Redirection Using Alignment

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ABSTRACT

Unobstructed locomotion in virtual reality (VR) using natural walking is often not possible due to the differing placement of obstacles in the physical and virtual environments. Redirected walking is a technique that helps to enable natural walking in VR by imperceptibly rotating the virtual environment such that users adjust their physical trajectory and avoid physical obstacles. Traditionally, the algorithms responsible for applying redirected walking focused mainly on steering users away from physical obstacles, with little regard for the locations of obstacles in the virtual environment. However, recent work showed that considering both the physical and virtual environments when applying redirected walking can lead to significantly fewer collisions with physical obstacles. We formalize the notion of *alignment*: the concept of comparing the physical and virtual environments according to some feature present in both environments. We provide a generalized definition of alignment that allows it to be used in any research problem, and we present an example of how alignment can be used to yield significant improvements in VR locomotion with redirected walking.

Index Terms: Redirected Walking—Alignment—Locomotion;

1 Introduction and Background

Exploration of virtual environments (VEs) using locomotion interfaces that enable natural walking is often preferred over interfaces that use artificial locomotion [7]. One such interface is redirected walking (RDW), which works by slowly rotating the VE around the user while they locomote, which causes them to adjust their physical trajectory to remain on their intended virtual path [6]. Using RDW, we can steer users away from physical obstacles that may otherwise obstruct their path in the physical environment (PE). The algorithm responsible for steering users is known as a redirection controller [5].

Over the years, many redirection controllers have been developed to try and minimize the number of collisions with physical obstacles that users incur while exploring large VEs. Since the VE can have any one of an infinite number of possible configurations, it is common for researchers to simply abstract away the VE as an infinite, empty plane in an attempt to develop controllers that can work in arbitrary environments. However, the VR locomotion problem is difficult precisely because of the differences in the sizes and locations of obstacles in the PE and VE. Thus, abstracting away the VE can actually hinder progress in developing effective controllers, since a large piece of information relevant to the locomotion problem is essentially being ignored.

Recently, Thomas et al. [10] and Williams et al. [12] showed that information from the virtual environment can be compared with information from the physical environment, and that this can improve the capabilities of redirection controllers. This technique of comparing information from the PE and VE has been coined as *alignment*. Thomas et al. [10] used the user's distance from a goal position in the PE and VE to apply redirection such that the user will reach the physical goal position when they arrive at the virtual goal position. This allowed the user to interact with a haptic proxy object located at the physical goal, which corresponded to an interactive object located at the goal position in the VE. Williams et al. [12] measured the user's proximity to obstacles in the PE and VE, and used the difference in these proximities to guide redirection as the user explored the VE, such that the user's proximity to obstacles in the PE and VE was as similar as possible. With this, they achieved significantly fewer collisions with obstacles than state-of-the-art controllers did.

While the concept of alignment, comparing information from both the physical and virtual environments, is new to the redirected walking community, it is not new to VR research as a whole. Yoon et al. [13] measured the similarity of the users' physical and virtual surroundings in order to optimize the placement of virtual avatars in telepresence applications. González-Franco et al. [2] measured the angular distance between an embodied virtual avatar hand and the user's physical hand and used this measurement to gain a better understanding of how much disagreement between the physical and virtual arm positions that users tolerated. Aymerich-Franch et al. [1] studied the impact of the difference between a user's physical and virtual body on their feelings of social anxiety. Though other researchers have used comparisons between the PE and VE to gain insight into their particular research problems, to the best of our knowledge this concept has not been studied formally until recently by Thomas et al. [10] and Williams et al. [12].

In this paper, we provide a formal and generalized definition for alignment, to make it easier for researchers to adopt the concept in their own research. We also showcase its usefulness in the context of virtual locomotion with redirected walking. Finally, we provide some advice on using alignment, and discuss potential applications of alignment to other locomotion interfaces.

2 A Generalized Definition of Alignment

Prior work that used concepts of alignment were specific to the research question those papers studied. Thus, their presentation of the idea of measuring and comparing features between the PE and VE is not easily extendable to other research problems. Here, we provide a generalized definition of alignment that is not specific to any particular problem space, so that it can be easily adopted in other research problems. To help solidify the concept of alignment, in Sect. 3 we provide a case study of a recent publication that used alignment to develop a redirection controller that achieves state-of-the-art performance.

Given a physical and virtual environment pair, we wish to compare some feature of the two environments. We define an *alignment metric*, $A(E)$, which measures the feature in a given environment, E. It is possible that the alignment metric is the metric that is normally used to measure the feature in question. Given a measure of the feature in each environment, we then define a distance function $dist(A(E_1), A(E_2))$ which computes the distance between the two metric values. This distance function tells us how similar or dissimilar two values of the alignment metric are. The metric and distance function should be defined such that when $dist(A(E_1), A(E_2)) = 0$, the feature of interest is *the same* in the PE and VE. As the configurations of the environments change, the similarity between the two environments changes, and the value of $dist(A(E_1), A(E_2))$

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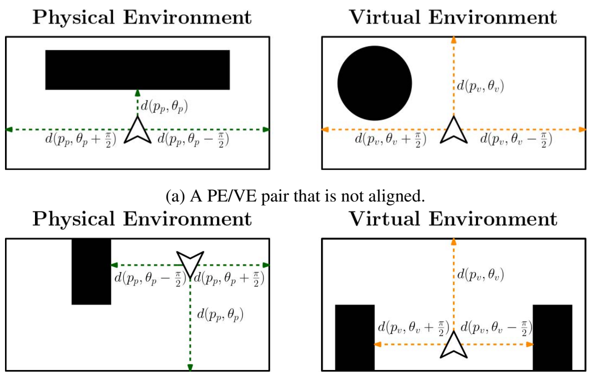

(a) A PE/VE pair that is not aligned.

