Strolling Through Cyberspace With Your Hands In Your Pockets: Head Directed Navigation In Virtual Environments

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Abstract. Head-Directed Navigation is a new and simple, yet efficient paradigm for navigating large virtual spaces. For walkthrough applications such as architectural visualization or games, the user is often required to cover simulated distances. In doing so, unexperienced users often have a hard time learning complicated navigation patters with 3-D mice or similar input devices. In large virtual worlds, this frequently leads to disorientation. With head directed navigation, the user navigates the virtual environment only by orienting his or her head. An orientation tracker mounted on the head-mounted display worn by the user is used to derive the navigation commands. Besides the approach's simplicity, the user's hands are left free for other tasks.

1. Introduction

Navigating through virtual environments can no longer be considered a task reserved for the expert. 3D-worlds and architectural walkthrough applications [Mine95a] for the common user require new, intuitive interface techniques. We present a simple navigational metaphor for immersive walkthrough applications called *head-directed navigation*. This method requires only the tracker attached to a head-mounted display (HMD). It is extremely easy to learn and doesn't require additional input devices, thereby leaving the users hands free for other tasks. In the following we discuss the properties of established navigation methods together with related work. We then give an overview of our approach together with details on implementation, evaluation and results.

2. Related work

The choice of the navigation method to be employed for a virtual reality (VR) application is constrained by both the need of the application and by the physical setup. The latter can broadly be categorized into desktop VR (screen and mouse only), fishtank VR (desktop VR with shutter glasses) and fully immersive setups (using head-mounted displays). While desktop systems usually have to employ navigation methods using simple devices such as mice or joysticks (e. g., [Strommen94]), immersive setups can make use of the larger number of degrees of freedom (DOF) provided by tracking systems [Meyer92], which have led to a variety of proposed navigation methods.

We discuss this related work with respect to their applicability for walkthrough applications. We therefore limit ourselves to methods that couple the user's view to the camera used to render the scene, and that are suited to general exploratory behavior (as opposed to object or goal driven movement such described in [Mackinlay90]).

Mine [Mine95b] identifies the following techniques for specification of direction in immersive virtual environments:

- Physical walking: While being most natural, the range of current tracking systems [Ward92] prevents the use for walkthrough applications. We also do not further consider "exotic" devices such as treadmills or stationary bicycles [Waters97].
- Gaze-directed: moving in the direction the user looks at. The head-directed navigation method proposed in this paper falls into this general category.
- Pointing: moving in the direction the user points the hand or prop (e. g. wand)
- Cross-Hair: moving in the direction from head to hand
- Physical controls: The use of physical controls (such as a steering wheel) and corresponding "vehicle" metaphors is often difficult in immersive settings, as the user cannot see the devices
- Virtual controls: These are often difficult to operate for their lack of haptic feedback.

Other forms of navigation involve obtain a global view of the virtual environment, such as “world-in-hand” metaphor of [Ware90] or “world-in-miniature” [Stoakley95]. However, these approaches are not strictly methods for walkthrough applications.

An approach related to ours was presented in [Hix95]: Pre-Screen projection allows the user to control the viewpoint in a fishtank VR setup by moving her head relative to the screen. However, their approach is limited to panning and zooming operations with a stationary viewpoint and cannot easily be extended to a fully immersive walkthrough application.

3. Quality factors for walkthrough navigation

Bowman et al. [Bowman97] state that navigation methods should be evaluated according to specific quality factors rather than to their suitability for particular applications, as the requirements of applications may be very different. These quality factors can then be used to determine the right navigation method for an application.

In the following, we discuss the most relevant quality factors for walkthrough applications. The intended application scenario is that of a walkthrough application with general exploratory character (e. g., for architectural visualization) used by people without computer experience and without training in an ad-hoc fashion. Such situations regularly occur when using VR for demonstrations to customers.

