The Missing Tip: Lack of Micro-Movements Impairs Navigation Realism in Artificial Social Agents

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Abstract: Navigation is critical to an intelligent social agent's ability to interact with the world and any other agent, virtual or otherwise. In order to create a truly realistic artificial social agent, unconscious human micro-movements need to be simulated. We see this as an important goal for the research area. Examples of these micro-movements include orienting while walking and back-stepping, strafing with attention focused elsewhere, and micro-orientations during locomotion. We postulate that there is a gap in research around these micro-movements within the field of navigation that we hope to contribute to filling. Most research in this field is focused on the understandably important pathfinding aspect of navigation; moving between two spatial locations. There is little to no research being done on micro-movements and making a truly realistic navigation system for artificial social agents. Moreover, there exists no canonical way of describing these movements and "micro-movements" that are so characteristic for human spatial behaviour. Here we propose a set of standardised descriptors of movement configurations, that will be able to be used as building blocks for spatial behaviour experimentation, and as the basis for behaviour generation models. We see this as an important tool in the creation of navigation systems that are able to more readily include these kinds of behaviours, with hope that the aforementioned configurations will improve development of realistic movement systems.

1 INTRODUCTION: HIERARCHY OF NAVIGATIONAL REALISM

The navigational behaviour of an artificial social agent plays a key role in the perception of realism humans feel when interacting with it. However, much current research into this area is focused primarily on allowing intelligent artificial social agents to navigate to their intended destination realistically, or to increase the visual fidelity of the artificial social agents themselves. This has created a gap in the literature with little to no research done into the micro-movements and orientation that we believe give an artificial social agent a much higher sense of realism and therefore foster a higher sense of immersion in the user; the subjective feeling of being in another world (Bartle, 2004). This is important in virtual experiences as it has been shown that a higher sense of immersion is key in creating effective virtual worlds. With virtual experiences being used more often for important experiences such as training (Lele, 2013), (Merchant et al., 2014), the onus is there to create immersive worlds in which the experience that humans gain is real and worthwhile. (Latoschik et al., 2017) confirmed this with their work on avatar realism and it's effect on various measures, finding that humaneness and attractiveness were both increased with human-like avatars over wooden mannequins, though eeriness was also increased. These findings were supported by (Pütten et al., 2009) looking into whether social presence can be elicited for virtual avatars, with results showing that they can, with the more behavioural realism the artificial social agent shows increasing this measure. Other than behavioural realism, movement is another key area of the realism of an artificial social agent, though it can be seen as one of the most important, (Pedica and Vilhjálmsson, 2008) found from their work on virtual avatars for online chat rooms that social perception and reactive manoeuvring in the form of grouping around o-spaces (Burgoon and Kendon, 1992) seemed to give the avatars a heightened level of realism showing that the orientation and positioning

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of people or agents can be just as important. This need for realistic movement can be seen again in the propagation of motion capture technology in many forms of media. This high cost, high time investment form of animation, uses recorded humans to create realistic movements for virtual characters. The capture of the micro-movements and unconscious actions is what make motion capture so powerful, if there were a way to simulate these micro-movements without the heavy cost of motion capture, the realism and believability of artificial social agents could increase without a heavy investment. This in turn would increase the overall immersion of the experience (Pedica and Vilhjálmsson, 2008). However the main focus of pathfinding, determining the path the agent takes from (a) to (b) is understandable, as for these micro-movements and navigations to occur, there must be a movement scenario for them to occur within. Thus, the construction of a believable human movement model can be viewed as a sort of pyramid (Figure 1). Inspired in part by A. Maslow's hierarchy of human needs (Maslow, 1943), with pathfinding laying the foundational systems for higher level behavioural systems to utilise. We see the micro-movement behaviours at the "tip" of the pyramid that are described in this paper as being supremely important in the development of realistic human artificial social agent, and that these behaviours, small movements, navigation and orientation all have a very important part to play in creating a realistic, immersive artificial social agent that evidences some facsimile of life (Pedica and Vilhjálmsson, 2008). For humans, these things happen subconsciously without thought (Burgoon and Kendon, 1992) but for artificial social agents, these need to be firstly measured from human participants, canonised and studied and then designed in such a way for an AI to perform these small actions. The current article addresses the scientific community, specifically around artificial social agents. It's goal is to increase the awareness of the shortcomings in the area of locomotion for artificial social agents, and realism in virtual worlds. The research areas are introduced first, with Pathfinding, Social Robotics and Micro-Movements explored in more detail. Examples of current locomotion data will be presented to illustrate the issue with current locomotion data collection, before moving onto the proposal of this paper; the presentation of the formalisation of these micro-movements we unconsciously make during locomotion.

