Shared Space Navigation

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Shared space is a concept of urban planning in which all barriers between cars and pedestrians, such as curbs and crosswalks, is removed to encourage heightened awareness of drivers and pedestrians, thus making city streets safer. The system has been highly successful, but can be highly stressful due to the lack of rules and signage. Thus, an adaptive feedback system that guides one safely through shared space could be essential for a shared space on the city scale. This paper imagines shared space at the city scale, and uses computational strategies to develop a system of adaptive collision-avoidance. By abstracting the movement of cars and pedestrians to properties of moving 'agents', collision detection and adaptive path finding models are developed, and then prototyped in an immersive environment that experiments with variable visual feedback based on user interactions.

Keywords: *Shared space, movement, visual feedback, traffic, urban*

INTRODUCTION

Shared space is the urban planning concept of getting rid of curbs, crosswalks, and lanes on city streets to allow pedestrians, cars, and cyclists to travel through the space at their own risk. The idea is that each person moving through the space will proceed with a heightened caution, therefore reducing accidents and contributing to an even flow of traffic. This system has been implemented most notably in Northern Europe, but has begun to be adopted - albeit on a very small scale - in the United States [1]. This paper confronts, at some level, what the effects of a city organized completely around shared space would be, and then sets out to develop a feedback system to ease the use of the shared space. The inventor of shared space, Hans Monderman, said that, "The trouble with traffic engineers is that when there's a problem with a road, they always try to add something. To my mind, it is much better to remove things" [4]. However, my hypothesis is that computationally providing certain traffic feedback and navigation advice - essentially one's own personal road signage - would be a beneficial for the users of shared space. This presented two avenues of research: one was to simulate the movement of agents and their interactions within shared space and shared space between built environments, taking particular care in analyzing patterns of collisions and bottlenecking around buildings. This is discussed in Section 3. The second was to design (and speculate) a feedback system for users that could provide the necessary information gathered from the simulation models to the user, which is discussed in Section 4. The contributions of this paper are in the translation of an algorithm for collision avoidance into a conception of a virtual environment for safe navigation of shared space.

RELATED WORK

To the best of my knowledge, there does not exist a precedent for an adaptive feedback system for shared space navigation. A notable work, which in part inspired the contents of this paper, is the Bjarke Ingels Group (BIG) project for the Audi Urban Future conference [3], which imagines a city of shared space, in which cars are self-driving and their future paths are displayed on the street by the way of LED lights embedded the Solar Road product [2]. However, the project does not confront the actual algorithms of navigation and avoidance within the shared space, and is more of an exercise in visualization. What is useful for our purposes is the use of the Solar Road as a means of sensing the movement of pedestrian agents as well as providing visual feedback in an immersive environment. Another important advancement that will factor into the discussion of system implementation is the development of augmented realities through current mobile phones (Takacs). Finally, Anvari et al developed a model of the movement dynamic between agents in shared space as well as route finding around buildings. The Anvari model is based on the Social Force Model (SHM), which determines an agents movement based on forces applied to the agent by other agents and barriers in the space. Although I built my own movement dynamics in the model simulation, Anvari et al's algorithm is more robust and will thus be considered useful in further development.

ABSTRACT MODEL FOR AGENT INTERACTIONS

This section presents two models for the simulation of agents in shared space, one based on the SHM

