

## EXECUTIVE SUMMARY

This thesis investigated human navigation performance in relation to various display viewpoint configurations. As a key factor for determining users' perspective during their interactions with a virtual environment, a viewpoint defines the frame of reference of displayed information. Previous research on egocentric and exocentric viewpoints has identified a performance trade-off between two navigational sub-tasks: local guidance and global awareness. It is the goal of this study to design a viewpoint that seamlessly integrates information from both the egocentric and the exocentric frames of reference, thus facilitating users' local navigational guidance and global spatial awareness simultaneously. The proposed solution is *dynamic viewpoint tethering*, an algorithm that supports the attaching of a viewpoint to an avatar through an elastic tether. Different from the conventional egocentric and exocentric viewpoints, in which a viewpoint is located either inside a moving avatar or is fixed with respect to the world, a tethered viewpoint will move with the avatar and preserve elements of an external view, therefore presenting information which is both egocentric and exocentric in nature.

In the thesis the mathematical modelling of a dynamic tether is described (chapter 3) and three experiments were conducted to investigate users' navigational performance with respect to various tether configurations. Experiment 1, as reported in Chapter 4, was a baseline experiment, with the goal of justifying the usefulness of the concept of dynamic viewpoint tethering by contrasting a dynamically tethered viewpoint to three conventional viewpoint formats: egocentric, exocentric, and rigidly tethered viewpoints.

The results of experiment 1 generally confirmed the advantage of viewpoint tethering for supporting navigation. Although the theoretical advantage of a *dynamically* tethered viewpoint was not explicitly demonstrated in the results, it was speculated that a more suitably configured tether might in fact outperform the conventional viewpoint conditions.

Experiment 2, as reported in Chapter 5, focused on identifying the optimal dynamic properties of a tether. The primary focus of the experiment was to investigate how local navigational guidance was affected by the rigidity and viscosity of a dynamic tether. The results revealed that, for at least one tested rigidity level, a reduction of guidance errors was observed with a critically damped tether compared with either the under-damped or the over-damped tethers. The second part of the experiment compared a series of critically damped tethers with different rigidity characteristics and showed an increase of guidance errors when the tether rigidity approaches its two extreme conditions, i.e. zero and infinite rigidity. An optimal tether was deemed to have "medium rigidity".

Experiment 3, as reported in Chapter 6, concentrated primarily on investigating how users' global awareness was affected by the viewing distance, which is determined by the length of a tether. Six tethered viewpoints were tested in this experiment. The results showed an improvement in global awareness with increased tether length. Local guidance, on the other hand, was best with a "medium length" tethered viewpoint, which balances display spatial resolution and preview capability.

In all three experiments, participants were asked to fly a virtual airplane through a set of tunnel-like virtual environments. Besides the main display effects, a significant tunnel

effect was also found in the experiments. Due to the constraints imposed by the testing software, the current method of generating tunnels lacked the flexibility to allow detailed analysis. Future improvements on tunnel generation algorithms are needed to look into this issue.

The highlights of the results can be summarized very briefly as follows:

1. Modelled as a mass-spring-damper system, dynamic viewpoint tethering provides a wide design space for characterizing display efficiency. By exploring the dynamic tether space, tethered viewpoints with various configurations can be constructed to accommodate different navigational task requirements.
2. As a way of seamlessly integrating information from egocentric and exocentric frames of reference, dynamically tethered viewpoints appear to support both local guidance and global awareness navigational subtasks simultaneously.
3. Local guidance performance is greatly affected by tether dynamic parameters, i.e. the tether spring constant and its damping coefficient. An optimal tether setting appears to be a *critically damped* configuration with a rigidity value in the "intermediate" range.
4. Performance with respect to both local guidance and global awareness are significantly affected by the length of a tether. With an increase of tether length from its minimum value, improvements in global awareness and reduction in local guidance performance are observed. The overall best navigational performance appears to be supported by an "intermediate" length dynamically tethered viewpoint.

Collectively, the series of analyses and broad exploratory experiments in this thesis have convincingly supported many of the theoretical advantages of dynamic viewpoint tethering for enhancing user navigation performance in virtual environments. Design

guidelines generated from this study are expected to provide general support for navigational display system implementation. Furthermore, the experimental data should advance our understanding of human navigation behaviour in virtual environments.