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Arm Swinging vs Treadmill: A Comparison Between Two Techniques for Locomotion in Virtual Reality

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Abstract

When it comes to locomotion in Virtual Reality (VR), a wide range of different techniques has been proposed in the scientific literature or as commercial products. However, the best choice for a specific application is still not immediate, being each technique characterized by different advantages and drawbacks. The present work reports on the results of a user study-based comparison between two methods: a locomotion treadmill, which supports omni-directional movements through walking in place over a hardware device, and Arm Swinging, which recognizes movement from the swinging back and forth of the user's arms (e.g., gathered by sensors embedded in hand controllers). Experiments have been carried out in a realistic immersive VR scenario, which requested users to respond to a fire emergency in a road tunnel by moving and interacting with the environment.

Categories and Subject Descriptors (according to ACM CCS): I.3.6 [Computer Graphics]: Methodology and Techniques— Interaction techniques

1. Introduction

Locomotion in Virtual Reality (VR) has always been a challenging issue, in the perspective of guaranteeing users a high immersion and sense of presence while exploring and interacting with Virtual Environments (VEs). With the explosion of consumer VR, a large number of hardware and software solutions have been developed to takle the above issue, but none of them has prevailed yet.

The aim of the present work is to carry out an evaluation of two of the solutions that have been proposed so far, by working with an application developed in order to support both. The application, named FréjusVR, is a serious game based on immersive VR technology that has been originally designed to study the behavior of the Fréjus tunnel's users in case of emergency. Within the road tunnel scenario, virtual users are presented with a number of interactions to be performed by moving and using their hands.

The reasons behind the choice of this application were twofold. Firstly, collecting qualitative and quantitive measures on an interactive experience which accurately represents a real-world setting could be more representative than using an ad-hoc scenario solely intended for locomotion testing. Secondly, being developed in length, the road tunnel is inherently a valid choice for experimenting with the two locomotion paradigms, which are both conceived for overcoming the physical limits of a room environment.

The VR system selected for the study is the HTC®Vive™. Comparison was performed by letting the users explore the VE using either a commercial treadmill or a well-know locomotion technique based on swinging arms. For the first approach, the Cyberith's Virtualizer treadmill [CH14] was considered, whereas for the second approach the Vive™ hand controllers were used.

2. State of the art

A number of studies tried to address the problem of developing ever more effective paradigms for locomotion in immersive VEs, or assessing and comparing existing ones.

According to Wilson et al. [WKMW16], navigation methods based on haptic devices (like keyboard and joystick) that have been largely explored by researchers in the past, proved to be inferior in terms of spatial orientation when compared with techniques based on tracking with Head-Mounted Displays (HMDs).

As stated by Ruddle and Lessels, the development of wide-area tracking techniques led to the development of interfaces that let the user walk through an empty space which corresponds to the virtual world (or part of it) while having all the proprioceptive information related to real walking provided by the system [RL09]. Unfortunately, though these methods (referred to as "room-scale") are perfectly suitable for relatively small VEs, when it comes to large environments different approaches have to be pursued in order to overtake the boundaries posed by the physical space.

One of the most common solutions adopted to cope with space limitations is represented by the "Point & Teleport" technique, also know as "teleportation" [BRKD16]. The idea is to use laser or parabolic pointers originating from hand controllers in order to let

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the user choose a point where instantly move to. In [NSN16], Nilsson et al. stated that teleportation is likely to be much more efficient than other forms of locomotion, but efficiency comes at the expense of naturalness. Hence, several applications may require for a more mundane metaphor, e.g., when a certain degree of physical effort needs to be simulated.