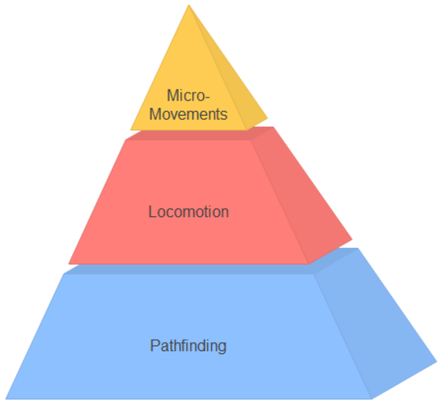

Figure 1: The requirements of a realistic human artificial social agent as a hierarchical pyramid; Pathfinding describing the routing method that generates the path for an artificial social agent to take. Locomotion is the actual movement the agent employs to displace itself to the intended direction. Micro-Movements are the small movements and orientations humans use during navigation such as rotating while stepping, that when lacking cause a lowering of realism of the agent.

1.1 Pathfinding - Getting from (a) to (b)

Pathfinding as a subset of navigation has a large body of research due to it's necessity regarding the control models of real-world robots, however this robotic focus has led to most systems having very low measures of realism when applied to an artificial social agent. When investigating multi agent systems (Wang et al., 2013) focused on creating a dynamic system for controlling multiple agents in an immersive environment, with special attention on path planning for avoidance. The purpose of this research was to increase the effectiveness of training simulations for evacuation of multiple agents and other real-time applications of crowd simulation, however misses the importance of increasing the realism of the individual movement of each agent. (Zhukov and Iones, 2000)'s work on navigational control for intelligent agents instead focused on the creation of navigational maps, with the goal of decreasing computational load and increasing the complexity of navigation for artificial social agents, but still only designed these navigational maps to translate an agent from point (a) to point (b) with no simulation of higher movement functions. With (Raees and Ullah, 2021) also focusing on pathfinding without the complexity of micro-movements we discuss in this paper. (Olcay et al., 2020) Took the extremely interesting angle of designing a simultaneous, collision-free motion planning system for fully autonomous robots, allowing groups of fully autonomous robots to motion-plan, even within an environment with moving obstacles or poor sensor range. This kind of SLAM (simultaneous localisation and mapping) control system will be hugely important as a facet of an autonomous true virtual human. However for the goal of creating computer controlled artificial social agents which move in a realistic way, autonomy is not a requirement. Reinforcing the research into navigation within an environment with movable obstacles, (Djerroud and Ali-Chérif, 2021) created "VICA" a vicarious cognitive architecture for autonomous robots, though this research differs as it follows the "theory of mind" in saying that a form of "vicariance" is important for a robot's strategy to interact with the outside word. This architecture employs a multi agent system to allow the robot a representation of how it's interactions would cause the outside world to react. (Sutera et al., 2021) have pushed the field of marrying navigation with learning even further, by using ultra-wide band technology for precise tracking combined with a low-cost point-to-point local planner learnt with deep reinforcement learning (the notion of intelligent agents taking actions to maximise a cumulative reward, see (Akalin and Loutfi, 2021)), they are able to path-find robustly in noisy and complex environments. This is something important for robots in real-world environments, but unnecessary for artificial social agents, who by virtue of their medium already have access to all data on their environment. These approaches once again however, all miss a vital component of realism in these artificial social agents, the micro behaviours that we propose need formalisation.

