[DC] Joint Locomotion with Virtual Agents in Immersive Environments

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Abstract

Many applications in the realm of social virtual reality require reasonable locomotion patterns for their embedded, intelligent virtual agents (VAs). The two main research areas covered in the literature are pure inter-agent-dynamics for crowd simulations and user-agent-dynamics in, e.g., pedestrian scenarios. However, social locomotion, defined as a joint locomotion of a social group consisting of a human user and one to several VAs in the role of accompanying interaction partners, has not been carefully investigated yet. I intend to close this gap by contributing locomotion models for the social group's VAs. Thereby, I plan to evaluate the effects of the VAs' locomotion patterns on a user's perceived degree of immersion, comfort, and social presence.

Index Terms: I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Virtual Reality;

1 Introduction

Computer-controlled, embodied, intelligent virtual agents (VAs) are increasingly common in various virtual reality (VR) applications: Besides enlivening sceneries to turn them into plausible and convincing scenes (e.g., [4]), VAs are required as advanced human interfaces for intuitive interaction in the realm of social VR. As such, they function, e.g., as guides imparting knowledge to users (e.g., [16]) or as instructors and peers enabling users to improve special skills (e.g., [9, 17]).

One frequent requirement for these use cases is locomotion in-between a social group consisting of a human user and one to several VAs. However, to the best of my knowledge, the research on locomotion conducted can be grouped roughly into two areas: (a) inter-agent-dynamics without the involvement of a user in, e.g., evacuation simulations [8] or body posture evaluations of VAs passing each other [11] and (b) user-agent-dynamics, in which VAs and users purely pass each other without being involved in a more direct interaction (e.g., [14]).

In contrast to those two areas, my research focuses on joint locomotion of a social group, defined here as social locomotion (SL). On top of pure movements towards the same goal, the group members are involved in a direct, personal interaction, such as a conversation about a scene- or task-relevant topic. A basic example is a group of a user and one VA functioning as a guide: *While the guide informs the user about certain locations of interest in a given scene, both are moving constantly through the respective scenario. For a more intense conversation and scene inspection, they may also stop at certain scene locations.* Although this example use case looks simple on a first glance, the VA's locomotion behavior is non-trivial: Based on the Equilibrium Theory, interpersonal distance and eye contact need to be considered (e.g., [3]), which are both strongly influenced by factors like age, sex, and the surrounding environment (e.g., [1, 2]). Furthermore, walker formations for socially-aware movements need to be respected, as also done for social robots [15, 12].

Thus, I intend to address the following research questions (Sec. 3):

Q1: How can SL behavior be algorithmically modeled?
- a: How to model a single VA's behavior in a SL with a user?
- b: How to extend the model for several VAs joining a user?

Q2: How does a VA's SL behavior affect a user's perceived immersion and comfort?

Q3: Can a SL model be used to simulate human characteristics, e.g., shyness, confidence, or obtrusiveness?

Q4: Are different VA behaviors, e.g., locomotion patterns, required with regard to the used VR display?

In summary, I plan to investigate the influence of algorithmically modeled SL behavior for VAs who jointly walk with a human user, on her perceived degree of immersion, comfort, and social presence. This also includes kinematic analyses of the SL behaviors w.r.t. to, e.g., interpersonal distance or gazing.

2 Examples of Work Accomplished

Within the first years of my doctoral studies, I accomplished works in various areas of social VR. I, e.g., conducted research on peer pressure and competition (e.g., [10]) or investigated realism of approach and departure strategies with respect to the user's waiting times for temporary required virtual assistants (e.g., [6]). A complete list of my publications can be found online[1]. However, in this work, I only focus on two projects building first bricks towards my striven SL model.

2.1 Interpersonal Distance

Many studies have been conducted to investigate interpersonal distance. However, mostly large-scale environments containing only the user, the VAs, and sometimes some single objects have been taken into account. Thus, I investigated the proxemics in a small-scale environment based on a controlled user study in our CAVE with 27 subjects [7]. While being immersed in a two-man office with detailed interior design, subjects had to reach the office door. Their way was blocked by a VA, introduced as their co-worker. On their way to the door, subjects either approached the VA's front, its back or its left side. When being close, the VA showed three behavioral locomotion patterns, by either standing still and ignoring the subjects, by stepping aside and giving more space to pass, or by walking away. The study results indicate that subjects prefer a VA in such narrow scenarios, which clearly and visibly reacts to their presence by mutual gaze. Moreover, the VA should bear prime or at least partial responsibility for collision avoidance by, e.g., stepping aside at an early stage. Based on this, I recommend establishing an awareness zone, triggering the aforementioned behavior on a user's approaching.