The above issues can be addressed by making the user walk in place, rather than on foot. This goal can be achieved through locomotion treadmills [DCC97] or through additional tracking devices. Treadmills, whose main drawbacks are the hardware cost and the bulkiness, should ideally provide the most natural "Walking in Place" (WIP) feeling. Unfortunately, the presence of body harness devices, the fact that gait is generally replaced by a feet sliding movement and the difficulty for the user to crouch or perform similar gestures risk to break the sense of presence. Methods based on external tracking devices can be very accurate, but costly, e.g., when professional optical systems are used (like in [NTN*16]). When affordable off-the-shelf tracking devices are exploited (like, for instance, the Microsoft Kinect [WNHW14]), they generally suffer from occlusion problems. Independent of the hardware used, when WIP is implemented through additional tracking devices, walking is typically replaced by a marching movement, which can be perceived as rather fatiguing. Moreover, other issues arise, e.g., related to the need to keep the user within a confined space.

When additional tracking devices are not available, the WIP paradigm could be implemented through the Virtual Treadmill technique in [SSU95]. By means of machine learning algorithms, this method uses HMD positional data collected over time to recognize WIP and generate the corresponding movement in the VE.

For interactive VR systems bundled with hand controllers, an effective solution which proved to be capable to preserve immersion is the "Arm Swinging" (AS) technique [MXM*15]. According to a study by Pai and Kunze [PK17], AS is perceived as particularly natural by the users and, compared with WIP, it allows for more prolonged usages while not sacrifying immersion.

As said, a number of works focused on analyzing results achieved by comparing the various techniques. For instance, in [BKH97], Bowman, Koller and Hodges operated a comparison between different techniques for moving inside immersive VEs with head tracking and HMDs while using 3D spatial input devices for interaction, but they did not include techniques based on physical user motion. By using the Myo Armband as wearable tracking device, Wilson et al. made a comparison between natural walking, WIP and AS [WKMW16]. In case of AS and WIP, the direction of gaze was used as direction for the generated movement, thus preventing looking around while moving. Given these premises, the result of the comparison showed the dominance of natural walk over the other two methods, while WIP resulted as slightly better than AS in terms of turning error. In [NSN13], Nilsson, Serafin and Nordahl operated a comparison between keyboard movement, Hip Movement (HM), a technique in which the user swings left and right the hip to generate motion, WIP and AS. Both WIP and AS were perceived as more natural than HM and keyboard, but AS better represented real walking in terms of physical effort and, led to lower positional drifts. Ferracani et al. [FPB*16] compared four interaction methods, i.e., WIP, AS, (finger) Tap (in the direction the user wants to walk) and Push (closing and opening the hand while dragging it). WIP and Tap obtained the highest scores in terms of naturalness, speed and collision avoidance.

Figure 1: *Cyberith Virtualizer treadmill and Arm Swinging locomotion methods.*

3. Case study

To the best Authors' knowledge, a comparison between locomotion treadmills and techniques based on physical motion data gathered through affordable sensors is missing. Hence, the purpose of the present work is to fill this gap by reporting on the results of a study comparing users' experience in exploring and interacting with a VE using these two approaches. In particular, the omni-directional Virtualizer treadmill (later referred to as VT) was selected to represent methods based on the first approach, as it was available at Authors' premises. For the second approach, AS was specifically considered because of the advantages discussed in Section 2 (though future comparison may include also other techniques). With both the approaches, the HTC®Vive™ VR system (headset and controllers) was used. The two methods are depicted in Figure 1.

As said, the tool selected for the evaluation activities was the FréjusVR application, which was developed with Unity3D and designed to communicate to the general users the emergency procedures concerning a fire scenario in the Fréjus road tunnel and to study their behavior under given conditions. Besides letting the users walk inside the tunnel, the application offers a wide set of interactions (Figure 2), which were modeled based on the security brochure provided at the tunnel entrance. In order to survive, the user has to reach an emergency shelter as quickly as possible, while trying to follow the prescriptions reported on the brochure (press a SOS button, call for help by using SOS telephones, briefly try to use the extinguishers, if possible, etc.). The presence of these forms of interaction is essential for the evaluation, since they stress the characteristics of the two locomotion methods, bringing to light strengths and weaknesses of both the approaches.

