Tutorial on ATM & Automation

“HALA! Position paper: New Paradigm Shift in Automation in ATM”

Philippe Palanque
Professor University Toulouse III, France
palanque@irit.fr
Introduction

Initial Concepts

Paradigm Shift to Higher Automation Levels

Research directions

• Roles assignment
• Metaphors issues
• Design issues
• Implementation issues
• Dependability and Usability
Initial Concepts

**ATM** is just “all management activities devoted to reach an efficient flight trajectory for all airspace users”

Thus **automation** must be understood in this context as a “tool used to improve ATM related processes through the use of technology”
Clock example

• Counting minutes, second and hours difficult for human
  – Especially when they sleep
• A watch is of great help for that
  – Is this automation of a human task (no human has been doing that – counting springs, using sun, ...)
  – Is this an autonomous entity
Clock example

- Counting minutes, second and hours difficult for human
  - Especially when they sleep
- A watch is of great help for that
  - Is this automation of a human task (no human has been doing that – counting springs, using sun, ...)
  - Is this an autonomous entity
The Paradigm Shift

SESAR will help create a paradigm shift

1. Shift from Airspace–Based operation towards a Trajectory–Based operation concept.

2. Shift from Tactical Management towards a more Proactive system.

3. Shift from a controller-based system towards a more distributed system.
Roles Assignment

- First dimension: “BEST TIME” for decision making: Strategic vs. tactical planning layer.
- Second dimension: “DECISION PLACE”: Controlled vs. autonomy.
- Third dimension: “BEST PLAYER”: Human vs. automated player.
Best Decision Time (timetable)

Considering that the overall system performance is taken as the main driver to decide when the decision or event should be initiated:

- Will the overall system maintain the required stability under the decided “best time”? This is important, because in an evolving ATM system during the various stages of the planning, buffers and feedback loops are necessary to react on unexpected changes.

- What is the impact of uncertainties in a system when most decisions are taken a long time in advance? E.g. how can this system react on a late passenger? Would it become mandatory to act like those airlines which “won’t wait, if you’re late”?

- How can an adaptive system be designed where the degree of strategic decisions can be chosen, e.g. depending on uncertainty and/or others factors?

- Do the greater number of functions allocated at strategic planning layers imply more complex and rigid operational scenarios?

- Can ATM system deliver required safety and efficient when most of decisions are allocated at tactical level?
Best Decision Place (centric vs autonomous)

Considering that the overall system performance is taken as the main driver to decide where the decision or event should be initiated:

- What is the level of correlation between complexity and centric processes?
- What is the level of correlation between autonomy and centric process?
- To what extend are segregated airspace structures the solution to the questions of where and when to implement autonomy?
- Do tactical decisions imply autonomous and fully automated processes?
- Is high traffic density/complexity a key factor limiting autonomy?
- In which scenario (centric or autonomous) will automation provide higher overall system performance?
- Does strategic decision making imply centric scenarios?
Best Decision Player (human vs system)

Considering that the overall system performance is taken as the main driver to decide where the decision or event should be initiated:

- Should trajectory management (e.g. Trajectory deconfliction, even tactical decisions) be fully automated?
- To what extent do strategic decisions require human intervention?
- How can uncertainty be managed in automated systems?
- Are the current frameworks for automation, cognition and human factors enough to capture ATM singularities?
- Is a fully automated air transport system socially/psychologically acceptable?
- Can the ATM system be decomplexified through automation?
- How to deal with transition issues when implementing higher levels of automation?
- How can resilience be taken into account in automated systems design?
- Does uncertainty require human centred decision making?
The Horse Metaphor (input)

Figure 7 – Control with Reins (Miller, 1975)

Figure 8 – Stopping (Western Equestrian) (Miller, 1975)

NASA/TM—2003-212672

The H-Metaphor as a Guideline for Vehicle Automation and Interaction

Frank O. Flemisch
University Munich, Munich, Germany
Catherine A. Adams, Sheila R. Conway, Ken H. Goodrich, Michael T. Palmer, and Paul C. Schulte
Langley Research Center, Hampton, Virginia
A Controlable Horse (output)

Auditory Signals:
- Snort = warning sound
- Neigh or whinny = distress call
- Nicker = greeting
- Squeal = anger

Ears as visual signal:
- Anger (turned back and laid down)
- Interest (ears pointed forward, but body relaxed)
- Fear (ears pointed forward, body tense)
- Relaxation (ears at angle to the side)

