Locomotion with Virtual Agents in the Realm of Social Virtual Reality

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ABSTRACT

My research focuses on social locomotion of computer-controlled, human-like, virtual agents in virtual reality applications. Two main areas are covered in the literature: a) user-agent-dynamics in, e.g., pedestrian scenarios and b) pure inter-agent-dynamics. However, joint locomotion of a social group consisting of a user and one to several virtual agents has not been investigated yet. I intend to close this gap by contributing an algorithmic model of an agent's behavior during social locomotion. In addition, I plan to evaluate the effects of the resulting agent's locomotion patterns on a user's perceived degree of immersion, comfort, as well as social presence.

Index Terms: H.1.2 [Models and Principles]: User/Machine Systems—Human Factors H.5.2 [Information Interfaces and Presentation]: User Interfaces—Evaluation/Methodology I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Virtual Reality; J.4 [Computer Applications]: Social And Behavioral Sciences—Psychology

1 INTRODUCTION

My research interest is the interaction of users with embodied, autonomous, intelligent, and conversational virtual agents (VAs). These computer-controlled, human-like characters are increasingly common in various virtual reality (VR) scenarios. For instance, VAs are used to enliven cultural heritage sites, turning them into plausible and convincing scenes [6]. Moreover, VAs are often required as advanced (emotional) human interfaces for intuitive interaction in the realm of social VR. As such, they function, for instance, as guides imparting knowledge to users [24] or as peers and instructors enabling users to improve their skills in training scenarios [15, 21].

One common aspect of these use cases is the need for social interaction between users and one to several VAs. As individuals spend 32% to 75% of their waking time in these social interactions [7], they are accustomed to certain behavior patterns shown by their real-life interaction partners. Examples of these patterns are people's interpersonal distance, eye contact, or (subtle) body postures. These behavior patterns are ranked among the 55% of non-verbal communication a social interaction consists of [22]. To this end, VAs have to closely imitate the human behavior patterns in order to represent authentic and believable interaction partners.

One feature in the field of user-agent-interaction is social locomotion (SL). Based on the Equilibrium Theory, especially the aforementioned aspects interpersonal distance and eye contact are important to be considered here [3, 5]. However, due to a variety of influencing factors like culture, sex, age or the surrounding environment [1, 2, 4, 16], modeling an adequate behavior is non-trivial.

To the best of my knowledge, the research conducted in the field of SL can be grouped roughly into two areas. The first area consists of scenarios describing user-agent-dynamics. Here, VAs and users purely pass each other without being involved in a more direct or personal interaction (e.g., in [19, 18, 23]). The second area is based on pure inter-agent-dynamics without the involvement of a user. Research examples are group-dynamics in evacuation simulations [14] or body postures for VAs passing each other [17].

In contrast to these state-of-the-art approaches, my research interest is on joint locomotion of social groups consisting of a user and one to several VAs. Thus, I intend to address the following main research questions, which will be discussed in more detail in Section 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 affects 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 user, on the user's perceived degree of immersion, comfort, and social presence.

2 WORK ACCOMPLISHED

This section contains an overview of my work accomplished within the first 2.5 years of my doctoral studies. I used the time to put my research interests into more concrete terms while developing first components for my dissertation. As six years is the average time to complete a doctoral thesis in our institute, I have 3.5 more years.

2.1 Interpersonal Distance

As stated in Section 1, proxemics between a user and VAs is a key element for SL. Two of my previous works focused on this aspect, both within the research area of user-agent-dynamics.

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 participants. While being immersed in a two-man office with detailed interior design, participants had to reach the office door. Their way was blocked by a VA, introduced as their co-worker. On their way to the door, participants either approached the VA's front, it's back or it's right side. When being close, the VA showed three behavioral locomotion patterns, by either standing still and ignoring the participant, by stepping aside and giving more space to pass or by walking away. The study results indicate that participants prefer a VA in such narrow scenarios, who 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. For more details, I refer the interested reader to the respective paper [13].