The Virtualizer's Software Development Kit (SDK) was used as it is, and the application was developed around its logic. For the AS locomotion technique, a custom solution exploiting the Vive™ controllers had to be designed in order to match the VT behaviour. Thus, starting from the ElectricNightOwl's AS implementation [Ele16], the Vive™ room-scale space was reduced to a

Figure 2: *Screenshots from the FréjusVR application: fire event scenario and available interactions.*

cylinder (one meter radius) around the user in order to prevent walk while preserving the HMD freedom of movement.

4. Methodology

Thirty volunteers were selected for the tests, fifteen per each locomotion method (to avoid learning effects). Twenty-nine of them completed the test, wheareas one of the (VT) users withdrew from the experiment before the end because of extreme motion sickness symptoms. Users were introduced to the experience through a presentation of the emergency procedures of the Fréjus tunnel followed by a training session, in which they were given time to familiarize with locomotion methods and interaction possibilities. When ready, users could start the simulation, which asked them to react to a fire emergency. Two videos showing the complete simulation and users' interaction with AS and VT are available at https://goo.gl/SP68Yt.
Evaluation was performed by means of a questionnaire, which was designed to compare users' experience with the two locomotion methods. The first part focused on usability, and included questions from the VRUSE questionnaire [Kal99]. In particular sections with questions on usability facors like functionality, user input, flexibility, simulation fidelity, error correction/handling and robustness, sense of immersion/presence and overall system usability were maintained (slightly adapted, when needed). Questions on user input were duplicated, in order to investigate both the perspective of locomotion and of interaction with objects. Sections on system output, user guidance/help and consistency were removed, as differences were not expected for these factors when changing the locomotion method. The second part, which was based on the Simulator Sickness Questionnaire (SSQ) [KLBL93], was aimed to quantify the possible impact of motion sickness.

5. Experimental results

Results concerning usability are well summarized by Figure 3, which reports the average scores assigned to the synthesis questions closing each of the VRUSE sections (in a five-point Likert scale). Statistical significance of the collected answers was evaluated using unpaired Student's t-tests.

In terms of functionality, the two methods did not differ in a significant way. More precisely, they resulted similar under every aspect except for the ease of access to all the functionality (control) of the system, where AS prevailed (VT 3.00, AS 3.60, p = 0.02).
In terms of locomotion-related user input, AS significantly outperformed VT in most of the questions. In particular, AS proved superior in terms of ease of use (VT 2.06, AS 3.40, p = 0.0001), response to user input (VT 2.26, AS 3.46, p = 0.0003), level of control over where to go (VT 2.06, AS 3.26, p = 0.0005) and ease of moving and repositioning in the VE (VT 2.20, AS 3.13, p = 0.01). Furthermore, VT exceeded AS in terms of errors made while using the locomotion system (VT 2.46, AS 1.00, p = 0.0001) and excessive complexity for an effective usage (VT 1.33, AS 0.50, p = 0.009). Finally, AS users considered the locomotion method ideal for moving within the VE more than VT users (VT 1.90, AS 2.93, p = 0.001), and they perceived its functionality as more adequate than the VT ones (VT 2.46, AS 3.20, p = 0.01). Still with respect to user input, but with a focus on interaction with objects, the two methods did not differ in a significant way.
Concerning flexibility, AS significantly overtook VT in most of the aspects. In particular, AS users found it easier to perform the task in the chosen order than VT users (VT 2.66, AS 3.33, p = 0.02); the latter were not able to achieve what they wanted to in the system more frequently than AS users (VT 1.5, AS 0.66, p = 0.01).
Regarding simulation fidelity, the two methods proved to be comparable under almost every aspect, though VT users seemed to perceive the application as freezing at some time during the simulation, whereas AS users did not (VT 0.60, AS 0.06, p = 0.01).
With respect to error correction/handling and robustness, AS significantly outperformed VT in most of the questions. In particular, AS users found it easier to undo mistakes and return to a previous state than VT users (VT 1.60, AS 2.60, p = 0.0002). They also found that the system provided a higher protection against trivial errors (VT 2.67, AS 3.33, p = 0.03) and that it was more robust than the VT one (VT 2.00, AS 3.00, p = 0.0003).
Sense of immersion/presence was comparable, though VT users stated that they did not know where they were in the VE more frequently than AS users (VT 1.13, AS 0.50, p = 0.03).
Finally, for what it concerns the overall system usability, the AS method slightly exceeded the counterpart (VT 2.75, AS 3.17, p = 0.02); in particular, VT users thought that the system was working against them (VT 1.13, AS 0.33, p = 0.003), and that the system did not work as expected (VT 1.46, AS 0.46, p = 0.001).
Regarding sickness, answers collected in the second part of the questionnaire (before and after the test) showed that the two methods had a similar impact on the users, and did cause any worsening of their previous health state. This result is probably correlated also to the short duration of the experience (about 3 minutes).
It is worth observing that users' success with the assigned task is a further (indirect) confirmation of the feedback collected through the questionnaire. In fact, AS users survived more frequently to the fire event than VT users, e.g., by reaching an emergency shelter (VT 40%, AS 80%, p = 0.025). Many VT users died inside the tunnel from intoxication, mainly for the lower ease of use of device (confirmed by direct feedback).

