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Short Paper: Comparing Virtual Trajectories Made in Slalom Using Walking-In-Place and Joystick Techniques

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Abstract

In this paper we analyze and compare the trajectories made in a Virtual Environment with two different navigation techniques. The first is a standard joystick technique and the second is the Walking-In-Place (WIP) technique. We propose a spatial and temporal analysis of the trajectories produced with both techniques during a virtual slalom task. We found that trajectories and users' behaviors are very different accross the two conditions. Our results notably show that with the WIP technique the users turned more often and navigated more sequentially, i.e. waited to cross obstacles before changing their direction. However, the users were also able to modulate their speed more precisely with the WIP. These results could be used to optimize the design and future implementations of WIP techniques. Our analysis could also become the basis of a future framework to compare other navigation techniques.

Categories and Subject Descriptors (according to ACM CCS): Computer Graphics [I.3.7]: Three-Dimensional Graphics and Realism—Virtual Reality; Computer Graphics [I.3.6]: Methodology and Techniques—Interaction Techniques

1. Introduction

In Virtual Reality (VR) applications, navigation is one of the fundamental 3D interaction tasks [BKLP05]. The ability to walk is one of the most basic and essential need to complete other more complex tasks within Virtual Environments (VE) (Figure 1). However, most of the time, the working space is limited and real walking cannot be used. Various techniques have been developed so far, based on specific devices such as treadmills or on software metaphors.

The Walking-In-Place (WIP) technique [SUS95] has been introduced to enable a real physical walking movement during virtual navigations. With WIP, the user can move infinitely inside the VE by consciously walking in place in the real world. The motions of the user's body are tracked and analyzed to be converted into inputs for the locomotion simulation into the VE. The first implementations were based on a neural network to detect the footsteps of the user [SUS95]. More recent implementations use frequency analysis [FWW08] or biomechanical state automaton [WWB10]. Another recent WIP implementation proposes to track the user's head motions with a webcam [TME*10].

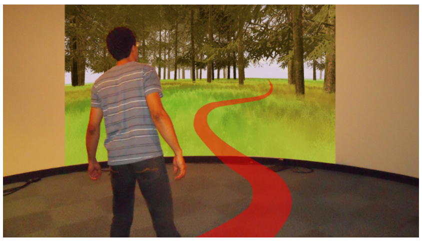

Figure 1: *Slalom navigation in a Virtual Environment.*

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Most of the evaluations of the WIP technique are based on subjective questionnaire to quantify the presence or potential motion sickness induced by this technique [RSS*02] [UAW*99]. Whitton et al. [WCF*05] have performed a quantitative study to compare the WIP technique to natural walk and joystick-based First-Person Shooter (FPS) techniques, in terms of task performance and kinematics of the task criteria, but only for straight lines. Other studies compared the trajectories produced by different interaction techniques, but only on qualitative criteria [ZLB*05]. However, the navigation techniques are usually used in complex navigations, including turns and changes of speed. To the authors' best knowledge, the WIP has never been evaluated on such kind of trajectories so far. In this paper, we analyse and compare the trajectories produced by the WIP with ones produced by joystick on slalom paths.

2. Experimental Data

The trajectories of 2 navigation techniques are compared: the WIP technique and a standard navigation using a joystick. We chose to implement the WIP technique proposed in [TME*10] using a webcam-based tracking (25 Hz capture), while the joystick was based on a classical analogical implementation. For the WIP technique, the advance speed was computed based on the lateral amplitude and frequency of the user's head oscillations. Both techniques were calibrated to provide the same average speed during the navigations. Because of the limited Degrees of Freedom of the tracking system, the orientation of the head on the roll axis was used to turn. For both techniques, the turns were based on a rate control law of $45°/s$. The WIP implementation, as well as the experimental apparatus used are described with more details in [TME*10]. During the experiment, the participants had to navigate in the VE through 2 different paths composed of eight 3m x 3m gates regularly placed composing a slalom. The instruction received by the participants was to cross the gates in the correct order.

Population: Twelve participants (10 males and 2 females) aged from 22 to 35 ($Mean(M) = 25.4$, $Standard\ Deviation(SD) = 3.35$) performed the experiment. All participants were used to VE but were naïve with respect to the WIP technique and the experimental setup.
Apparatus: The evaluation was performed within a 3D virtual environment without any contextual cues, except for gates that the user had to navigate through. A fog effect was added to mask the distant gates, allowing to perceive only the 2 or 3 closest gates. A texture on the ground provided visual flow information during the navigation. Participants were at a distance of 1.5 m in front of a 1.72 m large and 1.24 m height back-projected screen (with a physical field of view of 60° horizontally and 45° vertically). The resulting image had a resolution of 1600×1200 pixels.
Experimental plan: The participants were exposed to 2 blocks of 12 trials each: one block for each of the experimental conditions. Half of the participants started with the joystick condition, while the other half started with the WIP.
Collected Data: The trajectories of the participants in the VE were recorded at a frequency of 60 Hz for every trial. The orientation of the virtual camera was also recorded.

