Gaze Behaviour During Collision Avoidance Between Walkers: A Preliminary Study to Design an Experimental Platform

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ABSTRACT

When walking, vision is the main source of information that allows us to navigate safely by detecting potential collisions with other walkers. In order to gain a better understanding of the relationship between gaze activity and kinematics of motion during pedestrian interactions, we present in this paper a preliminary study towards designing a more comprehensive experimental platform. In this study, participants are asked to avoid collisions with an upcoming virtual character using a joystick, while we measure their gaze behaviours using an eye-tracker. As we are interested in the effects of potential collisions on gaze activity, i.e., where and when participants look to avoid potential future collisions, we display in our experiment a virtual character for which we vary the initial Time To Closest Approach (ttca) and Distance of Closest Approach (dca) values, to change its risk of collision with our participant. We then measure participant trajectory adjustments and gaze activity during the interaction. Our preliminary results show which type of data this platform produces, and demonstrate the interest of designing more comprehensive experiences and tools to analyze both gaze activity and kinematics.

Index Terms: Human-centered computing—Visualization—Visualization techniques—Treemaps; Human-centered computing—Visualization—Visualization design and evaluation methods

1 INTRODUCTION

In recent years, a lot of progress has been made on improving the visual realism of virtual crowds. However, these crowds are far from looking like real ones as they still lack some of the subtle behaviours displayed by humans. Introducing such subtleties in crowd simulators therefore requires to further understand how humans behave in crowds in order to reproduce these behaviours.

This paper follows up this trend by attempting to further our understanding of human behaviours during collision avoidance between two pedestrians. In particular, vision being our main source of information to detect and avoid potential collisions with other walkers, we are interested in this paper in the relationship between gaze activity and locomotion in such situations. Previous work suggests that optic flow has a strong impact on pedestrian locomotion (e.g., [16, 19]). While multiple studies have involved users wearing eye-trackers in real environments to analyze their gaze activity (e.g., [8, 9, 11]), such studies can be difficult to organize in real crowds because of technical, human, and experimental organization. A solution is therefore to design these experiments in Virtual Reality, which was demonstrated to show common properties with behaviours in real environments [13]. However, gaze activity during collision avoidance situations has not been explored yet in virtual environments. Therefore, the goal of this paper is to present such a preliminary study in order to prepare the ground for the design of a more comprehensive VR experimental platform.

In order to create these foundations, we designed an experiment in a simple virtual environment where participants are asked to avoid collisions with an upcoming virtual character using a joystick, while we measure their gaze behaviours using an eye-tracker. As we are interested in the effects of potential collisions on gaze activity, i.e., where and when participants look at to avoid potential future collisions, we display in our experiment a virtual character for which we vary the initial Time To Closest Approach (ttca) and Distance of Closest Approach (dca) values, to change its risk of collision with our participant. We then measure participant's trajectory adjustments and gaze activity during the interaction.

In this paper, we therefore present the design of the experimental platform and the framework of the preliminary experiment. While we have not yet produced any results, our contribution is also to present and discuss the type of data expected from such experiments, in particular through data obtained in preliminary tests. This data has been obtained by running a pilot version of the platform on a desktop screen for testing purposes, but our goal is to perform such experiments using an immersive setup in future, such as a CAVE or a Head Mounted Display.

This paper is organized as follows. Section 2 reviews the literature in connection with this work. Then, Section 3 introduces our objectives, and Section 4 describes our experimental framework. Section 5 presents some preliminary results. Then, Section 6 concludes on the experiment and presents our directions for future work.

2 RELATED WORK

2.1 Collision avoidance

Collision avoidance has been extensively studied in previous works. Especially, numerous authors focused on the kinematics aspects by describing motion adaptations performed to avoid a collision, such as speed and orientaion adaptations [14]. Moreover, avoidance strategies depend on the characteristics of the situation (e.g., walking speed, angle of crossing) rather than the characteristics of the walkers (e.g., gender, personality) [7] [10]. They also showed that walkers are able to accurately predict the future risk of collision during the interaction [15]. This notion of future risk of collision is based on the definition of *minimum predicted distance* (*mpd*), and depends on the current speed and orientation of the walkers. This is the closest crossing distance walkers would meet if they do not adapt their trajectory (constant velocity). Therefore, walkers adapt their motion if and only if the value of mpd at the beginning of the interaction is below a certain threshold ($1m$), i.e., when there is a future risk of collision if none of the walkers adapt their motion. When considering the evolution of mpd over time, Olivier *et al.* [15] described 3 stages in the interaction: 1) an observation stage where mpd is constant, meaning that no motion adaptation is performed, 2) a reaction stage, where motion adaptations are performed so as to increase the future crossing distance and avoid a collision, 3) a regulation stage, where mpd is maintained to a constant level. This latter stage shows that the collision avoidance task is solved before