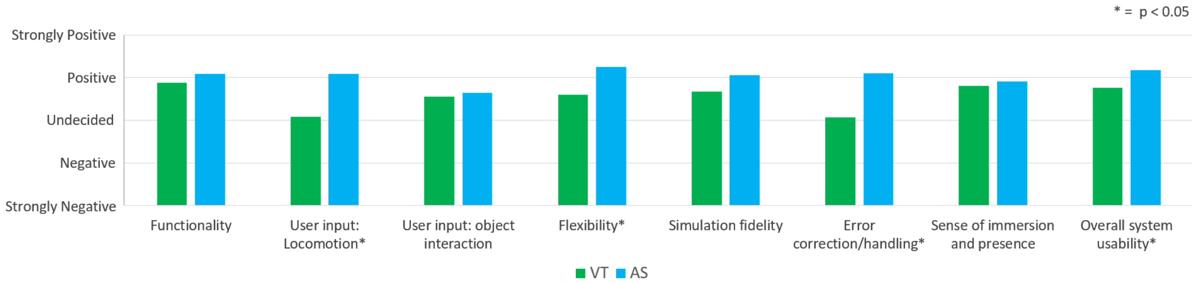

Figure 3: *Overall scores for the selected usability factors (questions adapted from the VRUSE questionnaire).*

6. Conclusions and future work

In conclusion, though the two methods were perceived as mostly equivalent in terms of usability factors like functionality, user input (w.r.t. interaction with objects), simulation fidelity, sense of immersion/presence as well as in terms of impact on motion sickness symptoms, AS prevailed in critical aspects like locomotion input, flexibility, error correction/handling and overall system usability. Users ascribed this outcome to the additional physical effort required by the VT, coupled with the unnaturalness of feet sliding and the increased encumbrance for interactions at foot level. Experimental setup, however, has some limits. In fact, the use of a complex scenario where not all the interactions are mandatory to complete the task (like handing an extinguisher and using it) could introduce a bias towards AS. A further bias could be caused by the fact that users never tried the two locomotion methods before the training session, which could be critical for VT (since it is intrinsically less intuitive that AS). It could have been also helpful to let each user test both the methods and collect feedback based on direct comparison.
Future work will be devoted to cope with the above limits, by designing further experiments capable to cover a wider set of conditions (different tasks and interaction requirements, etc.). Efforts will be also focused on including other locomotion methods in the comparison (e.g., based on wearable sensors, on different treadmills, etc.).