Tail as visual signal:
- Kink (ready to run and play)
- Held high (play)
- Waiving (comfortable)

- Stallion or mating call
- Rolling sigh (soft) = pleasure, comfort
- Listening to rider (one ear forward, one ear back)
- Between legs (frightened)
- Switching (irritated)

Look at the ears, the body shape and the tail (not easy)!!
A Controlable Horse (output)

Auditory Signals:
- Snort = warning sound
- Neigh or whinny = distress call
- Nicker = greeting
- Squeal = anger

Ears as visual signal:
- Anger (turned back and laid down)
- Interest (ears pointed forward, but body relaxed)
- Fear (ears pointed forward, body tense)
- Relaxation (ears at angle to the side)

Tail as visual signal:
- Kink (ready to run and play)
- Held high (play)
- Waiving (comfortable)

Stallion or mating call
Rolling sigh (soft) = pleasure, comfort
Listening to rider (one ear forward, one ear back)
Between legs (frightened)
Switching (irritated)

Look at the ears, the body shape and the tail
Listen at the noise from horse
Fuse that information from different sources

(not easy)!!
A Controlable Horse (output)

Auditory Signals:
- Snort = warning sound
- Neigh or whinny = distress call
- Nicker = greeting
- Squeal = anger

Ears as visual signal:
- Anger (turned back and laid down)
- Interest (ears pointed forward, but relaxed)
- Fear (ears pointed forward, body tense)
- Relaxation (ears at angle to the side)

Tail as visual signal:
- Kink (ready to run and play)
- Held high (play)
- Waiving (comfortable)

Look at the ears, the body shape and the tail
Listen at the noise from horse
Fuse that information from different sources
(not easy)!!
<table>
<thead>
<tr>
<th>Characteristics of the interaction</th>
<th>Conventional vehicle (w/o control automation, e.g. 20th century car without cruise control)</th>
<th>Conventionally automated vehicle (e.g. 20th century commercial aircraft)</th>
<th>Horse / H-inspired vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Direction</strong></td>
<td>Mainly unidirectional</td>
<td>Mainly unidirectional, some bi-directional</td>
<td>Mainly bi-directional</td>
</tr>
<tr>
<td><strong>Coding</strong></td>
<td>Analog / spatial</td>
<td>Mostly linguistic /abstract Some analog / spatial</td>
<td>Mostly analog /spatial, Some linguistic /abstract</td>
</tr>
<tr>
<td><strong>Modality</strong></td>
<td>Multimodal with haptic component</td>
<td>Strong visual component, some multimodal aspects</td>
<td>Multimodal with strong haptic component</td>
</tr>
<tr>
<td><strong>Discrete or continuous?</strong></td>
<td>Mostly continuous input</td>
<td>More discrete input and output</td>
<td>Mix of continuous and discrete input / output</td>
</tr>
<tr>
<td><strong>Importance of visual modality for the guidance task</strong></td>
<td>High</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td><strong>Redundancy in the interaction</strong></td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td><strong>Negotiation of different wills</strong></td>
<td>None</td>
<td>Non-overt, brittle, &quot;either / or&quot; (automation will is more implicit)</td>
<td>Transparent, fluid (&quot;automation&quot; will is explicit)</td>
</tr>
<tr>
<td><strong>Who is in the physical loop, human and automation?</strong></td>
<td>Human (automation only in low level functions, e.g. a governor in a car)</td>
<td>Exclusive either/or for specific axes</td>
<td>&quot;Automation&quot; and human are in the loop simultaneously</td>
</tr>
</tbody>
</table>
# The Horse Metaphor