Many different criteria for efficient navigation have been proposed [Bowman97]. We consider the following to be of importance for walkthrough applications:

1. **Easy to learn and easy to use**: A complicated navigation metaphor would be counterproductive in most cases: An architect who wants to show a new building to a client in a VE cannot expect the client to learn complicated commands and interaction with new devices, a police officer would like to concentrate on the mission goals and not on how to walk around the next corner.

2. **Minimum of additional devices**: The use of additional input devices for movement is not desirable. A soldier in a simulation should be able to hold his rifle in his hands and not some kind of navigation device like a joystick or 3D-mouse. When using fishtank VEs, the user is in a standard desktop environment, where the use of special input devices is acceptable, but when in a fully immersive environment requiring an additional device for movement distracts the user from the tasks at hand. Besides, if larger audiences are targeted, technical and financial constraints make the use of additional devices increasingly difficult.

3. **Avoid fatigue of the user**: Devices like a 3D mouse or a glove, used for pointing, strain the user into adopting unnatural positions caused by the necessity of lifting the device up into the field of view and lead to unnecessary gesticulation.

4. **Spatial awareness**: Exactly the ease with which one can change viewpoint and direction in a VE is one of the pitfalls of many navigation metaphors: turning around on the press of a button or the twist of a dial doesn’t correspond to any movement of the user in reality. The result can be loss of orientation similar to turning around blindfolded. Any instantaneous translational movements, like “teleporting” to a new location, equally disrupt the coherence of the mental map.

5. **Avoid translational limits**: Immersive VEs which simulate a person moving by foot in a contained space allow an easily comprehended one-to-one mapping (the user simply walks around in the simulated space), but place a physical limit on the distances the user can cover. An acceptable metaphor should extend this range without preventing the user from making small adjustments of viewpoint by changing position in reality.

6. **Make use of the floor constraint when appropriate**: When moving around in reality, one naturally accepts that ones feet always touch the floor, while in VEs, users are often allowed to fly. This additional degree of freedom however doesn’t help the user; on the contrary it requires the user to make additional height adjustments. For walkthrough environments, reducing the freedom of movement from 3 to 2 dimensions improves the ease of navigation.

In the following paragraphs we will show how our approach covers all these criteria.

4. Head Directed Navigation

Imagine a little kid playing “airplane”: It holds out its arms and tilts its whole upper body according to the direction in which the “plane” should move. It behaves like an airplane, rolling and yawing according to the laws of aerodynamics even without any knowledge of these laws (Figure 1). This observation inspired our approach of *head directed navigation*.

Figure 1: A little kid playing airplane naturally employs a metaphor akin to our approach

Of course this kind of interaction is not directly applicable in our case, since it involves directing the forward motion by foot (“running around the playground”), but if we sacrifice one degree of freedom - in our case the ability to move up and down, we are able to map head rotations to the movements of the whole user. Since our movements are already constrained to the plane of the floor (⇒ requirement 6, above), we can use the up- and downward sweeping motion of the head to control our speed. Moving forward is accomplished by nodding in the right direction. We gain the direction of motion from the horizontal component of the head direction - yaw - and the speed from the angle between the head direction and the horizontal plane (pitch).

none forward backward

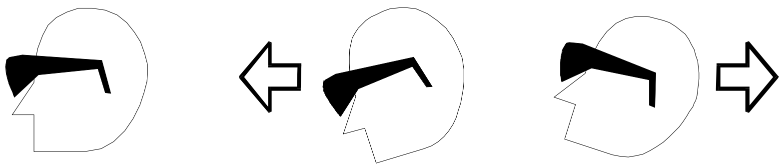

Figure 2: Association of pitch to translational motion

In a head-tracked setup, navigating can now be achieved by head rotation alone. Note that a 6DOF tracker is not even fully utilized, as only the three rotational measurements are needed.