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References

[BKH97] Bowman D. A., Koller D., Hodges L. F.: Travel in immersive virtual environments: An evaluation of viewpoint motion control techniques. In *Proc. Annual International Symposium on Virtual Reality* (1997), pp. 45–52. 2

[BRKD16] Bozgeyikli E., Raij A., Katkoori S., Dubey R.: Point & teleport locomotion technique for Virtual Reality. In *Proc. Annual Symp. on Computer-Human Interaction in Play* (2016), pp. 205–216. 1

[CH14] Cakmak T., Hager H.: Cyberith Virtualizer: A locomotion device for Virtual Reality. In *Proc. ACM SIGGRAPH 2014 Emerging Technologies* (2014), pp. 6:1–6:1. 1

[DCC97] Darken R. P., Cockayne W. R., Carmein D.: The omni-directional treadmill: A locomotion device for virtual worlds. In *Proc. 10th ACM Symposium on User Interface Software and Technology* (1997), pp. 213–221. 2

[Ele16] ElectricNightOwl: Armswinger, 2016. URL: https://github.com/ElectricNightOwl/ArmSwinger. 2

[FPB*16] Ferracani A., Pezzatini D., Bianchini J., Biscini G., Del Bimbo A.: Locomotion by natural gestures for immersive virtual environments. In *Proceedings of the 1st International Workshop on Multimedia Alternate Realities* (2016), pp. 21–24. 2

[Kal99] Kalawsky R. S.: VRUSE– a computerised diagnostic tool: for usability evaluation of virtual/synthetic environment systems. *Applied Ergonomics 30*, 1 (1999), 11–25. 3

[KLBL93] Kennedy R. S., Lane N. E., Berbaum K. S., Lilienthal M. G.: Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. *The International Journal of Aviation Psychology 3*, 3 (1993), 203–220. 3

[MXM*15] McCullough M., Xu H., Michelson J., Jackoski M., Pease W., Cobb W., Kalescky W., Ladd J., Williams B.: Myo arm: Swinging to explore a VE. In *Proc. ACM SIGGRAPH Symposium on Applied Perception* (2015), pp. 107–113. 2

[NSN13] Nilsson N. C., Serafin S., Nordahl R.: The perceived naturalness of virtual locomotion methods devoid of explicit leg movements. In *Proc. Motion on Games* (2013), pp. 133:155–133:164. 2

[NSN16] Nilsson N. C., Serafin S., Nordahl R.: Walking in place through virtual worlds. In *Proc. 18th International Conference on Human-Computer Interaction. Interaction Platforms and Techniques* (2016), pp. 37–48. 2

[NTN*16] Nielsen M., Toft C., Nilsson N. C., Nordahl R., Serafin S.: Evaluating two alternative walking in place interfaces for Virtual Reality gaming. In *Proc. IEEE Virtual Reality Conference* (2016), pp. 299–300. 2

[PK17] Pai Y. S., Kunze K.: Armswing: Using arm swings for accessible and immersive navigation in AR/VR spaces. In *Proc. 16th Int. Conf. on Mobile and Ubiquitous Multimedia* (2017), pp. 189–198. 2

[RL09] Ruddle R. A., Lessels S.: The benefits of using a walking interface to navigate virtual environments. *ACM Transactions on Computer-Human Interaction 16*, 1 (Apr. 2009), 5:1–5:18. 1

[SSU95] Slater M., Steed A., Usoh M.: The virtual treadmill: A naturalistic metaphor for navigation in immersive virtual environments. In *Selected Papers of the Eurographics Workshops on Virtual Environments* (1995), pp. 135–148. 2

[WKMW16] Wilson P. T., Kalescky W., MacLaughlin A., Williams B.: VR locomotion: Walking » Walking in place » Swinging. In *Proc. 15th ACM SIGGRAPH Conference on Virtual-Reality Continuum and its Applications in Industry* (2016), pp. 243–249. 1, 2

[WNHW14] Wilson P. T., Nguyen K., Harris A., Williams B.: Walking in place using the Microsoft Kinect to explore a large VE. In *Proc. 13th ACM SIGGRAPH Int. Conference on Virtual-Reality Continuum and Its Applications in Industry* (2014), pp. 27–33. 2