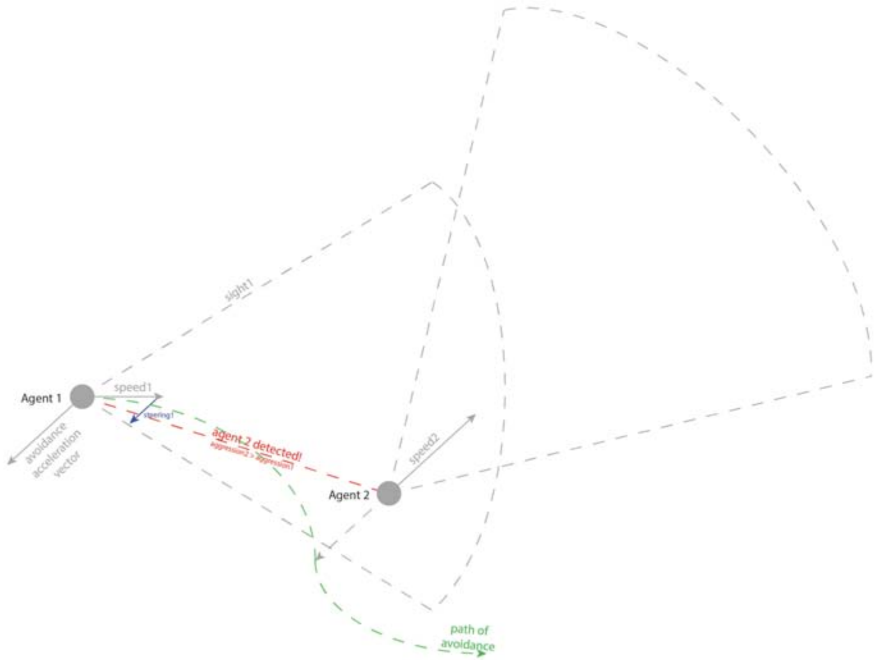

Figure 1
Parameter diagram for abstract movement model

(Anvari), and the other based on my own development of a geometry-based avoidance algorithm. The first model was useful for observing abstract trends of agent collisions and interactions with built environments (barriers). The second was a step towards a robust route generation through shared space based on current velocities of the agents within a space.

Model for Abstract Movements

This model incorporates various abstractions in order to produce a simulation of agents in shared space. The agents were imagined as homogeneous - so no distinction between cars and pedestrians was built in - however each agent was assigned a set of parameters to control its movement. These parameters were aggression, sight, steering, and speed. At each time step in the model simulation, an agent detects other agents within a cone of sight. This cone of sight has a radius and angle determined by the sight parameter. If an agent is detected within the cone of sight, the two agents compare aggression variables, and the least aggressive executes an avoidance maneuver to pass behind the agent in its sight. The avoidance maneuver in this model was to accelerate towards the negative velocity vector of the agent to be avoided. Once the agent executing the avoidance no longer detects an agent in its sight, it reroutes towards its initial destination. An avoidance function is also called if a built environment is detected by the agent, which similarly accelerates an agent towards a corner of the structure to allow it to pass. The speed and steering parameters determine how quickly an agent can accelerate linearly and radially. The parameters and avoidance functions are illustrated in Figure 1.

This model sets up a framework through which to analyze interactions in shared space. The goal was to introduce a built environment into the shared space simulation, and detect patterns of collisions. As one can see in Figure 2, built environment caused a high concentration of collisions in the intersections (where the paths of agents crossed often) and bottlenecks (where agents were forced into confined pathways. Another hypothesis was that by opening up places of high collision occurrence would reduce the number of collisions in the future. The test was conducted by constructing a high resolution of small structures, and then deleting structures as collisions occurred near them (Figure 3). The noisy pattern created reflected a pattern of collisions, yet it was found that collisions would still occur in the opened spaces. Thus, built environments in shared space were dropped in favor of a more adaptive, virtual environment.

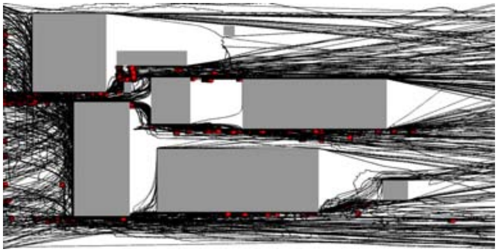

Figure 2
Bottlenecks and collisions with structures in agent simulation

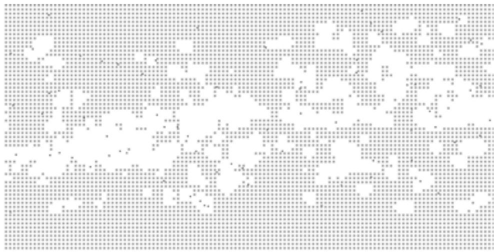

Figure 3
Generative subtraction of spaces from predicted collisions.