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the end of the interaction, meaning that the task is performed by anticipation. Also, it is important to mention that mpd is similar to the future distance of closest approach (dca), used in this article.

Because of the complexity of performing such studies in real situations, recent studies aimed at validating Virtual Reality (VR) as a powerful tool to study interactions between walkers. For example, virtual trajectories performed in a CAVE using a joystick to avoid a virtual walker showed very similar qualitative patterns as compared to real conditions [13]. In that context, Varma *et al.* [18] used an immersive VR platform to study the influence of the virtual agents' eye gaze direction on the behaviour of participants in a collision avoidance task. While participants' preferential tendency was to avoid the virtual agent turning right, participants changed their strategy turning left when the virtual agent shows non verbal cues through head and eye orientation indicating the intent to go to the right. Other studies use VR to investigate how participants avoid a group of virtual walkers, i.e., if they go through or around such groups [3], or to investigate the motion cues used by participants to successively interpret the motion of the virtual walker they are interacting with [12]. VR therefore offers new opportunities to study motion adaptations during interactions between walkers as well as more perceptual mechanisms allowing a perfect control of the information displayed to the participants.

2.2 Gaze and interactions between walkers

While all the previously mentioned studies focused on collision avoidance and virtual environments to study interactions between walkers, almost none of them used or explored information about participants' gaze activity in relation with the trajectory adaptations. However, vision is a fundamental perceptual system, that allows us among others to control locomotion (e.g., [16, 19]), giving us information about our own position and motion in the environment but also information about the static and dynamic characteristics of the environment. For instance, humans are able to perceive collisions, even in crowded environments, as was demonstrated by Andersen *et al.* [1] who designed an experiment where participants had to detect potential collisions with moving spheres on a computer screen. They showed that participants often detected collisions, but that accuracy decreased with the number of spheres, suggesting that collision detection is based on a visual search and is influenced by the number of objects.

In more ecological contexts, several works investigated gaze behaviour of walkers using an eye-tracking device in real environments. Kitazawa et Fujiyama [9] studied the relation between gaze and the Information Process Space (IPS) during a collision avoidance event with participants walking on a platform. They noticed that participants do not gaze more at objects and other pedestrians located in the scene than at the ground. Furthermore, they deduced that the IPS shape is not a homogeneous circle around the walker, but presents a more important anterior area. Similarly, Jovancevic-Misic and Hayhoe [8] demonstrated that participants adapt their gaze strategies depending on the behaviour of surrounding persons. By asking participants to walk around an oval track while other people acted in specific ways with predefined risks of collision, they showed that pedestrians with risky behaviours were more gazed at by participants. However, gaze behaviours were also demonstrated to be affected by other factors, e.g., related to the environment. For instance, Fotios *et al.* [4] demonstrated that participants gaze more at the ground when the lighting is diminished in the virtual environment, and that the probability of looking at other pedestrians was increased when they were in the range of 8 to 12m [5].

3 Objectives

A lot of work has been done to describe motion adaptations performed by a walker to avoid collisions with another walker. However, since vision is fundamental to control locomotion, other studies investigated the gaze behaviour performed by walkers when navigating in their environment. However, little is known about the coupling between gaze behaviour and locomotor adaptation during collision avoidance. For example, while three stages in the interactions have been detailed (i.e., observation, reaction and regulation) based on the kinematics of locomotion [15], no information about gaze behaviour has been provided. Our objective is then to study the relation between gaze and trajectory adaptations in a collision avoidance task between two walkers. We aim at analyzing the duration of gaze fixation as well as the timing of gaze with respect to trajectory adaptations and the risk of collision.

This paper is a work-in-progress article. We start answering this objective by developing an experimental framework involving a collision avoidance task between a participant and a virtual walker. The experimental platform design is detailed in the next Section.

