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The Jumper Metaphor: An Effective Navigation Technique for Immersive Display Setups

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(a) (b) (c)

Figure 1. Illustration of the jumper metaphor showing a jump sequence: (a) user's view to a target location before the jump, (b) frame during the jump, and (c) after the jump at the target location.

Abstract—**Recently, several novel user interfaces have been introduced, which allow users to actively move the body in order to interact with a displayed immersive virtual environment (IVE). However, in most situations the virtual world in which the user is immersed represents a space that is considerably larger than the available interaction space within which she can move. To overcome this limitation, traditionally, users can travel indirectly by exploiting input devices, with which the viewpoint in the environment can be changed without actually requiring a large physical movement. However, for several applications, it appears reasonable to consider more natural methods for traveling through IVEs. In this paper, we introduce the *jumper metaphor*, which combines natural direct walking with magical locomotion through large-scale IVEs. The key characteristic of the jumper metaphor is that it supports real walking for short-distances, whereas if the user intends to travel a larger distance, the metaphor predicts the planned target location in the virtual world and then lets the user virtually jump to that particular target. We evaluated this method in an IVE and found that the jumper metaphor has the potential to allow more effective exploration in comparison to real walking, with only minor effects on space cognition and disorientation.**

Keywords-3D user interface; navigation; locomotion; immersive display environments

I. INTRODUCTION AND BACKGROUND

During the last few years, virtual reality (VR) display technologies such as head-mounted displays (HMDs), stereoscopic projection screens and autostereoscopic displays became more and more popular for applications in the fields of entertainment, serious games and edutainment. These technologies can provide users with an unchallenged spatial impression of an immersive virtual environment (IVE) as well as understanding of distances between objects or landmarks in the environment [28]. However, immersive displays are often combined with interaction devices, e.g., mouse, keyboard, joystick or gamepads, for providing (often unnatural) inputs to generate self-motion.

More and more research groups are investigating natural, multimodal methods of generating self-motion. For example, in [23] Ware and Osborne compared three different metaphors to modify the viewpoint in desktop-based environments using six degrees of freedom (DOF) input devices. Due to the fact that each considered metaphor had various advantages and disadvantages, Ware and Osborne suggested that the choice of method should depend on the requirements of the interaction task. In the context of immersive virtual environments, world-in-miniature (WIM) metaphors are often used as an indirect metaphor for navigation [18, 22, 13, 27]. With these approaches the virtual representation of the user is directly manipulated within a hand-held miniature or map of the IVE. These manipulations are applied directly to the user's point of view in the IVE.

Several novel devices and user interfaces have been developed over the past years, which allow to capture user's body movements in front of a display and map detected movements to camera motions in a virtual world. These devices include motion trackers, such as Nintendo Wii, but also video- and depth-based solutions such as the Microsoft Kinect or Sony EyeToy. Corresponding interaction metaphors are often based on navigation techniques, which have been introduced years ago in the context of 3D user interface and virtual reality research [4]. For instance, in [4] Bowman et al. conducted a series of experiments in which they compared two different metaphors to specify the direction of travel: (i) gaze-directed and (ii) hand-directed. Regarding the effects of different transition techniques on spatial awareness, they found that an abrupt change of view is particularly disorienting and suggested to use smooth transitions.

With such tracking and immersive display devices, users may navigate through IVEs by *real walking* in a limited interaction space [12, 17, 29]. An obvious approach to support real walking in such a setup is to map a one meter movement of the user in the real world to a one meter movement of the camera in the virtual environment. This approach has the drawback that the user's movements are restricted by the limited range of tracking sensors and a rather small workspace in the real world. Thus, concepts for virtual locomotion methods are needed that enable walking over large distances in the virtual world while remaining within a relatively small space in the real world. Various prototypes of advanced VR-based interface devices have been developed to prevent a displacement in the real world. These devices include torus-shaped omni-directional treadmills [3], motion foot pads [8], robot tiles [9], motion carpets [15] and stroller-based walking platforms [19]. Although these hardware systems represent enormous technological achievements, they are still very expensive and will not be generally accessible in the foreseeable future.