Geometric Avoidance

A second model intends to choreograph movements more precisely within shared space. This second model is entirely geometric and assumes that agents comply fully with its rules, have perfect reaction times, and travel at a constant speed. At each time step, all agents project their current velocity vectors forward some integer N times. At each step of the vector projection, the model calculates whether an agents future position, as calculated by the projected velocity vector, will collide with another agent's respective future position (Figure 4 left). If a future collision is detected, then the model deflects the pathway of agent to the right by a magnitude proportional to

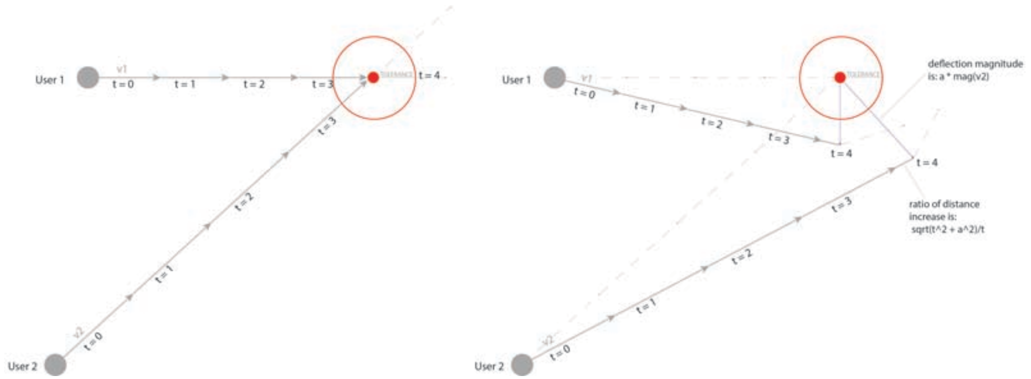

Figure 4
Projection of velocity vector, the detected collision, and the calculated geometric offset of path to avoid collision.

the magnitude of the agent's velocity (Figure 4 right). Both agents in this model deflect to the right, however it is possible for the two agents to compare a parameter that prioritizes one of the agents, forcing the less preferred to deflect. This is a scenario I wanted to avoid however. What is favorable about this geometric model as a form of shared space navigation is that it provides a calculable and unwavering path of navigation for the agent. Also, it adapts at each time step, which means that after a deflection, the agent changes direction and recalculates the agents future positions. Figure 5 visualizes the movement and computations of this model in an environment of built space and shared space. Thus, although the model deals with 100% compliance with the navigation system, the system is reliant on the current velocity of the agent at each time step, so even if the agent responds with 75% compliance, the system will keep calculating the agents future collisions and constantly display a path that avoids collision. This is ideal as a suggestive system of shared space navigation.

SHARED SPACE FEEDBACK INTERFACE

This section outlines one instance of prototyping for an immersive environment of motion feedback as an implementation for a shared space navigation system, and also speculates on the scaling up of such a feedback system to a city scale.

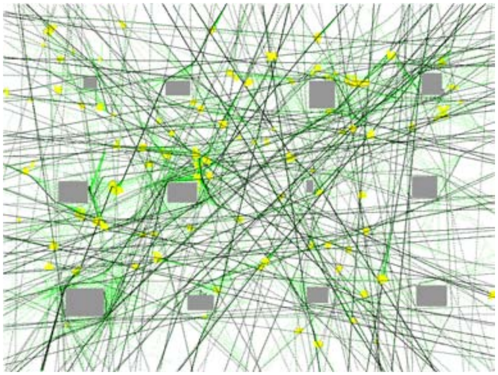

Figure 5
Geometric deflection model simulation. Green dots represent projected velocity vectors, yellow spots represent detected collisions that forces a geometric deflection. Black line represent actual movement of agents.