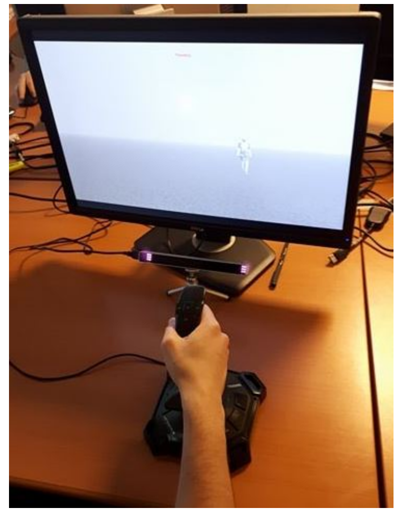

Figure 1: Example of a participant during our experiment. Participants are seated in front of a 24-inch screen. They use a joystick to navigate in the virtual environment and to avoid a virtual walker. An eye-tracker is located below the screen and records their eye movements.

4 Experimental Framework

4.1 Apparatus

Apparatus is illustrated in Figure 1. We used Unity 5.5.4 to design the 3D environment display and character animation. Participants navigate in the virtual environment using a joystick. The longitudinal axis of the joystick controls speed linearly from $0.8m.s^{-1}$ to $2m.s^{-1}$. The lateral axis controls the angular rotation speed linearly from $-25deg.s^{-1}$ to $25deg.s^{-1}$. If participants do not touch the joystick (rest position), the speed is set at $1.33m.s^{-1}$, which represents a comfort human walking speed [2], and the angular rotation speed is set to $0deg.s^{-1}$ (i.e., straight-ahead walk). This steering navigation interface combined with this transfer function was previously validated for the study of human walkers interactions in a virtual environment [13]. To ensure that ground displacements are perceived in the optic flow as participants are moving forward in the virtual environment, we chose a texture with a random noise for the virtual ground as suggested by Geri *et al.* [6]. While participants are seated in front of a 24-inch screen for the experiment, gaze activity is recorded using a desktop eye-tracker ("TheEyeTribe", accuracy: 0.5-1°, sampling frequency: 60Hz).

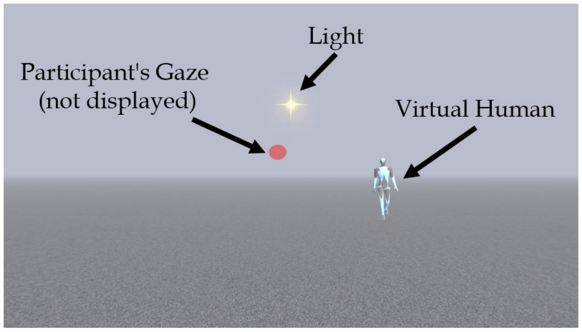

Figure 2: Illustration of the virtual environment, with the virtual walker to avoid, the goal to reach and the location of the participant's gaze in the virtual environment (not displayed during the experiment).

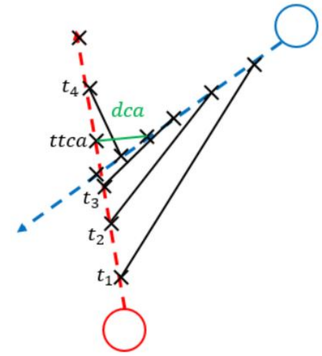

Figure 3: dca (distance of closest approach) and ttca (time to closest approach) computations. For each frame n of the interaction, these variables are computed by a linear extrapolation of trajectories given the current state of the user and walkers at frame n.

4.2 Task

Participants are instructed to navigate in the virtual environment towards a target located at $800m$ from the starting point (see Figure 2), while avoiding any collision with the virtual human walking within the same area. The virtual human displays a neutral appearance, to avoid any influence on gaze behaviour of factors such as gender, clothes, color, eye contact, and is driven by a RVO crowd simulator [17] with a preferred speed of $1.33m.s^{-1}$. It therefore walks along a straight path at a constant speed as long as there is no immediate collision with the participant, but also presents late reactions in cases when participants do not avoid it.