In the context of video games, some simple devices such as Nintendo's Power Pad and Balance Board have been proposed, which supports walking-in-place (WIP) [12, 2, 16, 24] and leaning techniques [11, 6], and thus enable simplified locomotion. These body-centric navigation methods allow hands-free navigation, e.g., LaViola et al. developed several body- and foot-based metaphors for navigation in IVEs, including a leaning technique, with which users could travel short and medium distances, whereas larger distances could be traveled with a floor-based WIM [11]. However, real walking has been shown to be a more presence-enhancing locomotion technique than other navigation metaphors [20]. While walking in the real world, sensory information such as vestibular, proprioceptive, and efferent copy signals as well as visual information create consistent multi-sensory cues that indicate one's own motion, i.e., acceleration, speed and direction of travel [14]. In this context walking is the most basic and intuitive way of moving. Keeping such an active and dynamic ability to navigate through large-scale environments is of great interest [5], i.e., several approaches suggest supporting real walking, but simply scale translation motions. For instance, Williams et al. have exploited uniform tracker gains [25] and used mechanisms, which reset the position of the participant within an IVE [26]. Using these approaches, users could travel through moderately large virtual spaces by directly walking within a smaller real space. Interrante et al. proposed the seven-league-boots metaphor in which translational motions are only scaled in the user's main walk direction and therefore, avoids discomfort due to lateral bumping [7].

In this paper we introduce and discuss the *jumper metaphor*, which is a new metaphor for hands-free traveling through moderately large IVEs, which is based on real walking, but in which the mapping between the user's actual movement in the real world and her movement in the virtual world is manipulated.

II. THE JUMPER METAPHOR

In this section we describe the jumper metaphor for effective exploration of IVEs. The main idea of this metaphor is to combine natural interaction in the real world with the magical world of VR and games to provide an effective, but natural navigation technique. For the exploration of objects in a small range, we simply use real walking such that the user can walk around objects, or use small head movements to explore the environment while perceiving motion parallax and occlusion effects similar to the real world. To travel over large distances, the user is able to specify the travel destination using her viewing direction, and then can initiate a jump, which will start a smooth viewpoint animation that transfers the user to the corresponding target position. In the following, we assume that we can track the user's head position as well as orientation, for example, by an optical tracking system or Kinect sensors, and map it to a corresponding virtual camera. The jumper metaphor is composed of the three steps described in the following subsections.

A. Jump Target Prediction

At first, the intended target position for the jump has to be identified. Two possibilities exist for how this target position can be specified, i.e., explicit or implicit.

As mentioned in Section I, we wanted to avoid explicit target selection via additional input devices for the navigation task. Therefore, we determine the target position $p_t \in \mathbb{R}^3$ of the jump implicitly by calculating the first intersection point with the scene geometry of the ray extending from the user's virtual head position $p_u \in \mathbb{R}^3$ (i.e., the position of the virtual camera) along the user's viewing direction $d_{view} \in \mathbb{R}^3$. Hence, if the user wants to specify the target position for a jump, she simply has to look to that position for $t_{gaze} \in \mathbb{N}$ milliseconds.

In head-tracked environments, usually the user slightly moves the head during the entire time, which complicates the specification of a jump target if the user has to look to one specific position over time. Therefore, we predict the jump target based on all focus points within t_{gaze} milliseconds and tolerate slight variations in the user's viewing direction d_{view}. To ease target selection with distant objects, we unproject all focus points with the inverted projection and model-view matrix of the first focus point within the last t_{gaze} milliseconds into image space coordinates. If all focus points in image space coordinates are within a circle with radius $r_{gaze} \in \mathbb{N}$ pixels for t_{gaze} milliseconds, we use the projection of the center of all focus points as the target point p_t. As users can move effectively by real walking for short distances, a jump can only be initiated to positions which are at least 2 meters away from the user's current position.

In order to give the user corresponding visual feedback about the target position, we display a visual target projected to the target position according to the user's viewing direction d_{view} and the face normal vector $n \in \mathbb{R}^3$ at the target position p_t (see Fig. 1(a)). The visual target grows constantly to its full size within $t_{grow} \in \mathbb{N}$ milliseconds. If the user wants to choose a different target position, she simply has to focus on a point outside the displayed target area. As soon as one focus point is outside the circle with radius r_{gaze} pixels, the projected visual target disappears and the user can specify a new target.