1.2 Approaches in the Social Robotics Domain

Robotics has a wealth of valuable data on navigation due to the field of Human-robot interaction (HRI) being one of the largest in artificial social agents, with increasing amounts of research being done in the area due to the uptake of complex and use-specific robots that exist in the world today (Goodrich and Schultz, 2007). One may think this domain has research into micro-movements due to it's size, however even though the field of HRI is so large, the most related research in this field is focused primarily on interactive social robots. For example (Ghazali et al., 2019) Looked at the effect of social cues in robots on user's psychological reactance, liking among other psychological measures, however they do not investigate navigational realism as a social cue, instead focusing only head mimicry and social praise timing. (Liu et al., 2018) investigated human-robot behaviour in a shopkeeper scenario and included locomotion in the multi-model behaviour of the robot. Finding that cross-validation on the training data showed higher social appropriateness of the robot's behaviours. Though once again this research was conducted on a wheeled form of locomotion, and realistic human movement was not the intention of the research. Apart from investigations into social robots such as these, the bulk of research is directed around navigation systems that create efficient (a) to (b) routes for robotic agents (Olcay et al., 2020), (Li et al., 2019). Despite the field of HRI being so large, it is still missing research into the micro-movements that we describe in this paper. This is primarily due to robotics in general not being advanced enough in their mimicry of human movement in a reliable way to focus on these higher-level behaviours, causing the area of advanced realism of movement to be something that will need to be researched in the future.

2 HOW DO HUMANS NAVIGATE?

2.1 Micro-Movements - The Small Movements We Make

Research into the small movements we unconsciously make is an even smaller subset of the navigation field and is ongoing, and these behaviours give a true sense of realism when simulated or replicated well, though most of this research is focused on face or arm movements, rather than the implicit orientations and movements we make during locomotion. These locomotion movements are what we hope to formalise, as work on facial realism and animation realism is quite mature in comparison due to the important role the face has for humanoid perception, as well as due to motion capture as a technology. For example (Davison et al., 2018) in their work in the field of micro facial movements have created a formalised dataset of micro-facial movements, poised to become the new standard. No such dataset exists for this kind of data relevant to human navigational movements however, and this sort of gap in the field explains why even in highly funded, yet unreleased video games such as "Star Citizen" (see (Ahrens et al., 2019)) non player character performance is still substandard, and often consists of movement to a position before rotating and continuing a path. (Onishi et al., 2003) investigated creating a new laboratory application to record human robot movements and test new humanoid robots, that describe in their future work section the need to capture human locomotion data accurately to make robots that realistically move like humans. This is a good example of the need for these realistic movements being recognised, with work being done to improve the data capture systems that are used to create spatial control systems which once again confirms the necessity for further research into agents' navigation if the aim is to increase the "sense of realism". (Kuffner et al., 2003) have done incredibly important work in the field, with their goal of creating a digital human, including sophisticated digital models of human physiology and biomechanics. However at least at this stage, they have been more focused on arm motion and upper body movements at a set location, rather than the movements we describe here. (Kagami et al., 2003) looks at using a motion capture system, force plates and distributed force sensors to record data from a human participant, as well as a humanoid "H7" robot, however they found difficulty comparing the human data with the H7 due to issues in differences between the mechanical nature of a human and a robot, (including link parameters, walking speed, step length, step cycle and mechanisms). These issues however do not exist in the virtual world unless explicitly designed, and the large amount of heavy data Kagami recorded emphasises the need for a formalisation of these naturalistic, realism focused, micro-movements. Even (Gratch et al., 2002) in their excellent paper on virtual human realism fail to mention navigation in any form, they note that the broad range of requirements virtual humans have poses a serious problem for research and the technology in general. But do not touch on the specifics of micro-movement that we describe here.

2.2 Human Movement Data

Human navigational behaviour is complex and the data required to fully understand it can have a lot of nuances, due to the innate complexity of the movement it is representing. When looking at tracked data from a human in an environment, such as the illustration in Figure 2 it is clear a simple location tracking of the participant gives a good representation of where the human moved, but not in what order, or where they were facing during the movement. If one was developing a human artificial social agent control system with an emphasis on realism, data like this may help in creating the pathfinding control, but this data is not able to be easily utilised in the creation of a control model that includes micro-movements. When the shoulders of the participant are tracked as in Figure 3, this gives a much better sense of where the human was facing during locomotion and can even convey a sense of turning while moving and strafing. This begins to highlight the complexity of human locomotion, as humans do not just face forward and move along a straight axis, and a better way to describe the different parts of this data would go a long way in increasing the ease of implementing micro behaviours in artificial social agents.