<table>
<thead>
<tr>
<th>Characteristics of the interaction</th>
<th>Vehicle class</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Conventional vehicle</strong> (w/o control automation, e.g. 20th century car without cruise control)</td>
<td><strong>Conventionally automated vehicle</strong> (e.g. 20th century commercial aircraft)</td>
<td><strong>Horse / H-inspired vehicle</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Direction</strong></td>
<td>Mainly unidirectional</td>
<td>Mainly unidirectional, some bi-directional</td>
<td>Mainly bi-directional</td>
<td></td>
</tr>
<tr>
<td><strong>Coding</strong></td>
<td>Analog / spatial</td>
<td>Mostly linguistic /abstract Some analog / spatial</td>
<td>Mostly analog Some visual</td>
<td></td>
</tr>
<tr>
<td><strong>Modality</strong></td>
<td>Multimodal with haptic component</td>
<td>Strong visual component some multimodal</td>
<td>Strong visual component</td>
<td></td>
</tr>
<tr>
<td><strong>Discrete or continuous?</strong></td>
<td>Mostly continuous input</td>
<td>and</td>
<td>Mix of continuous and discrete input / output</td>
<td></td>
</tr>
<tr>
<td><strong>Importance of visual modality</strong></td>
<td>High</td>
<td>Medium</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Reactivity</strong></td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
<td></td>
</tr>
<tr>
<td><strong>Negotiation of different wills</strong></td>
<td>None</td>
<td>Non-overt, brittle, &quot;either / or&quot; (automation will is more implicit)</td>
<td>Transparent, fluid (&quot;automation&quot; will is explicit)</td>
<td></td>
</tr>
<tr>
<td><strong>Who is in the physical loop, human and automation?</strong></td>
<td>Human (automation only in low level functions, e.g. a governor in a car)</td>
<td>Exclusive either/or for specific axes</td>
<td>&quot;Automation&quot; and human are in the loop simultaneously</td>
<td></td>
</tr>
</tbody>
</table>
The Horse Metaphor
The Horse Metaphor
The Details of the Metaphors
The Details of the Metaphors

frightened horses make BAD decisions

A Road Safety Initiative of the Queensland Horse Council Inc.
www.qldhorsecouncil.com
The Details of the Metaphors
The number of papers on automation has been increasingly growing since 1954.
Number of papers on automation (2000 – 2011)

ACM Digital Library

42.845
Dependability Issues for Automation

• Things will degrade
  – Make sure they degrade gracefully

• Things will fail
  – Make sure they will fail safely

• Operations will carry on
  – Make sure they carry on with good performance
Faults and Failures

Adapted from: Avizienis, A., Laprie, J.-C., Randell, B., Landwehr, C. Basic concepts and taxonomy of dependable and secure computing. In IEEE Trans. on Dependable and Secure Computing, vol.1, no.1, pp. 11- 33, Jan.-March 2004
Adapted from: Avizienis, A., Laprie, J.-C., Randell, B., Landwehr, C. Basic concepts and taxonomy of dependable and secure computing. In IEEE Trans. on Dependable and Secure Computing, vol.1, no.1, pp. 11-33, Jan.-March 2004
Faults and Errors

Security

Development software faults (Issue 1)
Malicious faults (Issue 2)
Development hardware faults (Issue 3)
Operational natural faults (Issue 4)
Operational human errors (Issue 5)

Mal=Malicious  Del=Deliberate  Nat=Natural  Hdw=Hardware

Phase of occurrence
System boundaries
Genotype
Dimension
Objective
Intent

Non Malicious
Non Malicious
Non Malicious
Non Malicious
Non Malicious
Non Malicious
Non Malicious
Non Malicious
Non Malicious
Non Malicious
Non Malicious
Non Malicious
Non Malicious
Non Malicious
Non Malicious
Non Malicious
Non Malicious
Non Malicious

Non Del Del
Non Del Del
Non Del Del
Non Del Del
Non Del Del
Non Del Del
Non Del Del
Non Del Del
Non Del Del
Non Del Del
Non Del Del
Non Del Del
Non Del Del
Non Del Del
Non Del Del
Non Del Del
Non Del Del
Non Del Del

Reliability
Fault Tolerance
Interactive cockpits architecture

Example: the engagement of the auto-pilot through a click on the corresponding PicturePushButton
Functional Failures modes

Control flow failures

Display flow failures
The FCU

Airbus A380 Flight deck
The FCU Backup

Airbus A380 Flight deck
Usability issues in ATM

• The Human-System interaction does not exist

• Human-System interaction takes place using an interactive system
  – More complex than the other systems
  – Hardware/software integration
  – Rapidly evolving
Usability issues in ATM

- The Human-System interaction does not exist.
- Human-system interaction takes place using an interactive system.
  - More complex than the other systems.
  - Hardware/software integration.
  - Rapidly evolving usability issues in ATM.
Design Issues for Automation

Fig. 11. Testing lower bound.