4.3 Factors

As detailed in Section 3, we hypothesized that a strong link exists between the user's gaze behaviour and the risk of collision with the virtual walker. Therefore, to assess this hypothesis, we propose to manipulate two factors related to the risk of collision: the future distance of closest approach (dca) and the time to closest approach (ttca). These factors can be computed at each frame of the interaction as illustrated in Figure 3. For a frame n, assuming that the user and the virtual human would keep a constant speed and orientation, we can linearly extrapolate their future trajectories and compute the minimum crossing distance (dca(n)) as well as the time remaining before the dca(n) will occur (ttca(n)). In this study, we will therefore manipulate the initial values of dca and ttca, i.e., when the user can first see the virtual human, in order to introduce variations in the initial risk of collision:

- dca will vary between -3 to $3m$ (following a uniform distribution), to consider situations were the future crossing distance goes from high values without collision if no motion adaptation is performed to full contact. The sign of dca relates to whether the user is expected to be in front of the virtual human at the time of crossing (dca$>$0), or behind at the time of crossing (dca$<$0).
- ttca will be set to $4s$ and $8s$, to consider short term and longer term potential interactions.
- the initial position of the virtual human in the user's field of view will be randomly chosen (following a uniform distribution) to avoid any confounding effects of the initial position.

5 Preliminary results

During a preliminary experiment, one participant (male, 26 years old) completed a number of 20 trials. In addition to gaze data, we recorded the trajectory of both the participant and the virtual human, which provides us with their positions and velocities over time. This data and the gaze position were re-sampled and interpolated for all the scenarios with an interval of $0.05s$ (20 frames per second). We defined a fixation when the participant gazed at the same point for more than 0.1s. Furthermore, we defined a collision threshold at $0.5m$, i.e, the approximated distance between two pedestrians from which a physical contact almost always occurs.

Figure 4 (Left) describes the trajectory of the participant and the virtual agent over time for 2 trials performed by the participant. Figure 4 (Right) shows the corresponding evolution of dca until the time of closest approach (ttca). A change in dca means that motion adaptations were performed by the participant. With respect to these Figures, we superimposed the gaze behaviour highlighting with several colours the elements of the environment the participant was looking at.

Figure 4, upper part, illustrates a trial with an initial value of dca equal to $-0.44m$ and a ttca of $4s$. This means that given the initial conditions of the interaction, if the participant does not adapt his trajectory, a collision would occur because dca is below the collision threshold. During this trial, we can observe that the participant gazed at the different elements in the scene: the target, the ground, the virtual human and the sky. In particular, we observe that the participant fixated the virtual human (between $2.1s$ and $2.6s$) just before adapting his trajectory, i.e., when the dca value starts changing.

Figure 4, lower part, illustrates a second trial with an initial value of dca equal to $1.66m$ and a ttca of $8s$. Contrary to the first trial, the initial value of dca is above the collision threshold. Theoretically, there is no major risk of collision in this interaction even if the participant does not modify his trajectory. As in the previous example, the participant gazed at the different elements of the virtual scene. Furthermore, we also noticed a fixation during the phase of observation as defined previously by Olivier et al. [15] (between $2.4s$ and $4.2s$). While this fixation is longer than the one of the previous example, the trajectory adaptation is however less important, as expected from the difference in dca.

In this paper, we only observe few trials. They illustrate the nature of data we can extract from our experimental framework. More specifically, they show the relevance of the framework to perform analysis of collision avoidance in space and time, coupling gaze and trajectory data. For example, in our examples, we can notice that participants gaze at the character when they initiate adaptations (dca start variating). Also, gaze patterns seem different before and after participants start adapting their trajectory, with shorter fixations during avoidance than before. We now need to perform a complete

