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Intuitive Navigation in Virtual Environments

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Abstract

We present several novel ways of interaction and navigation in virtual worlds. Using the optical tracking system of our four-sided Definitely Affordable Virtual Environment (DAVE), we designed and implemented navigation and movement controls using the user's gestures and postures. Our techniques are more natural and intuitive than a standard 3D joystick-based approach, which compromises the immersion's impact.

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1. Introduction

Immersive environments allow to enter virtual worlds which offer undreamed-of possibilities and new experiences. But being totally immersed requires to travel through the virtual world in an intuitive way. This means that interactions which would not have to be explained in the real world, should not be in need of an explanation in virtual worlds. When disregarding this basic principle the user interfaces create a barrier that compromises the immersion's impact.

Also, the user's inhibition threshold towards immersive interaction can be lowered remarkably. This is especially important for virtual reality (VR) installations that are often used for demonstration purposes or in exhibitions [FLL*93]. Visitors are almost always first time users who should quickly be able to try out the system. A good example in a non-immersive environment is *Nintendo's Wii Sports Tennis*. As no user tracking is available, only arm and hand movements are interpreted but not the user's movements and position. The computer sets the player's position automatically. In this way, the input device as well as the user interaction can be kept simple and user-friendly. In our DAVE we realized these basic principles in immersive environment applications that require special attention due to their unconventional needs.

2. Related Work

Various navigation methods in immersive virtual environments have been developed. Obvious options like pointing based methods were described over two decades ago. Some of them are summarized by WARE and OSBORNE [WO90]. More recent overviews categorize existing travel methods like the ones from BOWMAN [BKH97], [BKLP04] and MINE [Min95].

Several other application specific travel methods were implemented. For example, CIGER ET AL. use a magic wand for navigation using posture recognition or pointing in combination with speech recognition [CGVT03]. Without compromising interaction DELIGIANNIDIS researched how to navigate using a tracked cyber glove [Del04].

Some applications require hands-free navigation. LAVIOLA ET AL. describe multiple hands-free techniques for multi scale ground based walk navigation and also address the problem of a missing back wall in a CAVE. By amplifying the mapping of the user's orientation 360 degree views become possible [LFKZ01]. BOURDOT ET AL. use a stateless approach where different zones for the user's position are used for special behavior of the navigation [BDA99]. FUHRMANN ET AL. use head directed navigation inspired by kids playing airplane [FSG98]. A few of such methods use additional input strategies to change the mode or state of the navigation, e.g. by tapping with the feet [WPA97] or by voice commands. ADAMO-VILLANI ET AL. developed and evaluated a travel interface using stepping on a dance mat [AVD07]. BECKHAUS ET AL. also used a dance mat and developed a chair interface for traveling [BBH05]. LEEB ET AL. describe simple VR navigation with a brain computer interface by measuring neural impulses with a electroencephalogram [LSFP07].

Another type of setup is a mechanical locomotion interface such as 1D or 2D treadmills or hollow rotating spheres the user walks in. Among others, Iwata et al. developed several innovative locomotion interfaces like treadmills or moving tiles [IYFN05]. Fels et al. build a virtual swimming interface [FKC*05]. *CyberSphere* [FRE03] and *Cyberwalk* [STU07] are special platforms that allows the user to walk within a virtual environment. While the former system uses the rotating sphere, the latter one employs balls which are actuated by a belt on a turntable However, these locomotion systems require a huge mechanical effort and in practice often more difficult to use than one would expect. Eventually they still can't reduce simulator sickness problems because the real physical and virtual visually perceived accelerations do not match.

For pose measurement and reconstruction of a user in a VR environment, optical, mechanical, inertial or magnetic tracking systems can be used. The work most closely related to our implementation in Section 4.1 is about inverse kinematics with an optical tracking system by Grochow et al. [GMHP04]. Given a subset of markers, a motion capture data base is used to synthesize the most likely pose.

3. Setup

In our DAVE and at our stereo wall we use optical tracking systems primarily to adapt the 3D viewpoint according to the user's eye positions. With multiple cameras passive reflecting markers are detected and triangulated. Since all markers look the same an identification is only possible with heuristic estimations or a fixed constellation of markers that we call *target*. At least three markers are necessary for 6 degrees of freedom. In our current setup the cameras attached above the screen can't see markers that are low and close to the screens. As an example the tracked volume is quite limited for foot tracking and the constant low power lighting setup prevents marker detection during fast motions. However, the most common task of tracking targets works well.

We greatly improved the user experience compared to our previous magnetic tracking due to a higher frame rate, a much higher precision and no need for wires. These issues and the constraints of available input devices must be taken into account when designing navigation methods. With additional acceleration sensors for example, completely different ways of interaction would be possible.

4. Applications

4.1. Glider Simulation

To achieve an intuitive way of controlling a virtual glider we track the user's outstretched arms. The glider's roll/yaw behavior is controlled by the user's hand-to-hand line. The angle α of this line to the horizontal plane is taken as the roll-angle of the glider, also impacting it's yaw-angle. This is illustrated in Figure 1. The user's position in the DAVE affects the pitch angle of the glider. Like walking on a seesaw, going forward causes the glider to fly downwards, moving backwards results in flying upwards. By accumulating the pitch angle also loops are possible. For a better way of understanding the relations between arm motion and the glider's reactions, users see the plane from a point of view behind the plane rather than a cockpit view. An informal user study showed that users are quickly familiar with this navigation method. We also tested more sophisticated interaction details for more experienced users. Wing-span and consequently lift force can be varied by hand-to-hand distance. Furthermore, flutter movements can trigger altitude gain.