Motion Tracking and Immersive Environments

The first prototype for a feedback system for moving agents was an implementation of motion tracking with the Microsoft Kinect and floor projection. The Kinect registered the position of users that entered into its range, and then a Processing sketch would project information onto the ground at the feet of the user in the space. The system had two primary functionalities, each meant to test the basic conditions of the models described in the previous section with live users:

- The first was to generate information for each user based on the shared space conditions and display the information at the user's feet. The information displayed included a trail of the user's past movements, an arrow pointing to each other user in the shared space, a line pointing to the user's destination, and a circle of "personal space" around the user (Figure 6). The personal space circle changes from green to red if it comes in contact with another person's personal space (Figure 7). The expected result was that displaying such information would change how one moves through the space and interacted with others within that space. What was observed was that users, as seen in Figure 7, would seek the red warning circle as a reward for their movements. The expected result of using the red circle as a warning was reversed. Therefore, an effective system could employ feedback rewards for good compliance, so that the system would react positively in the case of good avoidance behavior. The other functions of displaying information were not found to have a significant effect on movement behavior.

- The second functionality was to choreograph movement, as the model in Geometric Avoidance section outlines. Paths were displayed on the ground, for users in the space to follow. Each path is a straight line from the user to their respective destination (which, in this prototype, is randomly generated), unless their projected velocity vector detects a collision with another user in the space. Since compliance is not guaranteed with live users, the path becomes more of a suggestion than a strict movement-bounding condition. At the scale of the implementation, it was hard to determine the success of the choreography, as the projection environment is only a few square meters. Two further additions could produce the desired results: a positive reward feedback system as discussed above would encourage compliance, and perhaps also generating a simulated agent that takes the desired path at a constant speed, so that the user could follow the agent as it successfully navigates the space. I speculate in the next section on possible implementations of a feedback system on the scale of a city.

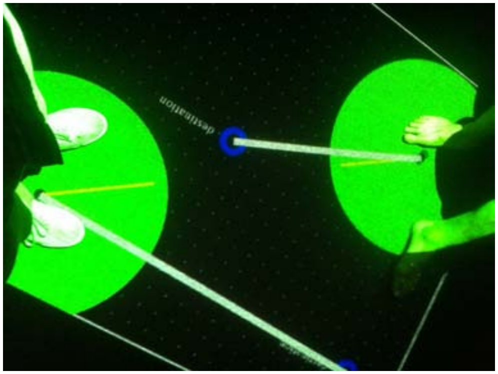

Figure 6
Projected personal bubble and route information.

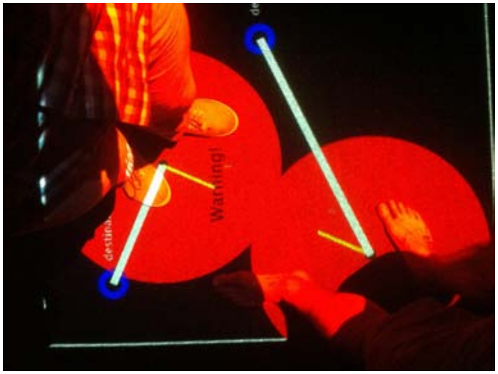

Figure 7
Visual feedback through ground projection for detected collisions.

Scaled Implementation Speculation

Scaling up a projection-based immersive environment poses numerous problems. It would require projectors strategically placed at all shared space road systems, there would be interference between the projection and the users, and projection is hard to see in daylight. The Solar Roadway [2] implemented as a feedback system would allow for effective ocular feedback as discussed in the previous section, and could be a viable alternative to projec-