According to experimental observation (cf. Section III), we use t_{gaze} = 500 milliseconds, r_{gaze} = 75 pixels and t_{grow} = 2000 milliseconds, i.e., when a user looks within a circle with radius 75 pixels in image space coordinates for 500 milliseconds she has specified a jump target position and the visual target, which is projected on this position, grows to its full size within 2000 milliseconds.

B. *Jump Activation*

After the user has specified the jump target position $p_t \in \mathbb{R}^3$, she can initiate the jump to that target by moving towards the target with a reasonable speed. Therefore, we define an acceleration threshold $a_t \in \mathbb{R}^3$ in meters per square second, which the user has to exceed in order to initiate the jump (see Fig. 4). We use this threshold to avoid unintended jumps and to allow the user to explore near objects by real walking with accelerations below a_t.

Due to the jitter and noise of the tracking system as well as head bumping during real walking (cf. Section I), numerical inaccuracies can occur when using two consecutive tracked head positions for velocity and acceleration calculations. Therefore, we use the tracked head positions $p_1,\ldots,p_n \in \mathbb{R}^3$ during the last $\Delta \in \mathbb{R}$ seconds to determine the direction of travel $d_{travel} \in \mathbb{R}^3$, velocity $v \in \mathbb{R}$ in meters per second and acceleration $a \in \mathbb{R}$ in meters per square second as follows:

$$d_{travel} = p_n - p_1,$$

$$v = \frac{\|d_{travel}\|}{\Delta},$$

$$a = \frac{v - v_p}{\Delta},$$

where $\|\cdot\| : \mathbb{R}^3 \longrightarrow \mathbb{R}$ is the Euclidean distance and $v_p \in \mathbb{R}$ is the predicted velocity Δ seconds ago.

According to experimental observation (cf. Section III), we use Δ = 0.25 seconds and a_t = 1.5 meters per square second, i.e., a user can initiate a jump by real walking with an acceleration greater than 1.5 meters per square second, where the prediction of the acceleration is based on the received tracking data during the last 0.25 seconds.

C. *Jump Animation*

As mentioned above, the jump is initiated if the user has specified a target and exceeds the acceleration threshold by walking towards the target. The start point $p_s = p_u \in \mathbb{R}^3$ of the animation is defined by the current position of the user $p_u \in \mathbb{R}^3$. The end point $p_e = p_t + \lambda n \in \mathbb{R}^3$ is given by the target position p_t, which is adjusted by $\lambda \in \mathbb{R}$ meters in the direction towards the user's current position along the face normal $n \in \mathbb{R}^3$ at the target position in order to prevent jumping directly into an object (cf. Fig. 1(c)). In addition, we adjust the height of the end point $p_{e,y} \in \mathbb{R}$ according to the start point height $p_{s,y} \in \mathbb{R}$ and the difference between the terrain height at the start point $h_s \in \mathbb{R}$ and end point $h_e \in \mathbb{R}$, i.e., $p_{e,y} = p_{s,y} + (h_e - h_s)$.

The position of the virtual camera during the jump animation is calculated using an interpolation function

$$f_i(p_s, p_e, t) : (\mathbb{R}^3, \mathbb{R}^3, \mathbb{R}) \longrightarrow \mathbb{R}^3,$$

where $t \in [0,1]$ denotes the time progress of the animation, i.e., the animation starts on $t = 0$ and ends on $t = 1$. The duration of the animation $t_{anim} \in \mathbb{R}$ in milliseconds depends on the distance $d \in \mathbb{R}$ to the target position p_t and a scaling factor $s_{anim} \in \mathbb{R}$, i.e., $t_{anim} = d \cdot s_{anim}$.