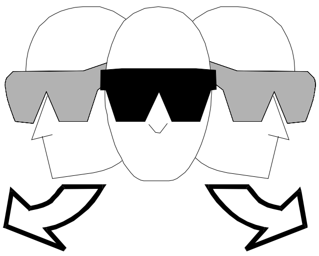

Figure 3: Steering is done by head rotation

This yields essentially the kind of behavior we aimed for in our “kid-playing-airplane” metaphor: The user moves forward by simply inclining her head while gazing at the target, stopping is done by leveling out the direction of view and moving backwards by leaning back (Figure 2). Steering is done by turning the head in the desired direction (Figure 3).

4.1 Discussion

Head-directed navigation can be seen as the equivalent to the navigation method used for desktop 3D browsers or computer games that have only a joystick or even cursor keys at their disposal. In these desktop applications, a horizontal axis controls the heading, while a vertical axis controls the movement.

No additional input devices are required besides the head tracker. This reduces the required hardware for the installation, which saves cost and also allows a larger number of simultaneous users if the number of tracking sensors is the limiting resource. It also simplifies briefing and dress-up if a larger group of users and short turnaround times are desired (e. g., trade shows or theme parks).

As navigation is controlled by head movements alone, the hand are left free for other tasks. If no additional devices are used, the arms can be placed in a comfortable position for complete avoidance of fatigue, a problem known to occur when using wands or 3D mice. Alternatively, a hand-held 3D input device can be completely dedicated to object manipulation.

Often an immersive application hosts a number of first-time users together with a guide or tutor, who is supposed to have more control over the environment than the users. Head-directed navigation allows the construction of an asymmetric application where the guide carried a wand or other 3D input device to control the application, while the other users are only equipped with a head-tracker for individual control of viewpoint, but not more.

Head-directed navigation does not fully utilize a tracker, as only the rotational DOF are used for input. The remaining positional DOF can be used to walk small distances by foot when examining a room or object. In this way, a combination of unconstrained movement and direct physical walking can be achieved.

The main restriction of head-directed navigation lies in the requirement that the environment must have a ground floor constraint. However, a significant number of applications is compatible with such a requirement.

Problems arise when the user inadvertently moves while trying to look around. This happens for example when the user doesn't look absolutely horizontal. We solved this by using a linear mapping from pitch to speed with a small zone – about 10° – of zero speed around the horizontal direction to tolerate slight head movements while standing still. Alternatively, if a higher top speed is desired to cover large distance, a pitch threshold can be defined beyond which a non-linear mapping from pitch to speed, as proposed in [Song93].

Scrutinizing a nearby object from top to bottom also cannot be accomplished without moving back- and forward. This is solved by defining a view mode with a stationary viewpoint and a walk mode where head-directed navigation is active. Switching between walk and view mode can either be done by an additional device (e. g., a button), if available, or by using the remaining DOF of the head tracker. The solution we developed works by tilting ones head to one side (Figure 4). This allows the user to switch modes while still keeping her hands free and utilizes a seldom used head position.

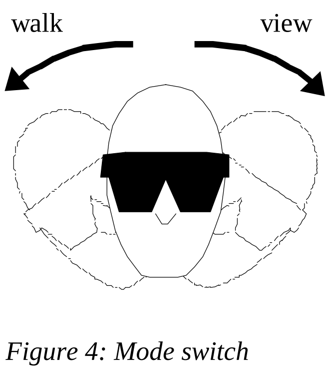

Figure 4: Mode switch

4.2 Example usage

Let us give some examples of navigational tasks which can easily be accomplished with our method:

