Extended abstract

Ecological Interface Design: Control Space Robustness in Future Trajectory-based Air Traffic Control Decision Support

The ongoing growth of air traffic worldwide is foreseen to exceed the capacity limits of the current Air Traffic Management (ATM) system within the coming decades. In order to facilitate this increasing demand, two large-scale international collaborative research efforts (SESAR in Europe and NextGen in the US) are focused on majorly overhauling the basic principles of how air traffic is controlled. A key pillar within both research projects is to transition from the current, hands on, form of tactical control towards highly precise time-based strategic airspace management. Rather than issuing discrete instructions by direct voice communication, the language between air traffic controllers and pilots will be that of automatically generated 4D-trajectories via digital data-link.

Although the success of such a system relies heavily upon the introduction of advanced automation and a new communication infrastructure there is a general consensus in operational communities that the human air traffic controller should remain in active control. That is, given that the stakes are high and that the work domain has too many unforeseen situations to allow for a fully automated solution, the human controller will have to retain the ultimate responsibility for the safety of operations. These responsibilities, together with the complexities of the new task, require the development of innovative controller decision support tools.

Scientific communities have been investigating constraint-based approaches to the design of decision support tools as a way to mitigate automation-related problems that have arisen in other complex socio-technical work domains (e.g., complacency, reduced vigilance, lack of trust). The rationale behind a constraint-based approach is to let the decision support tool provide the human with the set of functional constraints that bound a wide range of safe control actions rather than (a set of) explicit optimized solutions. It is foreseen that when such constraints are made directly visible on a human-machine interface, the human will be able to better understand, and directly act upon their work environment.

One commonly used visual form of constraint-based representations is to provide the human controller with a set of `go’ and `no-go’ areas within which any control action is valid to perform a certain task. In essence, all control actions are safe and good enough, whether optimal or suboptimal from a performance perspective, as long as they do not violate the functional constraints. This approach is formally known as Ecological Interface Design (EID) and is seen as more robust and resilient in coping with unanticipated system variability.

In previous research, and following the principles of EID, a constraint-based decision support tool has been developed for the task of strategic trajectory manipulation by air traffic control. Rather than presenting discrete solutions to the controller, the *Travel Space Representation* graphically represents the areas within the airspace through which an aircraft can be safely redirected. Control within this set of solutions guarantees a conflict free trajectory, and ensures that timing constraints of the aircraft at the sector exit point are met.

A human-in-the-loop experiment, however, demonstrated that when using this tool, controllers sometimes opted for solutions close to the boundaries of safe control, or for resolutions in narrow control spaces. Although such resolutions are valid, a small deviation of an aircraft from its path could rapidly evolve in an unsafe situation. Ironically, this would seem to contradict the claim that constraint-based representations are better to cope with system uncertainties.

In order to quantify and evaluate the robustness of control actions with the Travel Space Representation, a metric and two measures have been developed. The robustness metric quantifies the probability of a trajectory to remain feasible (i.e., to not violate separation constraints), despite a probabilistic deviation in the speed and heading of the aircraft. When this metric is evaluated over the trajectory, its *average* and *minimum* robustness can be quantified. The average measure of the metric provides a more global indication of the robustness of a trajectory, whereas the minimum robustness shows its bottleneck (e.g., the point least robust against disturbances).

A batch-analysis has been performed to investigate how these measures vary for a crossing pair of aircraft under various geometry. For this purpose, the crossing angle and closest point of approach between the aircraft was varied, and both passing in front and behind maneuvers were evaluated. Results from the analysis show that the geometry of a given conflict resolution strategy has a large effect on the resulting robustness of a trajectory. Further, although the current Travel Space Representation visualized safe and unsafe areas, it does not directly give insight to the controller into which solutions are more robust than others.

In a follow-up research, a more elaborate human-in-the-loop experiment was performed with participants with a different level of expertise. Here, the first group consisted of novice participants (PhD students from the TU Delft), the second group consisted of skilled participants (ATM R&D experts), and the third were operational experts (active air traffic controllers). The preliminary results from this experiment show that for all conditions (varying task load and complexity) the robustness of control actions with the Travel Space Representation mainly depended on the level of expertise of the controller. That is, although more robust solutions are not explicitly visualized in the constraint-based representation, controllers with a higher level of expertise were able to apply knowledge-based strategies and reasoning which resulted in more airspace-wide robust solutions. It can, therefore, be said that the effectiveness of ecological constraint-based representations depends largely on the expertise level and experience of the operator.

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