In order to avoid disorientation, we use a smooth ease-in/ease-out jump animation of the straight connection of the start and end point (cf. Section I). We achieve this by using a sigmoid logistic function for our interpolation function

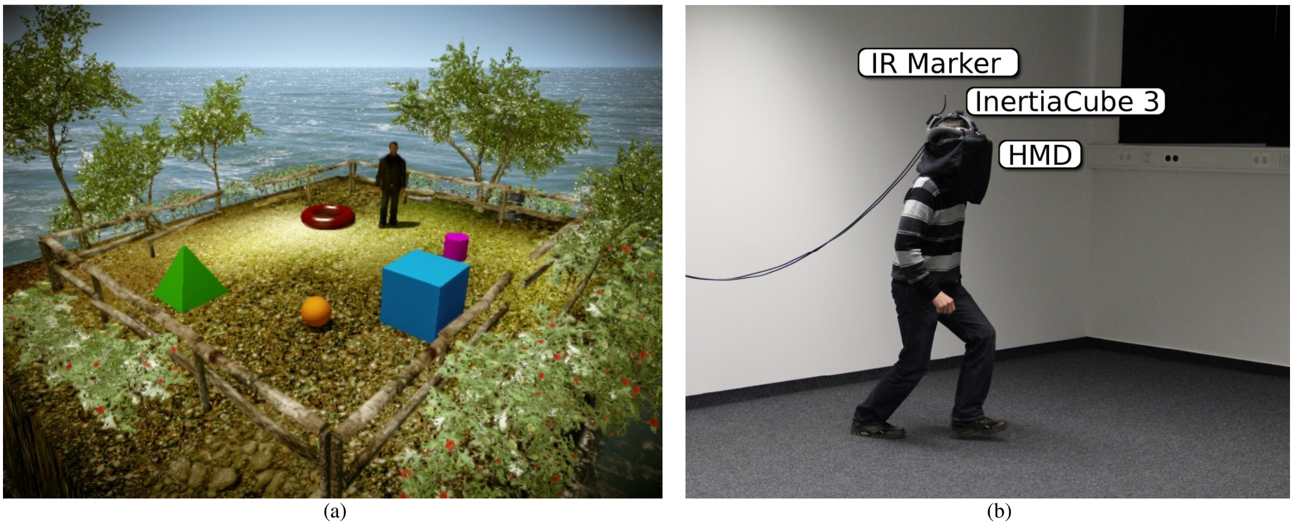
$$f_i(p_s, p_e, t) := \frac{1}{1 + e^{-14t+7}} \cdot (p_e - p_s).$$

To support the notion of a "magic" metaphor, we use a motion blur effect in the border of the viewport which fades out to the center (see Fig. 1(b)).

According to experimental observation (cf. Section III), we use s_{anim} = 180 and λ = 1 meter, i.e., the jump animation towards the end position, which is adjusted by 1 meter towards the user's current position along the face normal at the jump target position, lasts for 1800 milliseconds in case of a jump distance of 10 meters.

III. EVALUATION

In this section we describe the user study that we have conducted in order to evaluate the proposed jumper metaphor navigation technique. In the evaluation we compared the jumper metaphor to real walking to teleportation. The goal of the study was to evaluate if the jumper metaphor can be used as an effective navigation technique in immersive game environments.



(a) (b)

Figure 2. Example images of the evaluation: (a) simple game environment with a user's avatar (note: during the experiment, the user could not see her own avatar from a third person's view), and (b) subject walking through the laboratory space in order to navigate to randomly highlighted virtual objects.

A. *Materials and Methods*

We performed the experiments in a 10 meters times 7 meters darkened laboratory room. The subjects wore a HMD (ProView SR80, 1280x1024@60Hz, 80° diagonal field of view) for the visual stimulus presentation. On top of the HMD an infrared LED was fixed, which we tracked within the laboratory with an active optical tracking system (PPT X8 of WorldViz), which provides sub-millimeter precision and sub-centimeter accuracy at an update rate of 60Hz. The orientation of the HMD was tracked with a three DOF inertial orientation sensor (InertiaCube 3 of InterSense) with an update rate of 180Hz. For visual display, system control and logging we used an Intel computer with Core i7 processor, 6GB of main memory and *n*Vidia Quadro FX 4800.

At the beginning of the experiment, we introduced subjects to the metaphors in the three experimental conditions:

- **Condition RW**: In this condition users could navigate through the game environment only by real walking, for which we used a one-to-one mapping between real and virtual motions.
- **Condition JM**: In this condition users could navigate through the game environment by real walking and the jumper metaphor as explained in Section II (see Fig. 4).
- **Condition TP**: This condition was similar to condition JM, but we did not use an animation sequence for the jump, but rather placed the user directly to the predicted target location.

