Short-term Path Prediction for Virtual Open Spaces

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Abstract

In predictive redirected walking applications, reliable path prediction is essential for an effective redirection. So far, most predictive redirected walking algorithms introduced many restrictions to the virtual environment in order to simplify this path prediction. Path prediction is time-consuming and is also prone to errors due to potentially impulsive and even irrational walking behaviour of humans in virtual environments. Therefore, many applications confine users in narrow virtual corridors or mazes in order to minimise larger deviations from intended and predictable walking patterns.

In this paper, we present a novel approach for short-term path prediction which can be applied to virtual open space predictive redirected walking. We introduce a drop-shaped trajectory prediction which is described using a Lemniscate of Bernoulli. The drop's contour is discretised and we show how this is used to determine potential user trajectories in the virtual environment.

Index Terms: Human-centered computing—Virtual reality; Computing methodologies—Motion path planning

1 Introduction

Allowing a user to immerse in a virtual environment (VE) using a head-mounted display while really walking was shown to be the most natural and intuitive way of locomotion [5]. In the case of the VE being of equal or smaller size than the physical environment, a simple tracking system observing the user is sufficient for mapping the user's motion. However, since a VE is not necessarily limited in size, it is commonly larger than said tracked physical space. In order to compress such an extensive VE into this small tracking space, Razzaque et al. [4] introduced Redirected Walking which exploits the intrinsic capability of humans to unconsciously manage sensory conflicts to a certain extent. By inducing a slight mismatch between visual and vestibular cues through a head-mounted display, humans tend to adapt to this with their own real motion in favour of the visual stimulus. For example, most users intuitively adjust to small scene rotations around their virtual body (first person perspective) and walk on a physically curved path while assuming that they virtually walked on a straight line. These manipulations, so-called redirection techniques, are the core of redirected walking. However, since there are various redirection techniques, it may be more efficient to employ the most suitable redirection techniques depending on the user's position and heading (i.e. the user state). In order to account for various user states, so-called steering algorithms were developed to decide which redirection technique needs to be applied when. These steering algorithms can be further categorised into reactive and predictive algorithms, which describes the core concept of the algorithm. Whereas reactive steering algorithms simply apply a redirection technique based on the current user state, predictive algorithms determine potential future trajectories which the user could possibly take. Using such predicted trajectories, a planning algorithm can actively take into account future hindrances (e.g. a tracking space boundary) and adjust the redirection accordingly. So far, predicting these potential future trajectories was simplified to ensure real-time predictions and also to improve the prediction accuracy. Accordingly, many predictive redirected walking applications limited their VE to rectangular mazes and/or narrow corridors.

In this paper, we present a novel approach for short-term path prediction which will be applicable to predictive redirected walking in virtual open spaces.

2 Related Work

It was shown in many predictive redirected walking applications that if a virtual trajectory is completely known, planning algorithms greatly improve the redirection [1, 2, 8]. However, virtual trajectory prediction is not a trivial task. Especially in open virtual spaces it is very difficult to reliably estimate a user's behaviour. In order to find the virtual trajectory, there are different approaches for both short- and long-term predictions using the user's current movement or human locomotion models [3, 6]. They use defined target positions in the VE and estimate the probability for each of them based on the current state and walking behaviour. To do so, Nescher & Kunz [3] compared the smoothed direction of travel with the direction to the targets, while Zank & Kunz [6] used models of human locomotion as a reference to compare with the observed user path. Later, they extended this method to determine the location of the targets automatically from the VE's navigation mesh [7].

3 Methodology

Nowadays, many predictive redirected walking algorithms (e.g. MPCRed [2], FORCE [8]) employ a graph-based, probabilistic path prediction. Using such a graph in a narrowly constrained VE (e.g. a skeleton graph), the user state is assigned to a node or an edge (i.e. a connection between nodes) on this graph and a prediction is formulated based on various conditions. For example, in [2], the closest node to the current user state is identified as a starting node (see Figure 1(a)). Considering the smallest angular deviation between the user's heading and the edges connected to the starting node, a path prediction is made along the highlighted graph. Whenever the graph forks into multiple corridors, a probability is assigned to each path which is later accounted for in the planning algorithm.

This graph-based path prediction requires the VE to consist of mazes or similar, because the user could otherwise deviate too far from the graph, rendering the planning ineffective. In order to overcome this virtual constraint of narrowly confined environments, we propose a novel short-term path prediction, which is not relying on a graph anymore. In a first step, we assume that a user will always prefer to walk in the direction of his heading and not backwards. Then, in order to design the initial model, we assume the walking speed to be constant. This walking speed v is defined as a combination of translational t and rotational r movement, which both lie in the range of $[0,1]$. This means, for a single time frame (i.e. a single prediction), the user's movement is described by $v = (t, r)$. For example, a pure straight translation is denoted by $v = (1, 0)$, whereas a pure

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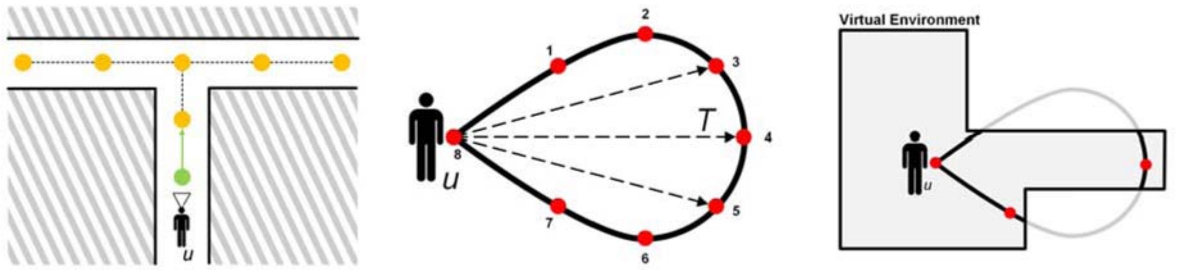

(a) Narrowly confined VE which is used for graph-based path prediction. The user state u is assigned to the closest node (green) and based on the user's heading, the prediction is aligned with the best matching edge. Yellow: Nodes; Dashed: Edges connecting the nodes.