We generalized the idea of using head and hand position to roughly estimate a user's posture and subsequently use it to control a VR application. The estimated posture reconstruction yields positions of the user's principal joints including neck, shoulders, elbows, hips, knees and feet - listed in decreasing grade of certainty. Of course no individual leg movement is measurable without additional sensors that could be attached to the user's feet. The following three techniques for posture reconstruction were implemented and evaluated.

Initially we implemented an approach with inverse kinematics. The user's joint distances can be guessed from his body height. Involving a simple geometric model of each joint's position in relation to the other joints, a likeliness prediction of the user's skeleton can be made. With regard to the glider application our implementation was mainly designed for standing poses where it performs well. However, interpreting very different poses requires a more complex implementation which was not examined more closely.

To overcome this limitation, we tried another two methods based on self recorded motion capture data. For further processing, a normalization step is applied to remove dependency of the user's orientation, position and size. After com-

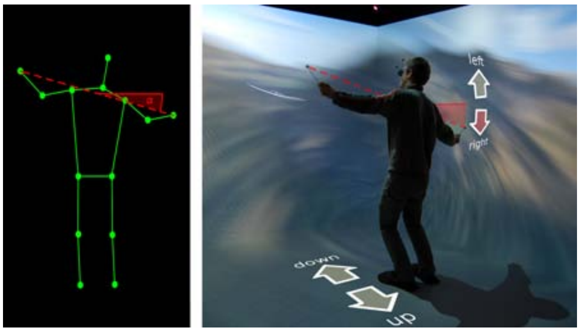

Figure 1: *A glider simulation. A skeleton is roughly estimated from the tracking data and used to control the glider. The arrows and lines are overlaid on top of the photo for illustration purposes.*

puting a skeleton, the inverse transformation is applied in a denormalization step.

The first approach uses a look-up table (LUT). We simply search the most similar hands and head constellation in that table and use their prerecorded joint positions. To decrease the best-fit search effort, instead of one big LUT we use several small sub-LUTs, each holding poses for one interval.

Finally we trained artificial neural networks on our motion capture data, where each joint is represented by three nets, one for each Cartesian joint position. For example, feeding the three right knee nets with the user's hands and head positions results in a hypothesis of the knee's position. By taking care of not overfitting the networks during the training phase, our implementation of this method shows the best results.

Since the problem is inherently under-constrained there is no general best setup for all possible applications. The last two methods can easily be adapted to a different application by using a different number and position of markers during interaction and another set of prerecorded typical poses.

4.2. Walk Navigation in Quake III Arena

As the full source code of ego-shooter game *Quake III Arena* was released by *Id Software* we decided to adapt it to our DAVE. Implementing a hands-free navigation the user is able to aim in another direction than his view, which is not possible in the original game. This is even more beneficial than a flystick, as one doesn't have to take control of two devices. We wanted the user to be able to aim with a gun independently of his viewing and walking direction unlike in the original game. Our solution is an intuitive hands-free navigation. Walking navigation is controlled by the user's head position. In center of the DAVE floor we draw a circle that defines a neutral area (see Figure 2). As long as the user is inside this region no navigation is triggered. Just as he steps outside the circle, the user's coordinate system in the virtual world is continuously translated so that he walks along in the virtual world. To enable moving just along the principal axes we use four areas positioned near the center of each axis. In the red hatched regions diagonal movement is possible. The distance from the center influences the walking speed exponentially. The concept with strict regions is easy to understand. However, in practise we use continuous functions for smooth accelerations.

Figure 2: *The user's head position controls the walk navigation speed in the game Quake III Arena. In this image the user moves sideways by standing left to the center. His hands are free for other interaction devices such as the gun. The bottom marks are overlaid for illustration purposes and are not visualized within the game.*

Figure 3: *Hands free navigation. A user controlling a penguin by his head position. The arrows and lines are overlaid on top of the photo for illustration purposes.*

As there is no back wall in our DAVE, the user's head orientation has to be taken special care of. We define a maximum neutral rotation angle to the left and right, relative to the direction normal to the front wall. If a user exceeds one of those angles, the whole scene smoothly rotates towards the front wall. We also implemented the actions "jump" and "duck" to be activated by the body movement of the user. Estimating a user's height it is easy to detect those actions with the vertical position of the glasses.

4.3. More Applications

We ported the open source game *PPRacer* (formerly *Tux Racer*) to our DAVE. A penguin slides down a snow slope collecting fish. The user's head position controls the speed. The penguin accelerates when the user lies down, copying the penguin's pose. Holding the head to the side, the penguin turns (see Figure 3). While the input value for turning is continuous, unfortunately the game only uses a binary decision. This uncommon way of controlling a game is fun but some visitors are not willing to lie down, being afraid to make a fool of themselves.

Applications in that the user looks at a large virtual world from inside are most suited for the DAVE. In contrast, for looking at a small object from all sides is not so well suited for a DAVE. For that reason we usually need navigations related to walk or fly-throughs. However, for another type of application we implemented a different navigation method. Playing a virtual 3D billiard game the user can orbit around the table by stepping to the side. The center of the table is always displayed on the front wall. This idea can be generalized to move along a predefined path with a corresponding view direction for each position.

5. Conclusions

We have presented novel ways of interaction and navigation in virtual worlds. Using the optical tracking system of our four-sided DAVE, we have designed and implemented navigation and movement controls using the user's gestures and postures. Our techniques are completely vision-based. Therefore the user does not have to learn how to use a new device. A reasonable use of VR applications is possible at early stages with a relatively light amount of training. This is a more intuitive interaction than commonly used approaches based on special input devices (3D joystick, cyber gloves, etc.), which compromise the user's VR presence.

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