(b) A PE/VE pair that is aligned.

Figure 1: A diagram of the alignment metric used in [12].

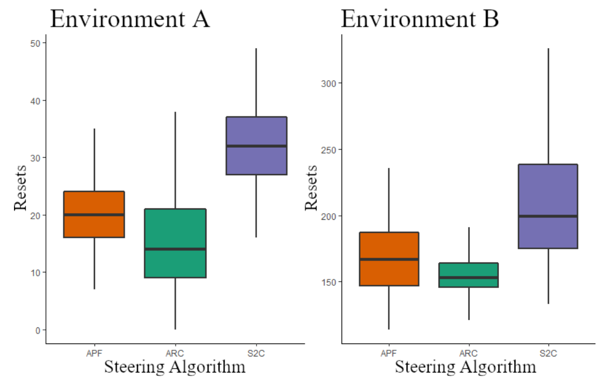

Figure 2: Results of steering using alignment (ARC [12]) or the state-of-the-art controllers (APF [11] and S2C [3]). ARC achieves significantly fewer collisions than the other methods.

changes. The value increases as the environments become more dissimilar, and decreases as they become more similar with respect to the feature of interest.

3 Example: Redirection Using Alignment

This example of alignment comes from the recent publication by Williams et al. [12], wherein they presented ARC, a redirection controller that steers users away from physical obstacles while they explore the virtual environment. In their work, the controller steered a simulated user in a physical environment with the goal of steering the user to a physical location that is aligned with the virtual one, to minimize the chance of collisions.

Their alignment metric is the user's distance to nearby obstacles directly in front of the user, and to the left and right of the user. Given the user's heading, θ, and location in the environment, p, the alignment metric $A(E)$ is sum $d(p,\theta)+d(p,\theta+\frac{\pi}{2})+d(p,\theta-\frac{\pi}{2})$. Here, $d(p,\theta)$ is the distance to the closest obstacle in the direction θ, starting from position p in 2D Euclidean space. Their distance function is the sum of the absolute value of the pairwise differences in the distances to obstacles in the physical and virtual environments:

$$\begin{aligned} dist(E_{phys}, E_{virt}) = & |d(p_{phys}, \theta_{phys}) - d(p_{virt}, \theta_{virt})| \\ & + |d(p_{phys}, \theta_{phys} + \frac{\pi}{2}) - d(p_{virt}, \theta_{virt} + \frac{\pi}{2})| \\ & + |d(p_{phys}, \theta_{phys} - \frac{\pi}{2}) - d(p_{virt}, \theta_{virt} - \frac{\pi}{2})|. \end{aligned}$$

Here, p_{phys} and p_{virt} are the user's positions in the physical and virtual environments, and θ_{phys} and θ_{virt} are the user's headings in the physical and virtual environments, respectively.

Using this alignment metric and distance function, Williams et al. developed a controller that steers the user such that their proximity to obstacles in the physical environment matches that of the virtual environment. A sample of the results of this controller is shown in Fig. 2. The full results (see [12]) indicate that steering based on alignment can significantly reduce the number of collisions a user incurs in complex physical and virtual environments.

Williams et al. found that, using their alignment metric and distance function, users steered by ARC experienced significantly fewer collisions with physical obstacles. Furthermore, they found that ARC steered users with rotations of the VE that were less intense than the rotations induced by other controllers. This leads to a more enjoyable experience for users since they are less likely to notice the VE rotations and experience simulator sickness while locomoting. For the environment pair in which the PE and VE were identical, but the user's starting location in the two environments was different, the authors found that in some cases ARC was able to steer the user in the PE such that their physical and virtual positions matched, at which point the redirection could be completely disabled—a behaviour which was not present in the redirection controllers they compared against.

4 Observations and Future Work

One especially attractive advantage of alignment is that, with a carefully defined metric and distance function, it works in any arbitrary environment. This is crucial if we wish to increase the democratization of virtual reality; specific solutions that only work in environments with particular shapes are not usable in the vast majority of use-cases for virtual reality.

In our experiments with alignment-based redirection controllers, we noticed that the alignment metric and distance function can have a large impact on the performance of the controller. That is, a metric that measures one feature may be much less descriptive of the environment than another feature is, and one distance function may be less accurate than another at measuring the similarity of two environments. This highlights the importance defining a metric and distance function that encapsulate environment information that is relevant to the research question. Doing this properly is not always easy, however. There may be multiple features that relate to the research question, and choosing the most relevant one may not be straightforward. For example, the user's location (coordinates) and their position relative to obstacles are both relevant features for VR locomotion. However, position relative to obstacles is usually more important since locomotion is mainly influenced by local environment features [4]. Additionally, since virtual reality is closely tied to human perception, it may impractical to define a meaningful alignment metric or distance function. For example, measuring and comparing the degree of presence evoked by being in two different environments is not easily framed in terms of numbers (alignment metric) and equations (distance function).

Despite potential difficulty in adopting alignment for some subjective research questions, we believe that alignment is still a powerful tool that can be used to help create better virtual experiences. The efficacy of measuring and comparing two environments with respect to some salient feature is supported by the fact that this idea has been utilized in areas outside of virtual locomotion [1, 2, 13]. In this paper, we presented an application of alignment to redirected walking controllers. Alignment can likely be applied to other types of locomotion interfaces. For example, alignment could be used to measure the user's position relative to open spaces in the physical environment, which can then guide the reconfiguration of the virtual environment architecture to most-closely match the nearby physical space in a locomotion interface like flexible spaces [8, 9].

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