Force Feedback Input Devices in Three-Dimensional NextGen Cockpit Display

Isis Chong and Mei Ling Chan

California State University Long Beach
# Table of Contents

Executive Summary ................................................................................................................ 3

1. Introduction .......................................................................................................................... 4

2. Background ............................................................................................................................ 5

3. Method ..................................................................................................................................... 5

4. Recommendations ............................................................................................................... 5

   4.1 Repulsive Force ............................................................................................................................ 6

      4.1.1 Obstacle Handling ............................................................................................................................... 6

      4.1.2 Path Manipulation .............................................................................................................................. 7

   4.2 Attractive Force ......................................................................................................................... 7

      4.2.1 Target Handling ................................................................................................................................... 7

5. Limitations ............................................................................................................................. 8

6. Conclusion .............................................................................................................................. 8

7. References .............................................................................................................................. 9
Executive Summary

The authors of this document were assembled to research and evaluate force feedback from input devices and its possible use in the Cockpit Display of Traffic Information (CDTI).

After examination of current research, two types of force feedback that could potentially enhance pilot use of the CDTI were identified: repulsive force and attractive force. In comparison to other types of feedback, it was found that these forces could benefit pilots the most. Based on the authors’ findings, a three-pronged force feedback model for cockpit input device design is proposed as follows:

- Repulsive force
  - **Obstacle handling** where a repulsive force “pushes” the waypoint (created by pilots using the RAT) away from the original route if it comes too close to an obstacle along the route.
  - **Path manipulation** where a force “pushes back” a waypoint if it is too far away from the original path.

- Attractive force
  - **Target handling** that “pulls” an aircraft towards a target destination when it approaches the target.

With different forces providing haptic cues in addition to the traditional visual feedback in the CDTI, pilots would be able to better manage the cockpit environment and make decisions with greater ease. Force feedback in the CDTI may ultimately help solve some current air traffic problems and enable a more efficient and safer future in the air transportation system.
1. Introduction

This report was prepared to provide information for designers, engineers, and other knowledgeable professionals on the Cockpit Display of Traffic Information (CDTI). This task was assigned to the authors for the purposes of creating recommendations for Next Generation Air Transport System (NextGen) future cockpit input device design. Two papers were reviewed to serve this purpose and the task was carried out over the course of two weeks.

The currently in use three-dimensional CDTI provides visual feedback regarding the current air traffic and weather. This display allows pilots to assess their aircrafts' surrounding air space and assists pilots in decision-making during real time flight management. The Route Assessment Tool (RAT) in the CDTI allows pilots to manually create a waypoint and modify the original route by dragging the waypoint to a new highlighted path.

Due to the unstable nature of the cockpit environment, pilots may not be able to perform precise inputs and thus could create possible dangers that may affect the safety of aircrafts. Therefore, the CDTI should provide additional feedback that allows pilots to make more precise inputs and have better control over their aircraft.

This document highlights force feedback development in the CDTI and makes recommendations for bettering the current design for the future.

![Figure 1. Example of RAT in CDTI display showing path A as the original path and path B is the modified path with waypoint.](image-url)
2. Background

NextGen is a program that aims to upgrade and better the National Airspace System (NAS) by introducing tools to increase efficiency, reliability, and safety. With NextGen, pilots, air traffic controllers, and air carriers, amongst others, will have new tool sets at their disposal.

Using the RAT, pilots can change a flight plan by selecting a waypoint at another distance. Selecting a new waypoint, however, may increase overall flight distance and the likelihood of coming in conflict with nearby obstacles such as other aircrafts and severe weather conditions. (See Figure 1 for a depiction of the RAT in the CDTI.)

Studies in NextGen have shown that the implementation of a haptic input device such as the Novint Falcon may allow pilots to give more precise and efficient inputs. Force feedback input devices could serve as an indicator to provide additional haptic cues to pilots when it is difficult to see in the cockpit, such as during turbulence and the aircraft cannot maintain stability. Furthermore, haptic feedback may decrease overall head down time during new route selections.

The CDTI is a display that carries a wide array of information for pilots and its functionality should be continually improved to better air traffic efficiency and safety.

3. Method

Two papers on the utilities of force feedback were reviewed and analyzed to make proper recommendations on force feedback implementation. Advanced Cockpit Situation Display, a CDTI demo software developed by NASA, was also used as a reference to better understand the CDTI and its functions.

4. Recommendations

Given current research findings, we recommend that the design for future cockpit input devices should include a combination of different types of force feedback that allow the input devices to provide extra information to pilots, especially when it is difficult to see in the cockpit and the aircraft is experiencing turbulence and instability. Ideally, force feedback should be an indicator of the effort that will be required to deviate from the optimal path so that pilots are "pushed" away from possible problematic areas and "pulled" toward their goal destination.

