Personal Command and Control: A Spatial Interface for Head-Worn Displays as a Platform for Everyday Visual Analytics

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Abstract
Many professional workers benefit from multiple data visualizations in command and control centres. We propose using a similar environment for personal visual analytics using a spatial interface on head-worn displays. Such a platform will provide unlimited display space at an affordable cost in a portable form factor. Furthermore, we believe that spatial movement will provide additional benefits in comprehending the connections made by interspatial links between multiple data visualizations.

Introduction
Command and control centres are special-purpose rooms containing an assortment of control panels and electronic displays for monitoring a complex set of real-time data. Typical settings for such environments include power-generating stations, transport networks or security facilities wherein military, governmental or industrial organizations maintain control of large spatially distributed networks. However, we believe that such environments can be useful for everyday people in everyday situations. In particular, we foresee the benefits of recently available, lightweight, head-worn displays for implementing Personal Command and Control systems (Figure 2) for analysing personal data.

Due to the ubiquity of computing, ordinary people have acquired access to large amounts of personal data. Sensors are now being embedded in people's homes, in the devices they carry and in the clothes they wear [6]. If a business traveller, for example, receives notification that something is amiss at home, she can view side-by-side images from an array of security cameras. Alternatively, during a morning run she can view the various sensor data about her speed, heart rate, number of steps and current location. At home, she can use spatially-situated views to monitor energy consumption at various household locations.

The spatio-temporal data in these examples can accumulate quickly, however much of it may never be used to its full potential. Viewing the data on the small screen of a personal device may be cumbersome, while waiting to view the data on a personal computer is not always practical, since the situational context may be lost. Moreover, insights gained from voluminous data sets can be enhanced by interacting with multiple, coordinated views of the data [8], a luxury not readily available outside of command and control centres.

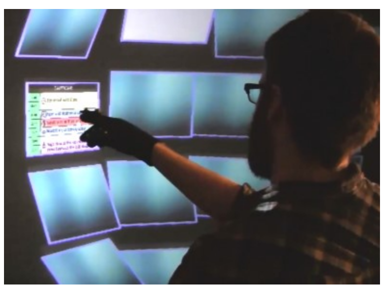

Figure 1. The Personal Cockpit [3], a spatial user interface for head-worn displays, leverages head and body motion for effective navigation and interaction with multiple information displays. We propose using this interface as a platform for personal visual analytics.

Supporting Data Analytics with Spatial UIs

As a solution for monitoring our personal data, we see potential in spatial user interfaces (UIs) implemented on head-worn displays (HWDs). Such devices, now available in lightweight form factors, can provide unlimited areas of virtual display space at a relatively low cost. HWDs are also being equipped with depth cameras and inertial sensors (e.g. [7]) that allow tracking of hand, fingertip and body motion for spatial interaction. To assist visual analytics, an array of virtual windows can be used to organize data into logical partitions. Our concept builds on the Personal Cockpit [3], which uses such a layout to provide effective application switching (Figure 1) by taking advantage of body and head motion for navigation. Several user-studies indicate advantages for interfaces that leverage spatial motion for navigation over traditional navigation methods [1],[3].

The form factor of HWDs provides several benefits that may be useful for personal visual analytics: 1) *Spatial Situation* - Virtual displays can be situated in one's environment without cluttering up living space. The viewer can configure a set of virtual 2D displays in 3D space and reposition her head and body to gain the best vantage. Alternatively, data visualizations can be spatially configured to best assist real-world tasks with minimal visual interference. 2) *Portability* - HWDs can be used in a variety situations. Virtual windows can follow along an 'analyst' on the go. 3) *Interspatial Links* - Multiple visualizations can be linked to highlight important connections in the data. Whereas visual links between planes have previously been explored in 3D graphic renderings [2], stereoscopic HWDs can make the links appear to span 3D space, which may improve comprehensibility and increase tolerance for clutter.

Scenario: A Morning Run

To illustrate how spatial interfaces can assist the analysis of personal data, we continue one of our scenarios from the introduction. We visit Mary in the soon-to-be future on her morning run; she is out on a bright spring morning wearing a lightweight, see-through head-worn display, now available in a fashionable form factor. Following her as she runs is a pair of virtual windows, which she periodically consults; the one to her left shows her step count, heart rate and estimated calories burned. The display to her right

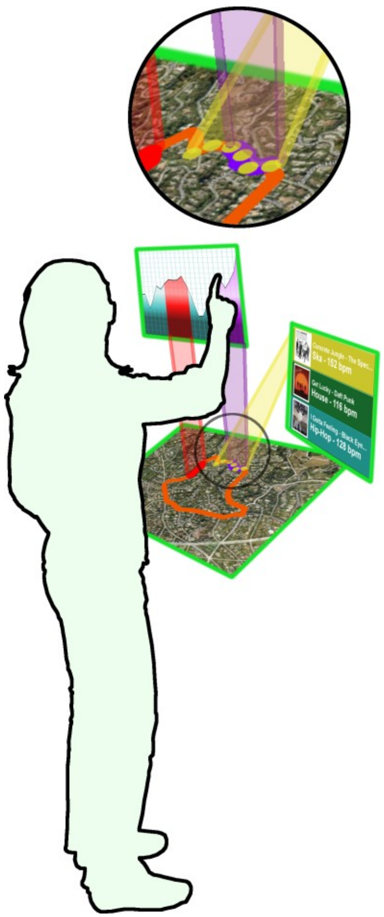

Figure 2. A user configures multiple windows in surrounding space. Interspatial links appear as 'shadows' projected from a heart rate chart onto a map. Head and body movement can assist analysis of such links in personal data.

contains a map, showing her current location and her predicted route, based on logs from previous runs. Neither of these windows occlude her view and she only needs to tilt her head slightly to observe them.

