on the effectiveness of the applied strategy.

Implementation & Evaluation

The proposed ATCCS has been installed on the PC with using C++ language. For preliminary evaluation of proposed simulation, a numerical experiment has conducted based on scenarios in which simulated ATCO is required to provide descent clearance to specific aircraft with resolving conflicts among them so that each aircraft can accomplish its altitude target. In the simulation experiment, ATCCS could successfully simulate the typical behavior of human controllers in the similar situations (Karikawa et.al. 2008).

For evaluation of visualization function of task levels, additional simulation experiment based on the scenario described in Fig. 3 has been conducted. In this scenario, the simulated ATCO must
accomplish the requirement of altitude target of JAL542, which is 13000 feet at TLE. Two departure aircrafts, ANA573 and ANA736 must be also controlled so that they can reach their cruises altitudes within this sector. The original flight planned route of ANA 736 is shown by dashed-dotted line in Fig 3. However, in this case, it is ineffective to follow the original planned route because it can lead to confliction between descending JAL 542 and climbing ANA 736 near GOC. Therefore, human ATCOs often reroute aircraft in order to resolve the conflict effectively in such a situation. In this simulation experiment, two possible control strategies were given by an actual ATCO instructor. The strategy 1 is making ANA736 shortcut to the prior fix directly. The strategy 2 is to lead ANA736 to west by radar vector and then providing instruction to direct to the prior fix after crossing. Both strategies are for resolving the confliction between JAL 542 and ANA736 by crossing both aircraft at earlier stage. The consequences of these strategies have been visualized and compared by using ATCCS (Fig.5).

The result of the simulation has shown in Fig. 4 ~ Fig. 7. In the Fig. 4 and Fig. 5, the task levels are overlaid on the trail of each aircraft with color code. The Fig. 6 and Fig. 7 are time series graphs of task levels estimated by ATCCS. The result of the simulation has indicated that the strategy 1 has lead to continuous higher task levels due to another confliction between ANA 736 and ANA 573. On the other hands, strategy 2 could successfully resolve not only the confliction between ANA 736 and JAL 542 but
also the confliction between ANA 736 and ANA 573 by displacing crossing point to north where ANA 573 is certainly expected to reach enough high altitude to maintain vertical separation with ANA 736. The task level has been reduced in the earlier time frame when strategy 2 has been adopted. This result indicates that the strategy 2 has an advantage in terms of reducing possible risk of confliction although it requires one more instruction for radar vector. It can also contribute to reduce cognitive load of an ATCO to monitor and resolve conflicts.

Through the simulation experiment, the developed ATCCS could successfully visualize the effect of ATCO’s control on air traffic flow for different strategies which is consistent with the opinions of actual ATCOs. This function of the ATCCS can helps trainee to understand the differences of the consequences of the different strategy more effectively.

Conclusion

In the present study, a cognitive system simulation of an air traffic controller called the Air Traffic Controller Cognitive Simulation (ATCCS) has been developed based on the results of cognitive task analyses of an ATCO. The function visualizing the difference of task performance has been implemented into the ATCCS. Using this visualization function, the effect of ATCO’s control on air traffic flow has been successfully visualized. Although the development of this simulation framework is still underway, the result of the simulation experiment has strongly implied that ATCCS equipped with performance visualization function can be utilized as a supporting tool for education of ATCO trainees.

Reference


