On the correlations between air traffic and controller's eye movements

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Outline

1. Introduction
2. Method
3. Results
4. Conclusions
Air traffic controllers are the final decision-maker and executor in the ATM System. The behaviors of the controllers have directly impact on the system’s safety and efficiency.
Introduction

Controller

★ Workload
★ Cognitive activity
★ Communication
★ Eye movement

Traffic

★ Flow
★ Dynamic density
★ Intrinsic Complexity
★ Complexity map
This paper aims to examine whether controllers’ eye movement have relationships with air traffic activities.
Outline

1. Introduction
2. Method
3. Results
4. Conclusions
2 Method

- Metrics
- Correlation coefficients
- Simulations
Basic measurement units of eye movement behaviors

We Select 6 eye movements metrics and calculate directly from eye movements data:

- Mean number of Area of Interest (AOI)
- Mean fixation duration
- Mean saccadic velocity
- Mean pupil diameter of left eye
- Mean pupil diameter of right eye
- Mean blinking rate
Air traffic complexity has been extensively investigated during the last decades. Research focus has been given on the identification of the quantifiable complexity factors. Building upon the previous work, we select the following 23 traffic-related metrics to describe various traffic behaviors. All these metrics can be calculated from recorded traffic data:

- Number of aircraft
- Aircraft count divided by the capacity of the sector
- Total controlled kilometers
- Mean controlled kilometers
- Total controlled time
- Mean controlled time
<table>
<thead>
<tr>
<th>Method</th>
<th>Metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Basic measurement units of traffic behaviors</td>
</tr>
<tr>
<td></td>
<td>Number of climbing aircraft</td>
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<tr>
<td></td>
<td>Number of cruising aircraft</td>
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<td></td>
<td>Number of descending aircraft</td>
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<td></td>
<td>Total climbing time</td>
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<td></td>
<td>Total cruising time</td>
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<td></td>
<td>Total descending time</td>
</tr>
<tr>
<td></td>
<td>Number of aircraft with heading change greater than 15 degrees</td>
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<tr>
<td></td>
<td>Number of aircraft with speed change greater than 10 knots</td>
</tr>
<tr>
<td></td>
<td>Number of aircraft with altitude change greater than 750 feet</td>
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<tr>
<td></td>
<td>Mean velocity of aircraft</td>
</tr>
</tbody>
</table>
### Basic measurement units of traffic behaviors

- Number of aircraft pairs with 3-D Euclidean distance between 0-5 nautical miles excluding violations
- Number of aircraft pairs with 3-D Euclidean distance between 0-8 nautical miles excluding violations
- Number of aircraft pairs with 3-D Euclidean distance between 0-13 nautical miles excluding violations
- Minimal horizontal separation
- Minimal vertical separation
- Number of potential conflicts
- Minimal time-to-go to conflict
Method

Correlation coefficients

1

• Pearson correlation coefficient

2

• Spearman's rank correlation coefficient
**Method**

**Pearson correlation coefficient**

\[ \rho_{ij} = \frac{\sum_t (fe_i^j(t) - \bar{fe}_i^j(t))(fc_i^k(t) - \bar{fc}_i^k(t))}{\sqrt{\sum_t (fe_i^j(t) - \bar{fe}_i^j(t))^2} \sqrt{\sum_t (fc_i^k(t) - \bar{fc}_i^k(t))^2}} \]

- \( fe_i^j(t) \) represents the \( j^{th} \) eye movement measure value \( i^{th} \) of the participant at the \( t^{th} \) slot.
- \( fc_i^k(t) \) represents the \( k^{th} \) traffic metric value.

Assess linear relationships
Method

Spearman's rank correlation coefficient

- Rank the time series $X$ in ascending sort order: $X_i, i \in 1, 2, ..., n$
  and note their locations as $\text{Rank}_{x_{ij}}$.
- For the time series $Y$, do the same process and we get $\text{Rank}_{y_{ij}}$.
- The coefficient can be computed as

$$\rho = 1 - \frac{6 \sum_{i=1}^{n} d_i^2}{n^3 - n}$$

where $d_i = \text{Rank}_{x_{ij}} - \text{Rank}_{y_{ij}}$

The Spearman correlation is equal to the Pearson correlation between the rank values of those two variables.

Assess monotonic relationships (whether linear or not)
## Method

### Spearman's rank correlation coefficient

<table>
<thead>
<tr>
<th>X</th>
<th>Y</th>
<th>Rank X</th>
<th>Rank Y</th>
<th>$d_i$</th>
<th>$d_i^2$</th>
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</thead>
<tbody>
<tr>
<td>106</td>
<td>7</td>
<td>7</td>
<td>3</td>
<td>4</td>
<td>16</td>
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<tr>
<td>86</td>
<td>0</td>
<td>1</td>
<td>1</td>
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<td>0</td>
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<td>100</td>
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<td>7</td>
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<td>10</td>
<td>-5</td>
<td>25</td>
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<tr>
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<tr>
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<tr>
<td>110</td>
<td>17</td>
<td>8</td>
<td>5</td>
<td>3</td>
<td>9</td>
</tr>
</tbody>
</table>
Based on the working experience and personal competency, controllers are qualified into five classes.