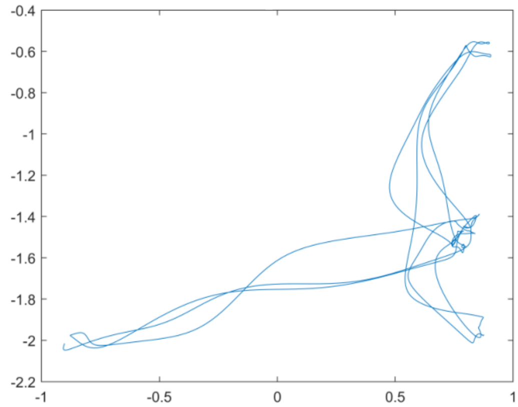

Figure 2: Centre of mass of a person moving through space between 4 different spatial locations.

When looking at the illustrative human acceleration data in Figure 4, one can once again see human locomotion is not as simple as moving to a location and stopping to turn and continuing along the calculated path, acceleration is more than just a linear up and down. The data instead includes a large array of different movements and angular velocities, further highlighting how complex this data can become, and again showing that humans indeed do employ micro-movements that if simulated can improve the realism of an agent, are so often missed out during research into navigation and are the exact movements we propose need to be formalised. With annotation of the human navigational data (Figure 3, one can see that each part of the movement data can be ascribed to a specific micro-movement, though even the rotate in place annotated here may be closer to rotate in walk. These micro-movements are described in more detail within the next section.

This issue of translating human movement into the virtual space has been wrestled with for a long time, and though we do not yet have a solution for this problem, we do propose a framework for describing and formalising this behaviour and improving ease of collecting useful data.

3 FORMALISING MICRO-MOVEMENT BEHAVIOUR

To have realistic agent behaviour, we need to develop spatial models that understand these micro be-

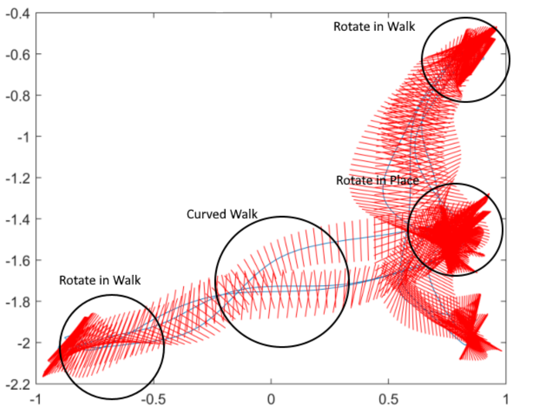

Figure 3: Orientation during locomotion between 4 different spatial locations, with specific micro-movement behaviours from the proposed formalisation annotated.

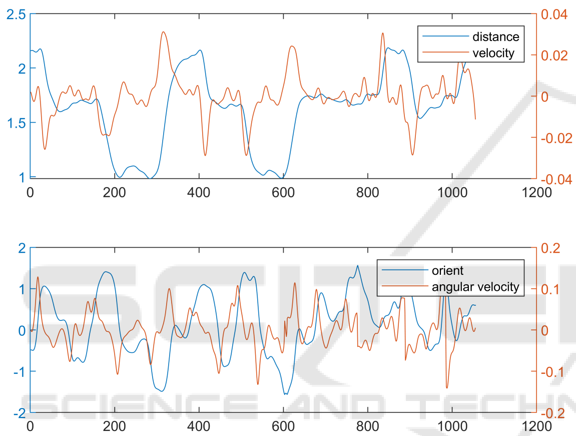

Figure 4: These Plots of Orientation, distance and velocity show that the orientation of a human is constantly changing and complex in it's nature, there is a lot of changes in acceleration, velocity and orientation rather than a simple (a) to (b) with constant velocity.

haviours, and to that end this paper proposes the formalisation of a testing framework, by associating the following descriptors to these micro behaviours with diagrams representing the 6 behaviours in Figure 5. If we assume that there are a finite set of movement strategies that humans will use, one can divide human locomotion into 6 key behaviours. We see these behaviours as consisting of; (A) "Linear walk," where an agent walks in a direct line congruent with their orientation direction. (B) "Backwards walk," where an agent back-steps without turning their orientation. (C) "Strafe walk," in which an agent steps to the side while facing forward. (D) "Curved walk," where an agent is orienting gradually as they walk. (E) "Rotate in Place," where an agent may turn on the spot without movement, and finally (F) "Rotate in Walk," in which an agent is rotating their orientation as they step in a specific direction, for example, turning as you back-step into a forward walk. One can view any navigation from point (a) to point (b) as a combination of any number of these actions, resulting in the ability for investigations into this field to more readily explain and describe the movement behaviours they record. At the very least, it is important for the field of agent navigation to recognise these important navigational micro-movements, as they are paramount in creating the next step in virtually real humanoid agents that foster a sense of immersion in users.