We tested the conditions with a within-subject design method. During the experiment the room was darkened, and a black curtain was fixed around the HMD in order to reduce the subject’s perception of the real world. The visual stimulus consisted of a simple virtual island with five virtual primitive objects, i.e., blue box, red torus, orange sphere, green pyramid and pink cylinder, rendered stereoscopically by Crytek's CryEngine 3 (see Fig. 2) as well as our own software. The game environment covered an enclosed space of 9 meters times 7 meters and fitted entirely into our laboratory space.

In the first trial subjects started in the center of one side of the room in the IVE as well as in the laboratory. Now one object was randomly highlighted and subjects had to navigate to this object by one of the three techniques and touch it with their hand. After the user successfully touched the object, another object was randomly highlighted and subjects had to move from the current location to the next target location and so on. After each object was reached three times (15 trials), the series was over and the next condition was tested. We measured the time the subject needed to fulfill the task. The sequence of conditions in which subjects participated was randomly chosen. We used a different randomly generated arrangement of the five virtual objects for each condition. The assignment of an arrangement to a particular condition was chosen randomly.

After each condition, the subjects had to draw the virtual primitive objects into a top view grid and fill out a user questionnaire for the used condition. The usability questionnaire contained questions concerning the ease-of-use, ease-of-learn, effectiveness, and satisfaction. Furthermore, subjects had to judge the difficulty of the task. All questions allowed responses on a 5-point Likert-scale.

The maps sketched by the subjects were compared with the original map and scored on a 5-point Likert-scale by an experimental observer regarding object position and dimension. The observer did not know which map belonged to which condition. In addition, subjects filled out Kennedy's simulator sickness questionnaire (SSQ) [10] immediately before and after the experiment as well as the Slater-Usoh-Steed (SUS) presence questionnaire [21].

B. Participants

9 male and 2 female (age 22-33, ø: 26.18) subjects participated in the study. All subjects were students of computer science, mathematics or psychology. All had normal or corrected to normal vision. 2 had no game experience, 1 had some, and 8 had much game experience. 5 of the subjects had experience with walking in a HMD setup. All subjects were naïve to the experimental conditions. The total time per subject including pre-questionnaires, instructions, training, experiments, breaks, and debriefing was 45 minutes. Subjects were allowed to take breaks at any time.

C. Results

Figure 3 shows the average Likert-scale scores as colored bars with the standard errors (SE) for conditions RW (blue), JM (red) and TP (green). The x-axis shows the usability categories, the y-axis represents a 5-point Likert-scale (0 corresponds to a negative and 4 to a positive rating of the metaphor).

We analyzed the mean Likert-scale scores for each usability category, i.e., ease-of-learn, ease-of-use, effectiveness and satisfaction, the map sketching task and the time to fulfill the task for each of the conditions with a one-way ANOVA and performed a post-hoc Tukey test in order to analyze statistical effects between the conditions. We have found a significant main effect ($F(2, 30) = 10.975$; $p < 0.01$) of the condition on the category satisfaction. Post-hoc analysis showed that subjects were significantly more satisfied while using real walking ($p < 0.01$) or the jumper metaphor ($p < 0.01$) compared to the teleportation metaphor. But, there was no significant difference in satisfaction between real walking and the jumper metaphor. The average Likert-scale scores for the conditions were 3.18 (SE: 0.12) for RW, 2.91 (SE: 0.16) for JM, and 1.82 (SE: 0.32) for TP.

In addition, we have found a significant main effect ($F(2, 30) = 4.731$, $p < 0.05$) of the condition on the subject's task judgment. The Tukey test showed that subjects judged that they were significantly better at the task using real walking ($p < 0.05$) and the jumper metaphor ($p < 0.05$) compared to teleportation. We found the following average Likert-scale scores: 2.70 (SE: 0.31) for condition RW, 2.58 (SE: 0.25) for condition JM, and 1.67 (SE: 0.21) for condition TP.