(b) Drop-shaped path prediction with eight discretised contour points which are connected to the user state u via a walking trajectories T.

(c) Overlaying the drop-shaped contour on the VE may eliminate predictions lying in inaccessible areas. Here, an arbitrary VE (grey: walkable area) eliminates many trajectories for this specific state u.

Figure 1: Moving away from constrained VEs to virtual open spaces using a drop-shaped short-term path prediction.

rotation by $v = (0,1)$. Combining these two assumptions results in a drop-shaped area of possible walking trajectories as shown in Figure 1(b). This shape is mathematically parametrised using the Lemniscate of Bernoulli with the origin coinciding with the current user state u. In a next step, we discretise the lemniscate and connect each of these i discretisation points to u using a trajectory T. Using these i trajectories, we cover most short-term paths in the direction of the user's heading including a rotation on spot. Additionally, since this lemniscate is easily scalable along its centre axis, we can adjust its size and shape based on the user's current walking speed. Concluding, each prediction iteration in a truly open virtual space provides a closed set of i predicted trajectories T for the user's current state u which can be transferred to the planning algorithm of the application.

3.1 Virtual Overlay

Virtual reality applications rely on a high framerate to prevent nausea and cybersickness. Therefore, any additional strain on the processing power of the computer could be fatal. Considering that the planning algorithm needs to evaluate each predicted trajectory, the calculation effort may quickly lead to a break in presence through sudden drops of the framerate. However, using this drop-shaped approach, a path prediction is not necessarily required to be completely online if we assume the VE to be static. Instead of predicting the trajectories on the fly, the possible trajectories can be calculated offline from the VE by overlaying the lemniscate for each valid user state within the walkable area (see Figure 1(c)). Since the static VE is completely known beforehand, the set of predicted trajectories can be uniquely determined for each user state and is then stored in a multi-dimensional look-up table (LUT). Using this offline calculation, the framerate can be kept high, since an LUT allows quicker access to the desired predictions than the mathematical overlay of the discretised drop on the VE. Additionally, invalid trajectories which lead to a predicted state lying in an inaccessible virtual user state (e.g. outside the virtual walkable area or inside a virtual object) can be eliminated since it is irrelevant for any planning algorithms. Consequently, besides using the LUT, the only calculation which needs to be done online is the scaling of the trajectories using the walking speed of the user. These scaled predicted trajectories are then transferred to the planning algorithm.

4 Conclusion and Future Work

In this paper, we showed a drop-shaped short-term path prediction for virtual open spaces. The employed lemniscate considers the user's walking speed and its number of discretisation points can be adjusted to the available computational power. Further, we showed how this short-term path prediction can be used offline to generate a look-up table of potential trajectory predictions based on user states and the available VE.

Future work will focus on a step-wise implementation of this path prediction and its application in predictive redirected walking. In a first step, the path prediction will be tested against common human locomotion models to identify the best initial size, shape, and discretisation of the drop. Additionally, the offline calculation for arbitrary VEs will be implemented and tested to validate the trajectory predictions. Then, a predictive redirected walking approach will be adjusted to handle this new prediction method. Eventually, it will be interesting to see, if it is even possible to chain multiple drops together in order to achieve very long trajectories.

References

[1] M. Azmandian, R. Yahata, M. Bolas, and E. Suma. An enhanced steering algorithm for redirected walking in virtual environments. In *Virtual Reality (VR), 2014 iEEE*, pp. 65–66. IEEE, 2014.

[2] T. Nescher, Y.-Y. Huang, and A. Kunz. Planning redirection techniques for optimal free walking experience using model predictive control. In *3D User Interfaces (3DUI), 2014 IEEE Symposium on*, pp. 111–118. IEEE, 2014.

[3] T. Nescher and A. Kunz. Using head tracking data for robust short term path prediction of human locomotion. In *Transactions on Computational Science XVIII*, pp. 172–191. Springer, 2013.

[4] S. Razzaque, Z. Kohn, and M. C. Whitton. Redirected walking. In *Proceedings of EUROGRAPHICS*, vol. 9, pp. 105–106. Manchester, UK, 2001.

[5] M. Usoh, K. Arthur, M. C. Whitton, R. Bastos, A. Steed, M. Slater, and F. P. Brooks Jr. Walking > walking-in-place > flying, in virtual environments. In *Proceedings of the 26th annual conference on Computer graphics and interactive techniques*, pp. 359–364. ACM Press/Addison-Wesley Publishing Co., 1999.

[6] M. Zank and A. Kunz. Using locomotion models for estimating walking targets in immersive virtual environments. In *Cyberworlds (CW), 2015 International Conference on*, pp. 229–236. IEEE, 2015.

[7] M. Zank and A. Kunz. Optimized graph extraction and locomotion prediction for redirected walking. In *3D User Interfaces (3DUI), 2017 IEEE Symposium on*, pp. 120–129. IEEE, 2017.

[8] M. A. Zmuda, J. L. Wonser, E. R. Bachmann, and E. Hodgson. Optimizing constrained-environment redirected walking instructions using search techniques. *IEEE transactions on visualization and computer graphics*, 19(11):1872–1884, 2013.