3. Trajectories Analysis

The proposed evaluation is based on both spatial and temporal analysis. Moreover, the spatial analysis focuses on both macroscopic and microscopic aspects of trajectories.

3.1. Spatial Analysis

The produced trajectories are time parametric functions. However, some relevant information can be extracted from the shape of the trajectories, independently of time.

Distance to Shortest Trajectory: To characterize the differences between the two conditions, we computed for each participant the mean difference between the produced trajectories and the shortest trajectory for each condition. The shortest trajectory was defined as the trajectory composed of straight lines between the inner post of each gate. We conducted a one-way repeated measure ANOVA on the technique used (joystick and WIP). The ANOVA revealed a significant dependency between the distance to the shortest trajectory and the interaction technique used ($F(1,11) = 16.94$, $p = 0.002$). The area between the trajectory and the shortest trajectory is significantly smaller with the joystick technique ($M = 86.55\ m^2$) compared to the WIP technique ($M = 110.93\ m^2$).

Mean Trajectory: To further stress the differences between the two techniques, we computed the mean trajectory for all participants for each set of conditions for the two paths. We re-sampled the trajectories with samples every $1m$ in the forward direction. The new samples were computed as the mean of all the values in the sample interval. A sample of the mean trajectories for the joystick and WIP conditions on the first path is displayed in Figure 2. The standard deviations of the mean trajectories represented in Figure 2 stress higher variability of the trajectories produced with the WIP technique. Moreover, the behaviour during the crossing of the gates seems to be different.

For each gate of the 2 mean trajectories, we computed the signed distance of the inflexion point to the closest gate, as well as the distance to the center of the gate when the users crossed the gates. For both criteria, we conducted a one-way repeated measure ANOVA on the technique used (joystick and WIP). We found a significant effect of the technique on the position of the inflexion points ($F(1,13) = 17.33$, $p = 0.001$). With the WIP technique the inflexion point is located after the gate ($M = 0.14\ m$), while it is located before with the joystick technique ($M = -0.42\ m$). We also

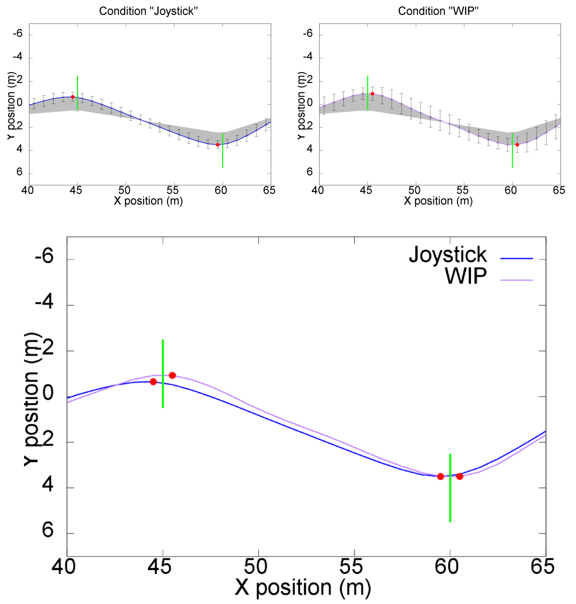

Figure 2: *Samples of the mean trajectories of WIP and joystick. The error boxes represent the standard deviations. Gates are represented in green, the distance to the shortest trajectory in gray and the inflexion points in red.*

found a significant effect of the technique on the distance to the center of the gate during the crossings ($F(1,13) = 34.75$, $p < 0.001$). Thus, the user crossed the gates closer to their centers with the WIP technique ($M = 0.38$ m) compared to the joystick ($M = 0.63$ m). In other words, with the WIP technique, the participants turned after crossing the gates, while they turned before with the joystick.

Curvature of the Trajectory: In order to further stress the differences in the behavior during the turns, we focused our analysis on the curvature of the trajectories. We computed the curvature at a microscopic level of trajectories parametrically defined as plane curves over time. This elicits a high difference in magnitude of curvature peaks between WIP and joystick. The Figure 3 illustrates this difference for two trials of the 6^{th} participant. The signal made of the curvatures of the trajectory over time is composed of impulses. In order to count and detect impulses, we used a first order continuous-time low-pass filter with a cut-off frequency of 10 Hz to filter the computed curvatures, and set a detection threshold for impulses at 0.02 m^{-1}.

To characterize the properties of the curvature for the different conditions, we computed 3 different criteria based on the detected impulses: (1) the number of impulses per trial, (2) the length of the impulses (in seconds) and (3) the area of each impulse. For each criterion, we computed the mean for each participant and we conducted a one-way repeated

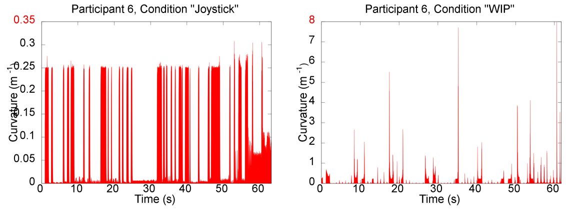

Figure 3: *Curvatures of trajectories for two trials of the 6^{th} participant.*

measure ANOVA on the technique used (joystick and WIP). The analysis revealed a significant dependency to the technique used for all 3 criteria. The results are summarized in Table 1.