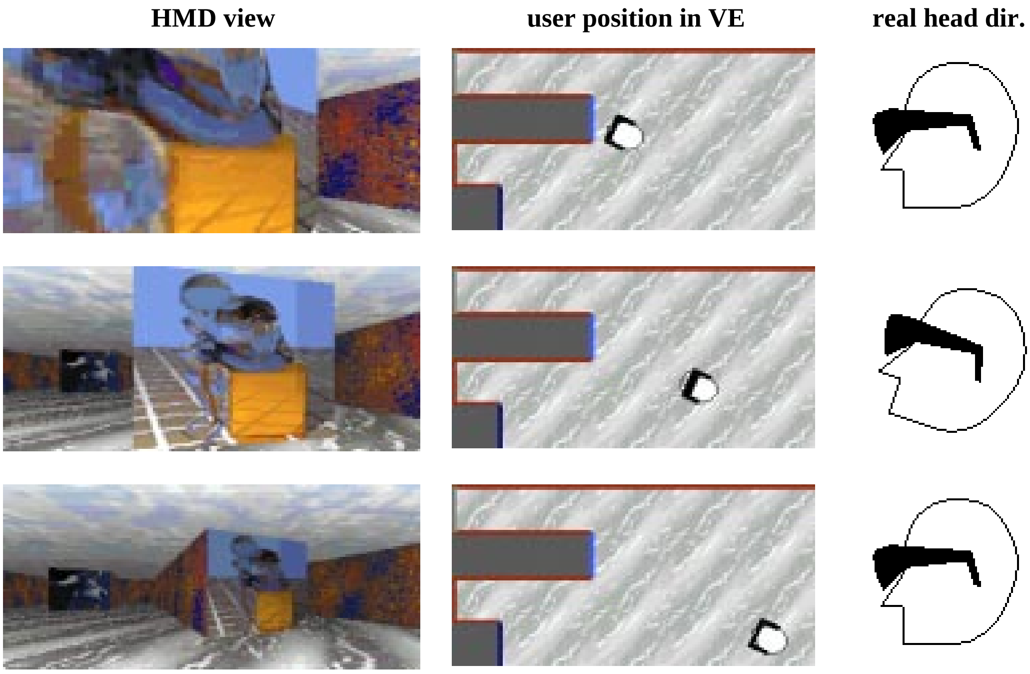

Figure 5: Moving away from an object is done by leaning back

- **Moving away from an object to gain an overview**: The user leans her head back, like when looking at the top of a tower, until a sufficient distance has been reached (Figure 5).

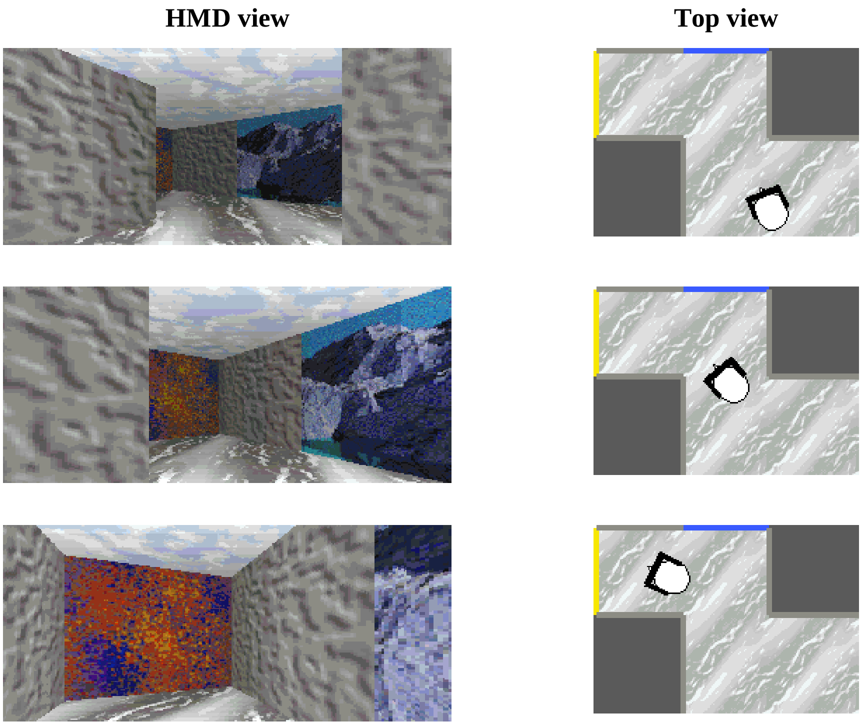

Figure 6: Walking around a corner is done by gradually inclining ones head

- **Walking around a corner**: The user inclines her head while looking parallel to the wall until reaching the corner, then turns around the same way one uses when looking around a corner (Figure 6).