2.2 Personal Space Influenced by Emotions

For a second study [5], colleagues of our universities Department of Psychiatry, Psychotherapy and Psychosomatics and I focused on the influence of a VA's emotion on the subject's preferences on the so-called personal space (PS), a flexible protective zone individuals maintain around themselves. We altered the VA's facial expression, between happy and angry. Again, 27 subjects were immersed in our CAVE, either being approached by a single male VA or a group of three males in an empty, large-scale environment. As PS is strongly influenced by culture, sex, and age, we limited the subject's variety to German males in the age of 18 to 30. Our results indicate that, at least for the subjects' characteristics, an increasing amount of interaction partners also increases the distance kept between subjects and VAs. Moreover, we could show that a larger distance was chosen to angry VAs compared to happy ones.

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[1] http://vr.rwth-aachen.de/person/6/

3 Future Work

This section deals with my research questions $Q1$ to $Q4$.

3.1 Influence of VA's Emotion on User-Agent-Dynamics

Thanks to an accepted annual Exploratory Research Space Seed Fund Project, I am intensifying my research on the influence of a VA's emotion on users' PS preferences (see Sec. 2.2) in cooperation with the Department of Psychiatry, Psychotherapy and Psychosomatics. In the extended approach, the emotions will be expressed not only via facial expressions but with an additional, appropriate body posture. Moreover, locatable footstep sound will be added, allowing to analyze the users' PS preferences also in the users' backs, where the approaching VAs are out of sight. Based on the results, I intend to algorithmically model different behavioral patterns for a single VA, answering $Q1a$. Thereby, the realizable shall range from consciously respecting the PS of a user or another VA to consciously violating it. Through this project, a first elementary basis for different research areas in the field of social VR is provided: respecting the PS is a key element in all social VR applications. However, the conscious violation opens up new research areas in the field of social behavioral studies and thus enables us to conduct VR-based research on aggressive or even violent offending behaviors.

3.2 User-Agent-Dynamics of Social Groups

The SL model of Section 3.1 is based on user-agent-dynamics of passers-by. In a follow-up step, I want to adapt the model to match requirements arising by a VA joining the user, e.g., as a virtual guide in a scene exploration. The adaption will affect kinematic aspects like PS, but also new aspects like mutual gaze in conversations during walking, addressing $Q1a$. In a second step, I intend to increase the number of VAs joining the user to represent a small, social group of about ten VAs. A use case is a group exploring a scene with a virtual guide. Addressing $Q1b$, the last step's SL model has to be extended by inter-agent-dynamics. Furthermore, as more interactions partners are involved in the SL, the respective kinemetic aspects have to be adapted.

While developing the SL model for the social groups' VAs, I want to investigate if and how the user's perceived feeling of being present in the scene, her perceived social presence, as well as her comfort level is influenced by the motions and the behaviors of the VAs (see $Q2$). My aim is to, e.g., induce a high sense of belonging to the social group and by this a high level of comfort, and (social) presence.

Starting from the conscious violation of the interpersonal distance constraints (see Sec. 3.1), I intend to evaluate whether the SL model can also be used to simulate different personal characteristics of the VAs (see $Q3$). Easily recognizable personality traits like shyness, confidence or obtrusiveness will be tested. If this succeeds, the SL model will be beneficial for representing a variety of characters and by this enhancing the plausibility of enlivened VR scenarios.

3.3 VR Displays as Influencing Factor

Due to the latest developments in the hardware sector, VR has become a more attractive tool for science, industry, and entertainment. Thus, I intend to investigate whether the VR display used has an influence on the user's acceptance of the behavioral patterns by the developed SL model. More precisely, I plan to compare the models in our CAVE, a high-end display, to the models on an HTC Vive Pro, a widely used, low-cost, consumer display.

One aspect differentiating both devices is the supported field of regard (FoR). While our CAVE provides a 360° horizontal FoR, current HMDs are limited to 110°. Thus, HMDs do not support a user's peripheral view. By this, more space for behavioral locomotion patterns is provided in the CAVE: a VA might, for instance, walk side-by-side with a user and is still seen. To this end, my research question $Q4$ is whether a display's FoR influences the SL model.

The second difference between both displays is the perception of the user's own body. In a CAVE a user can see herself, while an HMD blocks the vision of the own body. Thus, I will do the comparisons with and without a body avatar. By this, I will also contribute to the HMD-based research area of the illusion of virtual body ownership.

4 Conclusion

My research interest is SL of a user and one to several accompanying VAs through immersive virtual scenes. Concluding my position paper, I highlight some questions to be discussed during the doctoral consortium: (1) Do the four research questions meet the requirements of a Ph.D.? (2) As SL is influenced by a huge variety of factors, which factors are important to be included, and which should I consciously exclude to keep the work feasible? (3) Which deep learning or machine learning mechanisms, e.g., reinforcement learning [13], may support modeling the various social locomotion behaviors?

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