Criterion	$F(1,11)$	p
Number of impulses	30.27	< 0.001
Length of impulses	13.43	0.004
Area of impulses	6.77	0.025

Table 1: *Results of the ANOVA on the curvature criteria.*

The participants significantly turned more often with the WIP technique ($M = 1108.9$, $SD = 284.6$) than with the joystick ($M = 608.9$, $SD = 77.2$). However, they turned significantly for a shortest amount of time with the WIP ($M = 0.33$ s, $SD = 0.08$ and $M = 0.45$ s, $SD = 0.07$ respectively). Finally, the area of impulses revealed that the participants significantly turned more with the WIP technique ($M = 0.19$ $s.m^{-1}$, $SD = 0.14$) than with the joystick ($M = 0.08$ $s.m^{-1}$, $SD = 0.02$).

3.2. Temporal Analysis

Speed: We computed the advance speed of the participants depending on the experimental conditions. We filtered and re-sampled the data using the same method as with the computation of the mean trajectories. To characterize the speed behaviour during the trajectories, we computed the average speed for all participants at each gate. We conducted a one-way repeated measure ANOVA on the technique used. We found a significant effect of the technique used on the speed at each gate ($F(1,13) = 195.46$, $p < 0.001$). The users were faster with the WIP technique ($M = 2.48$ $m.s^{-1}$, $SD = 0.1$) compared to the joystick technique ($M = 2.10$ $m.s^{-1}$, $SD = 0.007$). These results suggest that participants tended to cross the gates at full speed with the WIP technique.

Smoothness: The maximum smoothness model [PHA*07] was used as another criterion. According to this model, natural motions tend to be as smooth as possible to minimize the energy involved. For each participant, we computed the mean value of the integrated absolute value of the jerk over the time for each trajectory. Greater jerk corresponds to a smaller smoothness of the trajectory and thus can be considered as less natural. A one-way repeated measure ANOVA on the technique used (joystick and WIP) revealed a significant dependency between the cumulated jerk and the technique used ($F(1,11) = 59.56$, $p < 0.001$). The trajectories are smoother with the joystick technique ($M = 10.7\ m.s^{-2}$, $SD = 1.6$) compared to the WIP technique ($M = 197.5\ m.s^{-2}$, $SD = 84.0$). Thus, the trajectories produced by the joystick seem to be closer to realistic natural walking trajectories compared to WIP, according to the smoothness model [PHA*07].

4. Discussion

Our results show strong differencies between trajectories produced by the WIP and the joystick, according to different criteria. The characteristics of the curvatures highlight more frequent and tighter changes in direction with the WIP technique. It seems that the users were not able to predict their future trajectory accurately with the WIP technique, resulting in a continuous adaptation of the advance direction. The position of the inflexion points and the distance to the center of the gates at each gate are consistent with this hypothesis. The implementation of the turns with the WIP might explain those results. Indeed, if the user's head oscillations were too important, turns could be triggered inappropriately.

Moreover, our results suggest that the trajectories produced with the WIP technique are less "efficient" in terms of traveled distances as well as naturalness compared to those made using the joystick. This difference could be explained by the difference in training of the participants. Indeed, all of them were proficient with the joystick but were using WIP for the first time. The control law for turns can be another reason, as the participants were apparently less able to choose their direction accurately with the WIP technique.

Finally, the curvature of the trajectories is clearly more important with the WIP technique. The participants tended to follow tighter turns. However, the underlying implementation of the turns for both joystick and WIP conditions were strictly identical. Thus, the participants decreased their speed during the turns with the WIP. The users seem more able to modulate their speed precisely with the WIP, which provided more varied navigation patterns. These results could provide guidelines for future implementations of turns when designing a WIP technique.

5. Conclusion

In this paper, we compared a WIP technique to the joystick interface. When observing slalom trajectories produced with both techniques, we found that the navigation strategy of the user was different with the WIP technique compared to the joystick. The participants had more difficulty to anticipate their trajectory with the WIP. We also found that the speed during the turns decreased and the user modulated their speed more precisely with the WIP technique. The trajectories produced by the WIP had more jerk than those produced by the joystick and thus were less likely to feel natural for the users. However, the WIP provided a better control of advance speed while the joystick was more precise for controlling direction.

Taken together, our results provide insights on the behavior of users when navigating using WIP vs. joystick. They could inspire guidelines for future design and implementations of WIP techniques, notably concerning the handling of turns. Last, a future framework to compare 3D navigation techniques could be built based on the proposed analysis.

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