<table>
<thead>
<tr>
<th>Levels of controllers</th>
<th>Number</th>
<th>Gender (Male/Female)</th>
<th>Age</th>
<th>Working experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level-Two</td>
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<td>33</td>
<td>12</td>
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<tr>
<td>Level-Three</td>
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<td>1/0</td>
<td>30</td>
<td>8</td>
</tr>
<tr>
<td>Level-Four</td>
<td>4</td>
<td>3/1</td>
<td>28-29</td>
<td>5-7</td>
</tr>
<tr>
<td>Level-Five</td>
<td>9</td>
<td>9/0</td>
<td>23-28</td>
<td>2-5</td>
</tr>
</tbody>
</table>

Total: 16 (15 males, 1 female)
Method

Apparatus

FaceLAB 5 by seeing machines, can record:

- Eye movement;
- Head position and rotation;
- Eyelid aperture;
- Pupil size.
Two levels of traffic scenarios are prepared based on the real schedule.

- **Normal**
  - Normal traffic, weather was good

- **Hard**
  - Normal traffic, serve weather

Every simulation exercise lasts about 20-30 minutes.
Method

Scenarios

➢ To investigate controllers eye movements, a **two weeks real-time simulations** were carried out in the radar simulation lab at NUAA in June, 2015.
➢ **Traffic data** were record by the simulation systems.
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Results

- We have calculated all the correlation coefficients (Pearson coefficient & Spearman's coefficient) between eye movements measures and traffic measures.
- According to the statistical results and controllers’ cognitive process, we focus on three categories of activities:
  - target tracking
  - conflict recognition
  - attention allocation
Results

- Not all the combinations of controller-traffic behavior have the regular correlation characteristics.
- One eye movement measure and two traffic metrics are closely correlated for most of controllers (>93%).
- The mean saccadic velocity is **positively** correlated with the mean velocity of the aircraft within the sector but has a **negative** correlation with the number of the aircraft.

(a) Mean saccadic velocity-mean velocity

(b) Mean saccadic velocity-the number of the aircraft
The mean saccadic velocity reflects the capability of controllers in dealing with tasks. If there are more aircraft in the sector, there will be more targets to be focused on by the controllers when monitoring the traffic situations; and they have to look at every flight, which will reduce the frequency of the controllers in switching the targets and thus reduces the saccadic velocity. Therefore, the mean saccadic velocity is in negative correlation with the number of the aircraft. If the mean velocity of the aircraft within the sector becomes faster, the evolution of traffic situation becomes faster. In order to adapt to the changing trend of the object spatially, controllers should also adjust the personal behaviors and improve the speed of monitoring targets. Therefore, the mean saccadic velocity is positively correlated with the mean velocity of the aircraft.
In the field of target tracking, Spearman's rank correlation presents a similar pattern from the same activity combinations.

Now we will provide a detailed description of correlations from the rest two aspects: conflict recognition and attention allocation.
The number of aircraft pairs with 3-D Euclidean distance between 0-5 nautical miles:

- positively correlated with mean fixation duration;
- positively correlated with the mean number of AOIs.

(a) Mean fixation duration

(b) The mean number of AOIs
A minimum of 10km should be maintained between any aircraft pairs. If there are more aircraft pairs with separation less than 5 nautical miles, there will be more potential conflicts in the sector. To resolve the potential conflicts, controllers will pay more attention to related aircraft.

When the number of the aircraft with separation less than 5 nautical miles increases, the difficulty for conflict resolution will also increase. Therefore, it is necessary to gather more information to resolve the conflict. And controllers will pay more attention to more AOIs.
Both mean pupil diameter and mean fixation duration are positively correlated with total controlled time;

(a) Mean left eye pupil diameter  
(b) Mean right eye pupil diameter
Both mean pupil diameter and mean fixation duration are positively correlated with total controlled time;

(c) Mean fixation duration-total controlled time
Mean Saccadic velocity is **negatively correlated** with total controlled time.

(d) Mean saccadic velocity-total controlled time
Air traffic controllers' eye movement metrics indicate the distributions of their attention. **Fatigue** can directly result in the dilation of left/right eye pupil. When the controlled time increases, controllers are more likely to feel tired and cannot be able to concentrate on the work. Therefore, the mean saccadic velocity will slow down, and mean fixation duration will increase. These results can be explained as the unreasonable allocation of attention.
1. Introduction
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**Conclusions**

**Contributions**

We do find that some of eye movements metrics have relationships with traffic activities.

- Mean saccadic velocity
- Mean fixation duration
- Mean number of AOIs
- Mean pupil diameter of left/right eye
- Mean velocity of the aircraft
- Number of the aircraft
- Total controlled time
- Number of aircraft pairs with distance between 0-5 nautical miles
Conclusions

Limitations and future research

- Individual difference should be further analyzed, such as control level, working experience.
- Investigate the effects of traffic scenarios on correlation coefficients.
Thank you!

Questions?