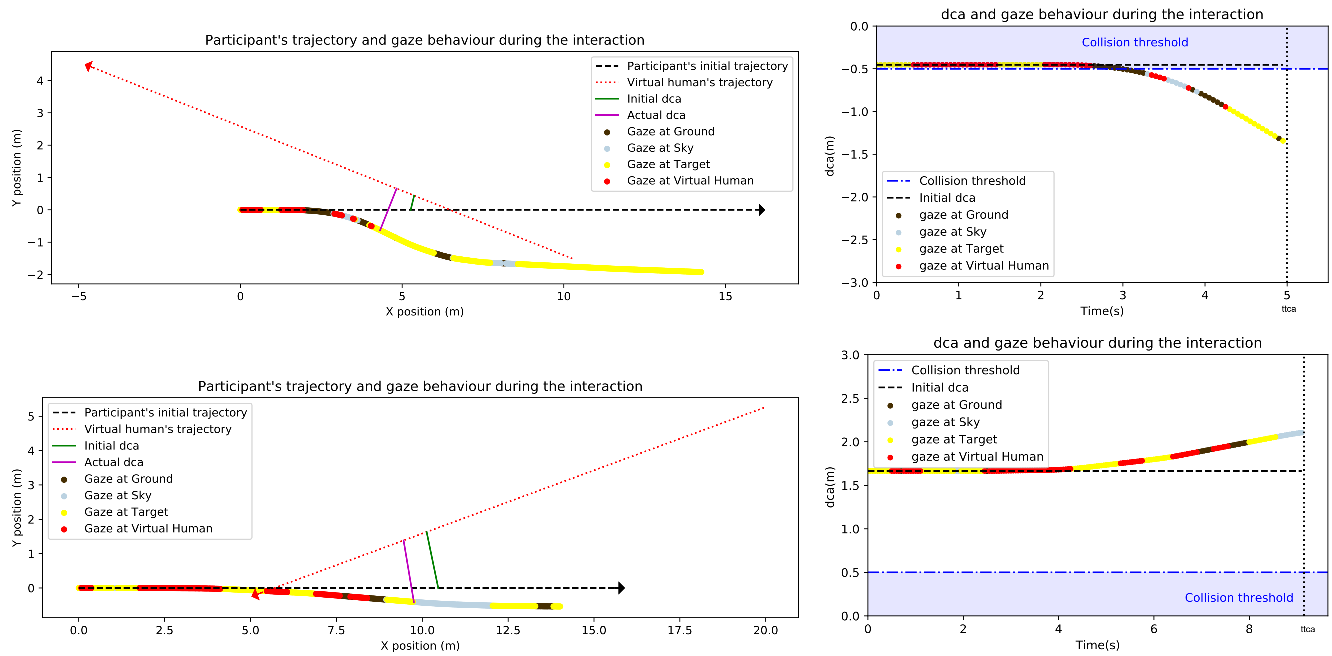

Figure 4: All Figures: Gaze locations in the virtual environment are color-coded on the curves. Up-Right: participant and virtual human trajectories during one trial where initial dca is $-0.44m$ and ttca is $4s$. Up-Left: evolution of dca over time during this scenario, until the time of closest distance. Bottom-Right: trajectories for one trial where initial dca is $1.66m$ and a ttca of $8s$. Bottom-Left: evolution of dca over time during this scenario, until the time of closest distance.

experimental campaign in order to confirm our conclusions.

6 Conclusion & Future work

In this paper we present an experimental framework to study the gaze activity during a collision avoidance task between a participant and a virtual walker. Using an eye-tracker to record eye movements, a joystick to navigate in a virtual environment and a desktop setup, we are able to know what participants are looking at and to make the link between their gaze behaviour and the adaptation of their trajectory to avoid potential collision.

Using this platform, we performed a preliminary experiment, whose very first results show trends in line with our initial hypotheses. For instance, in the two examples described in Section 5, the participant looked at the virtual human just before performing adaptations. However, more work is now required to explore these factors, including more participants on a complete experimental plan. We also plan to conduct this experiment in an immersive setup such as a CAVE, rather than on a desktop PC. Technical issues will therefore need to be tackled to use the eye tracker in such a setup.

Concerning the virtual environment, we are currently considering an improvement of its visual realism. In particular, we plan to add character shadows because of their importance on perceiving 3D trajectories, which is a main parameter for navigation. We are also considering using more realistic characters and environments (e.g., street or city square), but such changes will require to carefully account for potential confounding factors, e.g., character gender or the color of its clothes.

In terms of analysis, we plan to compute the duration of fixations, as well as their timing during the interaction. They will be studied with respect to the dca values as well as motion adaptations, which will be made possible by our experimental control of the dca factor. One main objective will then be to identify standard gaze behaviour patterns during a collision avoidance task. If some invariant patterns are found, they could be used to design new animation techniques based on real-user gaze behavior. This can result in more realistic interactions between a user and a virtual walker. Finally, this platform will allow us to subsequently study the relationship between gaze activity and locomotion under the influence of other variables such as the number of people in the scene or their facial expressions.

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