5. Implementation and Evaluation

We first implemented head-directed navigation as motion metaphor in a PC-based walkthrough system which represented a virtual gallery. HMD and tracking devices were virtual-io i-glasses, an inexpensive solution capable of displaying stereoscopic graphics. The integrated tracker uses gravity and a compass to track three rotational degrees of freedom and is orders of magnitude cheaper than professional 6DOF magnetic tracker systems. The implementation was a straightforward application of the above principles.

5.1 Setup

Our setup consisted of a PC with attached HMD. The graphics output was additionally routed to a large monitor which allowed bystanders and experimenter to see the same as the immersed user. This enabled potential users to get a preview of the environment and the navigational method by comparing head movements of the immersed user to the view of the VE and generally shortened briefing of new users.

Our demonstration environment consisted of a labyrinth containing a gallery of images depicting work done at our department. To enliven the environment we implemented sliding doors which react to proximity and one exit which stopped the program when reached by a user. The task of finding a way out provided an additional goal to the otherwise pure exploratory character of the environment. We used a straightforward implementation of head-directed navigation without switching between walk and view mode. By using the degree of freedom normally used for mode switching to implement movement to the left and right (strafing), viewing of the gallery while moving sideways was made possible.

5.2 User responses

Since the advisor had to introduce every user to the virtual environment and the navigation within, we were able to obtain an informal sample of user responses. Unfortunately, the situation at the fair precluded a comparison with other navigational methods. Thus we are not able to draw a direct comparison, but the user responses were throughout positive.

After the initial orientation period, many first-time users were fascinated by the possibility of moving around in a virtual environment and soon concentrated on experimenting with doors and different points of view while apparently not focusing on navigation itself. With a few exceptions, most users also liked the hands-free approach. When we interviewed users on their experiences in the virtual environment, they often used phrases like “when I was walking through the door on the right”, which indicated to us that users accepted navigation without thinking about it.

The most severe complaints we recorded did not concern the navigation, but the small field of view of the HMDs, which we compensated by using a fisheye view into the environment.

5.3 Observations

Because of its simplicity, our approach proved extremely easy to learn. Most users quickly overcame initial steering problems, which mostly consisted of mastering control of the head to velocity mapping. These initial problems can be compared to the adaptation process one goes through when using a new mouse with unfamiliar resolution. After about a minute, most users grew accustomed to velocity control and were able to easily navigate the environment. Since the orientation of the user in reality and virtuality is the same, disorienatation due to lack of bearing almost never occurred.

Head-directed navigation requires a minimum of activity in head movements. Therefore, we did not observe the almost paralyzed posture typical for first time HMD users who are not aware that they can move around or too frightened to do so. The method of moving along the gallery by sliding sideways had to be suggested to most users, but was then readily adopted.

As our navigational method constrains the user to movement on a ground floor, it requires control of only two independent dimensions, which is a minimum for navigation in a realistic environment. Therefor users were not bothered with unnecessary freedom of control which can quickly lead to disorientation in “flythrough” navigational situations, as we have observed from other applications. The use of an additional monitor not only enabled the advisor to help the user adjusting to the VE but also reduced initial reservations of novice users regarding the HMD.

6. Conclusion and future work

From our experience we have learned that head-directed navigation is a simple and intuitive way of navigation. While is limited to walkthrough applications that work with a ground floor constraint, the method in its simplicity is particularly useful for novice users and when virtually no training time is available. The lack of need for additional devices apart from the head tracker is helpful when cost is a factor or when multiple simultaneous users must be supported with limited hardware resources.

Future work is planned to develop head-directed navigation as an aid for disabled persons.

For further information, see `http://www.cg.tuwien.ac.at/research/vr/hdn/`

7. Acknowledgments

This work has been supported by the *Austrian Science Foundation (FWF)* under project P-12074-MAT and the city of Vienna (*Hochschuljubiläumsfonds der Stadt Wien*).

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