Furthermore, we have found a significant main effect ($F(2, 30) = 4.500$; $p \leq 0.02$) of the condition on the map drawing task. In the post-hoc analysis, we found that subjects were significantly better at the map drawing task using real walking compared to the teleportation metaphor ($p < 0.02$). However, there was no significant difference in sketching the map after real walking compared to the jumper metaphor. The average Likert-scale scores for the conditions were 2.73 (SE: 0.24) for RW, 1.91 (SE: 0.21) for JM, and 1.64 (SE: 0.34) for TP. We have not found a significant main effect of the condition on the categories ease-of-learn, ease-of-use, effectiveness, and the time to fulfill the task.

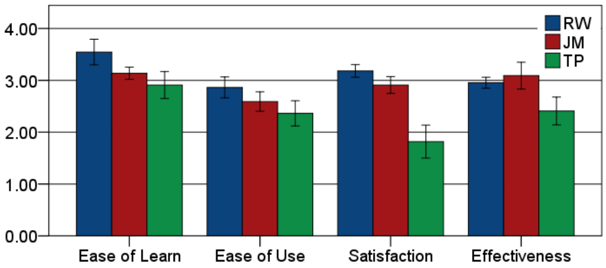


Figure 3. Pooled results of the usability questionnaires of the (blue) real walking (RW), (red) jumper metaphor (JM) and (green) teleportation (TP) condition.

The subjects' mean estimation of their level of feeling present in the IVE averaged to 4.38 on a scale from 1 to 7, where a higher score indicates greater presence. Kennedy's SSQ showed an averaged pre-experiment score of 1.27 and a post-score of 3.0 for the experiment, which is a typical result for HMD setups [1].

D. Discussion

On average subjects judged that the jumper metaphor is slightly less (but not significant) easy to learn and use compared to real walking in an immersive setup (0.41 average Likert-scale score difference for ease-of-learn, respectively 0.27 for ease-of-use). Since the jumper metaphor extends real walking by an additional way of locomotion, it is reasonable that additional learning and training is required to use the jumper metaphor compared to real walking.

Although we have not found a significant effect on the effectiveness and time to fulfill the task, on average subjects were 15.5 seconds (11.81%) faster using the jumper metaphor compared to real walking even for the short distances (<6m) during the experiment. The efficiency benefit of the jumper metaphor compared to real walking depends on the distance a player intends to travel, i.e., the larger the distance to travel the larger the efficiency benefit of the jumper metaphor.

Subjects were significantly worse at map sketching after using teleportation compared to real walking, which is an indicator for disorientation during the experiment. Subjects were also slightly (but not significant) worse in map sketching after using the jumper metaphor in comparison to real walking. However, subjects stated that they were not disoriented more often using the jumper metaphor compared to real walking (0.0 average Likert-scale score difference). We assume two possible reasons for this: (1) subjects were more focused on the metaphor itself than on the object remembering task when using the jumper metaphor, (2) the duration of the jump animation was too short (as also one of the subjects stated as a comment in the questionnaire).

The jump animation seemed to play an important role not exclusively on disorientation, but also on the user acceptance, because subjects evaluated the teleportation metaphor as significantly less satisfying and more difficult to fulfill the traveling task. Even for the short distances


(a) (b) (c) (d)

Figure 4. Illustration of a user triggering a jump during the evaluation: (a)-(b) user accelerating from a standing position until (c) the acceleration threshold is exceeded, triggering the jump, and (d) user decelerating.

during the experiment, 54.55% of the subjects preferred the jumper metaphor over real walking and teleportation. For long distances such as in typical game levels, 90.91% of the subjects preferred the jumper metaphor.

IV. CONCLUSION

In this paper we introduced the jumper metaphor, which combines the strengths of real walking with magical jump navigation for effective exploration of large-scale IVEs. We showed that a jump can be initiated based on real walking only, without the need for additional 3D input devices. The evaluation has shown that the jumper metaphor has the potential to allow a more effective exploration of IVEs in comparison to real walking, with only minor effects on space cognition and disorientation.

The jumper metaphor can easily be used with current immersive display setups and novel video game interfaces such as the Microsoft Kinect sensor. Due to the positive evaluation of this metaphor, we plan to expand the study to such video game interfaces. In addition, we will analyze different animation effects as well as camera trajectories in order to further improve the jumper metaphor and to increase efficiency and space cognition.

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