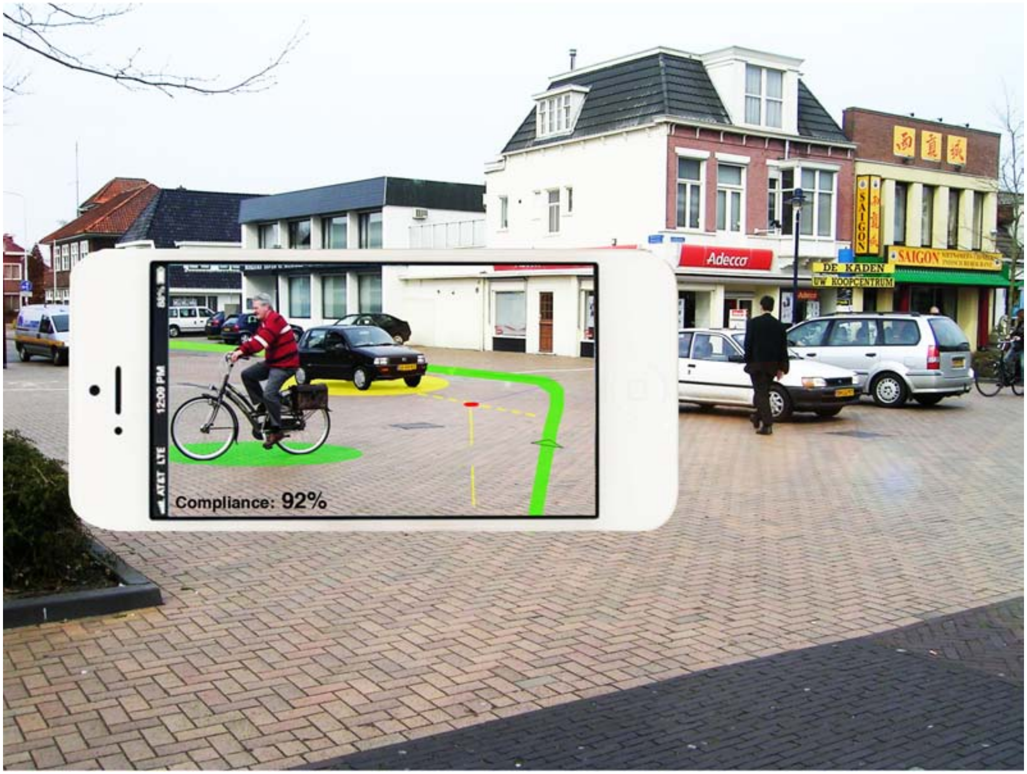

Figure 8
Visualization of possible implementation of geometric avoidance system on a mobile phone in shared space.

tion. It still has aesthetic and functional drawbacks, though. Mobile augmented reality is another possible option. A personal projector attached to the user could project their path in front of them using technology proposed by Schöning et al, but this still deals with the problem of luminosity of the projector. Specific audio headsets could given auditory feedback, but the results of route finding with the study done by Vazquez-Alvarez et al reveal low accuracy of user movements given auditory signals. Mobile phones, however seem to be the most useful tool, as they are widely used and dependable. Takacs et al have developed an augmented reality algorithm for mobile phone cameras, allowing virtual images to be displayed over real images. By displaying the shared space navigation feedback onto a mobile phone screen, the system could function as a more detailed and precise implementation of current navigation features on GPS-enabled mobile phones. GPS-enabled mobile phones also provide a platform for motion tracking, as the GPS data can inform the vector calculations of the model. Ocular-centric feedback has produced noticeable results in the prototype of the previous section, thus translating signage as a virtual reality onto mobile devices should be considered in the development of shared space navigation (Figure 8).

CONCLUSIONS AND FUTURE WORK

Implementable shared space navigation in the form of adaptive movement feedback requires further development to become a robust and scalable option for making transportation through shared space more manageable. This paper has outlined a basic model of geometric collision avoidance, and presented one possible prototype of integrating live users into the model via an immersive projection environment. Such an immersive environment should not be considered a final design implementation, however, and other avenues of displaying motion feedback and navigation should be considered, such as implementation in mobile phones. Future research should focus on an effective mobile feedback system that is sleek, user-friendly, and relatively invisible, as well as develop the robustness of a geometric collision avoidance system.

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