\[ E|X| < 1 - \left( 1 - \frac{4m^{1/3}}{n} \right)^{\frac{1}{3} - \frac{1}{2}} \left( 1 - e^{-3^{-1/3} n^{1/3}} \right) \times \frac{64 \log n}{\log 3} \]

By Markov's inequality (and choosing a small enough \( \epsilon \)), the probability that \( \sum X_i \) exceeds 1 is less than 1/10. In the following, \( c_1 \) and \( c_2 \) denote some sufficiently large constant. Let \( Y_j \) be the indicator variable for the event that \( 0 \)-step falls within \( e^{-1/2} \), of either boundary of \( L \).

\[ E|Y_j| < 1 - \left( 1 - \frac{4m^{1/3}}{n} \right)^{\frac{1}{3} - \frac{1}{2}} \frac{8c_2}{\epsilon n^{1/3}} \]

\[ E \sum Y_j < 8e^{2/3} E|Y| < (10)3^{1/3} \]

Again by Markov's inequality, the probability that \( \sum Y_j \) exceeds \( 1/10 \) is less than 1/10. With probability at least 8/10, 0-steps by themselves did not detect a violation, and at most a 1/10 fraction of edges visited by 0-steps fall within \( e^{-1/2} \) of a stretch boundary. Assume that this happens. Any violation detected must involve an 1-step. With probability at most 1/10, \( e^{-1/2} \) of 1-steps were needed for detection. Since the total number of steps is \( e^{-1/2} \) of \( e^{-1/2} \), (a union bound shows that) the algorithm will fail with probability \( < 7/10 \).

We show that the filter for convexity (when the input is a linked list) is essentially optimal with respect to \( n \) (within log factors).

THEOREM 2.20. Any filter for 2-dimensional convexity requires \( \Omega(\sqrt{n}) \) lookups per query, where the input is given in a linked list format.

Proof. We prove a lower bound for the following problem - given \( P \) and an edge \( e \), output whether \( e \) is good or bad. If \( e \) is deemed bad, then a violating edge must be provided. All good edges must be in convex position, and the number of edges deemed

violate convexity with \( S \). Since there are \( O(k \log k) \) Voronoi cells, the total number of queries which are not in convex position with the stack are \( c_1 \log n \). All the remaining edges are in convex position with each other. This constant \( c_1 \) is independent of \( c_2 \) in other words, we can make \( e_1 \) arbitrarily larger than \( c_1 \).

The filter guarantees to change at most \( c_2 \log n \) faces. Set \( c_2 \log n \approx c_2 \log n \approx c \cdot 2^p \). In this way, any edge that visits a triangle of \( P \) cannot return the triangle unchanged. Indeed, \( c_2 \log \), then the entire stack \( \tau \) of \( c_2 \log n \) triangles would later have to be modified, which would prove the filter invalid. Modifying the violating triangle of \( P \) appropriately requires knowing where \( (P_{\tau+1})_n \) is placed around the \( (P_{\tau+1})_n \) band, which takes \( O(\log n) \) expected time.

The aortic and higher values of \( \epsilon \) is quite straightforward. Essentially, the number of near-circular rings or near constant factors equal to \( c \). Fix some parameter \( m \). We choose a small number of polygons \( P_0, P_1, \ldots, P_n \) such that \( P_i \) has a constant number of vertices, \( P_i \) has \( \theta(\log n) \) vertices, and \( P_i \) has \( \theta(\log n) \) vertices (for some sufficiently large constant \( c \)). The outermost polygon \( P_0 \) is as before a slightly scaled up version of \( P_i \), and the polygon \( P_{i+1} \) consists of circles of subpolygons (as before) with stack size of \( c \cdot 2^p \). One of these sets is stacked to ensure that it violates the convexity of \( P_i \) but violates the convexity of \( P_i+1 \) subpolygons in each ring. The parameter \( m \) is chosen so that the total number of faces is \( \epsilon \). The distance to convexity is \( \epsilon \), using the same argument we can force a query for a common violating triangle in \( P_i \) to make a modification. For this, the total stack of subpolygons must be deleted, which take time \( O(\log n) \).

THEOREM 3.16. Any convexity filter for an arbitrary triangle \( P \) of \( k \) faces has a worst-case query time of \( O(\log n) \) for any such that \( (\log n) \approx \epsilon \).

REFERENCES


Thank You for Your Attention

“As for research, as long as there are things to find, nothing is really lost” – ICS philosophy