To reach the aforementioned goal of achieving the best performance on the part of the pilot, we recommend a three-pronged force feedback model that includes (1) a repulsive force for obstacles, (2) a repulsive force for distance, and (3) an attractive force for targets. For the purposes of this document, the two former types of feedback are grouped together under repulsive force.
4.1 Repulsive Force

A small amount of repulsive force feedback (10 mN/pixel) should be applied to the CDTI input device design to help avoid both obstacles and lengthy trajectories. It has been found that force feedback can maintain a similar level of accuracy of a computer mouse in short distance movements (Park et al., 2013). Repulsive force feedback may decrease accuracy for longer movements and increase movement time as more force is applied when the path distance increases. By using only a small amount of force feedback, pilots will be able to receive information on his or her aircrafts’ surroundings, and will have higher ability to overcome the negative effects of the repulsive force. In other words pilots will ideally be able to extract information for the purposes of picking an optimal path without facing impediments to their performance.

4.1.1 Obstacle Handling

A reverse-type of gravitational pull, or repulsive force, should be used to avoid possible accidents when creating a new path. The force feedback provided by the input device would be able to cue and warn pilots if they moved the waypoint to a new path that risked an encounter with a nearby obstacle. For example, if a pilot selected a waypoint and dragged it to a new location, the repulsive force would “push” the waypoint away from the obstacle. In this way, the pilot would be discouraged from drawing a new path that could come too close to obstacles, such as another aircraft, and thus, a conflict free distance with nearby obstacles would be maintained. Refer to Figure 2 for a visual representation of the repulsive force that would be emitted from a conflict aircraft.

![Figure 2. The conflict aircraft (point X) would emit a repulsive force that would allow a pilot to select a more optimal path (path B) from the original path (path A). The area surrounding the conflict aircraft depicts the force feedback that would be emitted in its’ surrounding area.](image-url)
4.1.2 Path Manipulation

A repulsive force should be used as waypoint selection moves further away from a target and from its original path. It is necessary for pilots to receive feedback discouraging them from deciding upon a path that is far too great a distance. When such a path is selected, pilots decrease fuel and time efficiency. For this reason, pilots should receive feedback that prevents these costly errors (See Figure 3).

![Figure 3. The pilot would receive a repulsive force the further away he or she chose to travel. The arrows along path B depict the force feedback the pilot would receive from the modified path.](image)

4.2 Attractive Force

Across human computer interaction tasks, it has been found that attractive force reduces task completion times, error rates, and reported musculoskeletal discomfort (Rorie et al., 2013). When individuals perform simple tasks that require them to move toward a target on a screen shot of the CDTI, gravitational force has also been found to improve movement time (Rorie et al., 2013).

4.2.1 Target Handling

An attractive force should be implemented to encourage pilots when approaching an optimal path. As pilots move their aircraft closer to their target destination, they should receive force feedback in the form of a “pull.” As they approach the target, they will find that they move with greater ease through the airspace, as depicted in Figure 4.
Figure 4. The pilot would receive a repulsive force the closer he or she was to the target area. The arrows depict the force feedback the pilot would receive.

5. Limitations

Unlike the simulated figures shown above, the display of a pilot’s surrounding air space is neither simple nor free of clutter. With a growing number of aircraft in our airspace, we must keep in mind that several aircraft may all be emitting a repulsive force at once. For this reason, this design should ideally take into account the number of aircraft in the surrounding area and adjust the force feedback emitted to an appropriate level that would prevent interference with completing a task.

Also, our recommendations are based on force feedback research. However, most research thus far has only focused on the benefits of gravitational force on simple tasks that have meant to emulate the CDTI. Despite the evidence found for the benefits of gravitational force, the benefits may not be as great when this type of feedback is used on an actual CDTI display.

Furthermore, to successfully implement the repulsive force design, pilots would be required to enter their ultimate destinations (e.g., airports) so that the appropriate type of force feedback could be emitted.

6. Conclusion

After reviewing research on the CDTI and input devices, we posit that force feedback may prove useful in the cockpit by providing additional sensory cues to help pilots make more accurate and effective decisions. With a growing number of aircraft in our airspace, it is imperative that we equip pilots with as many tools as possible so that they are able to handle and prevent conflict as soon as they present themselves. Given the success of haptic feedback in areas such as the surgical field, among others, it would behoove one to apply these suggestions to the cockpit display.
7. References