4 WHERE TO NEXT?

From the research discussed above, it is clear that there exists a gap within the field of navigational research centred around the simulation of micro-movements that humans unconsciously employ during path-planning and execution of movement. Behaviours such as these have been found to foster a higher sense of immersion within virtual worlds, something that is key to creating impactful, efficient virtual simulations. This is especially important in the field of virtual reality training, as the closeness to the real-world is what makes it such a powerful tool. With the formalisation of these micro-movements that occur during locomotion, researchers will be able to look at complex human locomotion data and ascribe these formalised terms to the different micro-movement techniques that are employed. This will result in researchers being more well equipped to tackle the issue of realistic human movement in a virtual space, creating this much needed and oft missing sense of realism to the artificial social agents that inhabit these virtual spaces. Formalisation is just the first step however, and this future work must look at collecting data on these micro-movements during locomotion from real-life human participants, and create an autonomous system that is able to replicate in a realistic way and simulate these micro-movement behaviours for an artificial social agent. Whether by reinforcement learning systems, finite control models or some other system. This is specifically for AI controlled agents in virtual spaces, as user-controlled agents do not run into this issue as the user is in full control of the navigation and thus any strange movement is overlooked. The list that has been outlined here can be seen as complete, though is open to being improved upon, and is a starting point for the standardisation of these concepts for ease of understanding and formalisation.

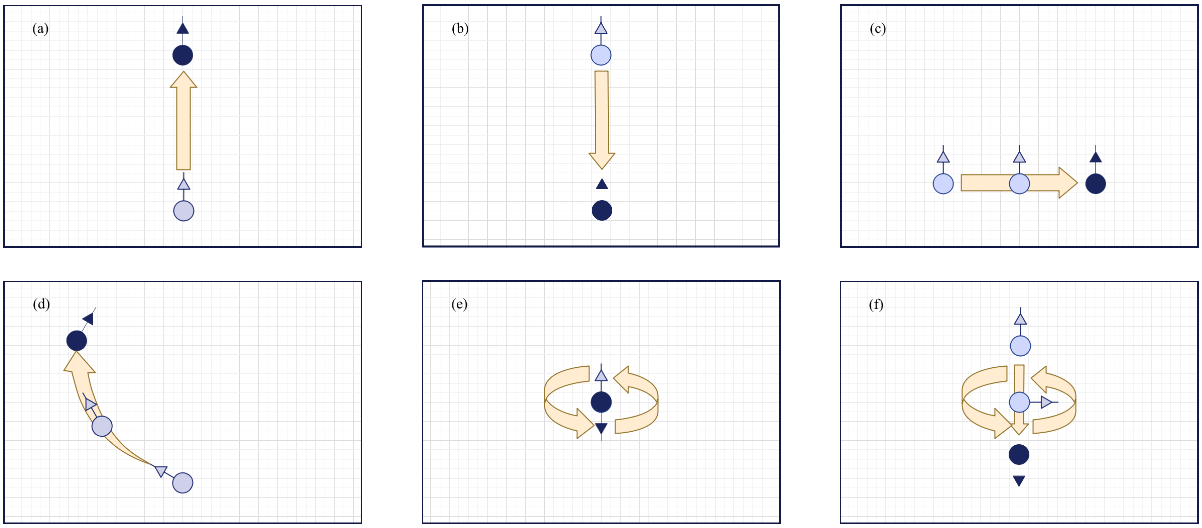

Figure 5: Proposed list of atomic micro-movements, complete in that we posit there is no further way to break these motions down in a meaningful way. The start location of the agent is the lighter blue circle, the darker blue circle denotes the end location of movement. The arrows on the circle show body orientation, the yellow arrows denote the displacement path irrespective of body orientation. (A) Linear walk in a direct line congruent with body orientation. (B) Linear back-step in a direct line. (C) Strafe (side-step) to the side while facing forward. (D) Curved walk with gradual body orientation along the curve. (E) Rotating in place with no translation of the center of mass of the body, the original and final orientation differ by 180°. (F) Rotation during displacement along a path, the original and final orientation also differ by 180°.

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