Mary pauses for a break and takes a look at her progress. She makes the map window larger and places it at sloped angle at about waist level. At eye level Mary opens a second window showing a graph of her heart rate since the start of the run. To identify the most challenging parts of her route, Mary selects two regions on the first graph where her heart rate was highest. In a delightful animation, the highlighted regions change colour and project 'shadows' onto the map below. Each shadow highlights the corresponding segment of her route on the map, revealing spatio-temporal associations with the heart rate data (Figure 2). Mary notices that one of the heart rate increases occurred during an uphill section of the route. What was the cause of the second heart rate increase?

Mary opens another window showing the playlist she has been listening to on the miniature speakers built into her HWD. In this window, Mary sees a list of songs, with each item showing a picture of the artist and other details, such as the song's music genre, duration and tempo. As with the regions of the heart rate graph, each song region has a 'shadow' that projects down to a corresponding segment of the map, revealing the section of the route where each song was played. Mary identifies the segment where the second heart rate increase took place (Figure 2, inset) and traces the link up to the music playlist. As it turns out, on that segment of the run she was listening to a 'ska'-genre song with a particularly quick tempo. Could that song have made her run a little harder?

To test this new theory, Mary opens another window on her right with another graph (not shown in Figure 2). From her stored records over the past three months, Mary populates the graph with data showing her average heart rate by music genre. The graph shows that her average heart rate is indeed a little higher during the ska songs than for other music genres. Mary is particularly fond of that style of music, so she is satisfied that she has solved her puzzle. Feeling invigorated, she creates a new random ska playlist and continues on with the remainder of her morning run.

Prototype Implementation

We implemented a version of the above scenario to demonstrate the concepts behind Personal Command and Control. This prototype contains only a preliminary layout of static window content and interspatial links, but shows how spatial interaction can facilitate users in gaining insight form multiple interlinked visualizations. Our prototype is implemented using Open GL and VR Juggler. It uses an Epson Moverio BT-100 display [4] tethered to a desktop machine running Windows 7. The Moverio HWD is tracked using a Vicon tracking system. As newer HWDs enter the market, such a prototype will run on fully self-contained units that will enable head- and position-tracking as well as direct gestural input.

The current prototype configuration (Figure 3) contains three windows that portray the situation in Figure 2, in which a user examines a map (3b), heart rate chart (3c) and music playlist (3d). Visual links (3a) connect regions of the chart and playlist to corresponding segments of the route shown on the map. Using spatial navigation, our imagined subject gains the best vantage point for making insights.

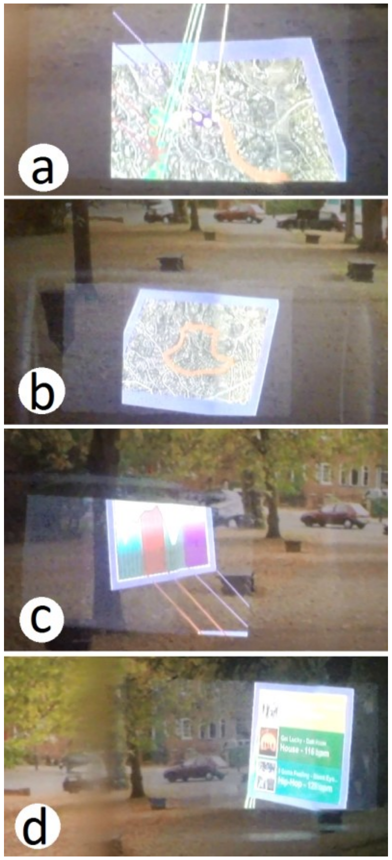

Figure 3. Actual images of our implementation, through a Moverio BT-100 [4] display. The spatial UI assists the user in gaining insight from interspatial links (a) between a map (b) heart rate chart (c) and a music playlist (d). A video demonstration of this prototype may be found here: http://youtu.be/ZV8fa2TuzXk

Design Considerations

The implementation of Personal Command and Control presents many design challenges. First, there are many issues related to the design of the spatial UI (e.g. [5]), and customization of the multi-window layout. For instance should visualization windows be placed in mid-air or mapped to nearby surfaces? Can in-air direct interaction provide intuitive control of visualization windows? When is indirect input required for precise selection? Can interspatial links fill a secondary function as waymarkers in HWDs with a limited field of view?

Beyond these low-level issues we face many questions about applying our platform to facilitate personal visual analytics. Our interface should not only be appealing and easy to use [8], but should provide advantages over existing platforms. In what ways can we leverage a spatial HWD interface to facilitate personal visual analytics? What new spatial interaction methods are needed to summon relevant visualizations and provide accurate control over interspatial links? How advantageous is a portable interface over one at a desktop for conducting analyses in mobile situations? Can the immediacy of an always-available, hands-free interface outperform the small but tangible screen of a mobile device? What are the limits of mental workload when perusing complex visualizations while walking?

Conclusion

We propose Personal Command and Control as a platform for personal visual analytics. We believe a spatial UI will provide opportunities for intuitive and effective interaction with multiple interlinked visualizations. We present a prototype implementation of our proposed platform to demonstrate its potential benefits. We outline several challenges that lie ahead in applying spatial interaction to personal visual analytics. We are currently adding additional features to our prototype, including a depth camera for detecting multi-finger input. This enhanced prototype will allow us to explore ideal 3D window configurations for exploring linked visualizations and new gestural interactions for creating and manipulating visual links.

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