For a second study, I teamed up with colleagues of the Department of Psychiatry, Psychotherapy and Psychosomatics at RWTH Aachen University to focus on the influence of a VA's emotion on the participant's preferences on the so-called personal space, a flexible protective zone individuals maintain around themselves. We altered the VA's emotions, which were only expressed via a facial animation, between happy and angry. Again, 27 participants were immersed in our CAVE, either being approached by a single male VA or a group

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of three males in an empty, large-scale environment. As personal space is strongly influenced by culture, sex, and age, we limited the participant's variety to German males in the age of 18 to 30. Our results [8] indicate that, at least for the participants' characteristics, an increasing amount of interaction partners also increases the distance kept between participants and VAs. Moreover, we could show that a larger distance was chosen to angry VAs compared to happy ones.

2.2 Realism vs. Minimal User Waiting Times

Typically, VAs have to closely imitate human behavior in order to be accepted as authentic interaction partners. However, I found evidence that sometimes also unrealistic behavior is tolerated by users: In a behavioral study with 40 participants, published in [10], I evaluated approaching and departure behaviors of a temporarily required, female assistant. The study scene was a small-scale apartment with a detailed interior design, as apparatus our CAVE was used. Several times during the study, participants had to call for the absent VA to ask for certain information. For the approaching, the VA either instantly faded in, walked by or ran by from a neighboring room. At the conversation's end, the VA mirrored her approaching behavior for the departure. The results indicate, that designing the approaching and departure behavior less realistic is accepted by a lot of users as their waiting time for the social interaction was reduced. However, conversations and locomotions of the VA have to be realistic, e.g., with slight variations in formulations or walking trajectories.

2.3 Fringes of My Research

Besides my research focus on SL, I teamed up with colleagues of our universities School of Business and Economics to conduct research on peer pressure and competition, published, e.g., in [12]. The results obtained are in line with the prediction of social peer effect theories and indicate that being exposed to competition by a VA induces strong incentives to increase the own performance. This indicates, that VAs are meaningful interfaces for social interaction.

Furthermore, as virtual crowds are required to achieve realistic and enlivened scenarios, I published a theoretical approach to automatically identify potential interaction partners in a virtual crowd [11], realized partially in a first, very basic approach [9].

3 Future Work

This section deals with the research questions $Q1$ to $Q4$, which I intend to focus on in for the remainder of my doctoral studies.

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

I will intensify my research on the influence of a VA's emotion on users' personal space preferences (see Sec. 2.1): in an 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' personal space 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 personal space of a user or another VA to consciously violating it. This work in collaboration with the Department of Psychiatry, Psychotherapy and Psychosomatics will be funded by my university as an annual Exploratory Research Space Seed Fund Project. Through this project, a first elementary basis for different research areas in the field of social VR is provided: respecting the personal space 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 in traversing the scene, e.g., a virtual guide. Although it's only two individuals, this constellation is considered as a social group. The adaption will affect the interpersonal distance, but it also requires new aspects like gazing in a conversation during walking, also addressing $Q1a$.

In a next 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 of participants in a guided tour through a scene, e.g., in the context of cultural heritage. Addressing $Q1b$, the SL model has to be extended, e.g., by inter-agent-dynamics.

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 in 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 the user's acceptance of the behavioral patterns by the developed SL model. More precisely, I plan to compare the model in our CAVE, a high-end display, to the model on an HTC Vive, 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 nearly 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 topic is based on the aim to provide an algorithm for locomotions in a user-agent-dynamic through immersive VR scenes of social groups consisting of a user and one to several VAs. Concluding my proposal, I want to highlight some questions, that I would like to discuss during the doctoral consortium: (1) Do the strived research questions meet the requirements of a Ph.D.? (2) Is the strategic alignment on the social locomotion in social groups consisting of the user and one to several VA a meaningful contribution to the social VR? (3) As social locomotion is influenced by a huge variety of factors, which factors do I have to include, and which should I consciously exclude to keep the work feasible? (4) Which deep learning or machine leaning mechanisms, e.g., reinforcement learning [20], may support modeling the social locomotion?

Acknowledgments

I wish to thank Prof. Torsten W. Kuhlen and Dr. Tom Vierjahn for their continuous support and encouragement.

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