Human Realistic Walking Simulation Using Dynamic System

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Abstract

The goal of this work is to create human-realistic simulation for virtual characters' walking behaviors. In particular, their route selection, obstacle avoidance and pursue behaviors. Though various algorithms exist for path finding and steering behaviors, the simulated behaviors are typically not created based on models of human behaviors. This work presents a computational model of walking simulation, which is based on the ecological theories of psychology and using parameters extracted from real human data. The system has been fully implemented. This paper presents the algorithms in detail, followed by preliminary results, discussion, and proposed future work on evaluating the models.

Keywords--- **Walking Simulation, Virtual Character, Dynamic System**.

1. Introduction

In recent years, games that emphasize the social and narrative aspects of the player's experience have become increasingly popular. Game designers have been looking into ways to use human-like characters to engage the player and to provide the central experience of the game. This is evidenced by recent major titles such as Mass Effect, Fallout 3, and Heavy Rain. Human-realistic characters that have natural facial expressions, and can talk and act as real humans, can greatly facilitate the success of such games. Such characters make it natural for the player to identify with them, and treat them as real people when interacting with them.

This project targets one aspect of human-realistic character modeling: the character's walking behavior, i.e. how should a character move from one location to another; what if there are obstacles in between; and how can a character follow another moving character?

These problems are usually tackled in game AI as either a path finding problem or a steering problem. Path finding algorithms generate a path from the character's current location to its destination and avoid the obstacles in the environment. Steering algorithms generate paths for agents to wander around, chase or flee away from a target.

Various algorithms have been developed for both path finding and steering problems [1, 2]. Through existing algorithms are often sufficient for driving non-human-like agents, such as monsters and vehicles, it is questionable whether they can simulate people's walking behaviors realistically. The existing algorithms are seldom data driven. Instead, they were designed based on the designer's intuition and/or for reaching computational simplicity/efficiency. For example, path finding algorithms normally operate over either a set of manually designed way points, or a mathematical partition of the space, such as a simple tile partition, and find the shortest path from one location to another. However, the way people move is not consistent with such a simplified vision from artificial intelligence. For example, people are not always looking for shortest path. Moreover, most existing AI algorithms treat moving and sensing the environment as two distinct processes. The sensing process provides information based on which the agent makes decisions on how to act. People, on the other hand, can/do not always pick up all the information from the environment at once. Instead, for human beings, visual perception and actions are tightly integrated -- walking not only leads the person to his/her destination, but also is an important way of information gathering. According to the ecological theory of psychology, people do not observe the environment by standing still [5, 6]. Instead, people move in ways that enable them to see better and to plan better. Though this process is usually unconscious, constant behavioral patterns can be observed across subjects in empirical studies.

This work presents an approach for simulating human realistic walking behavior, which is based on the ecological theories of psychology and human data. More specifically, the algorithms are derived from Fajen and Warren's work of human locomotive behavior [3, 4], which is described below.

2. Fajen and Warren's Models of Locomotion

Dynamic systems, which are composed of a set of differential equations, are often used for modeling people's goal-directed behaviors. Fajen and Warren conducted various experimental studies on people's locomotive behaviors. Based on the observations of the subjects' walking behaviors, they derived two dynamic systems. One models scenarios which are similar to traditional path finding problems -- the character approaches a stationary goal in an environment which has stationary obstacles [3]. The other models scenarios which are similar to traditional steering behaviors -- the character chases a moving target without having obstacles in the environment [4]. In both models, the goal corresponds to the attractor of the dynamic system, and the obstacles correspond to the repellers.

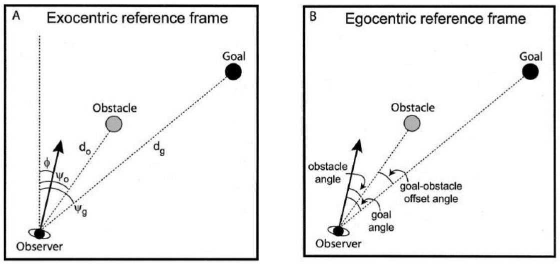

Figure 1 Definition of Terms for Approaching Stationary Target

2.1. Approaching Stationary Target with Obstacles

Fajen and Warren [3] used head mounted displays and virtual environments in their studies. The subjects were instructed to walk towards a stationary goal and avoid the obstacles which were also stationary. Their data indicated that the subjects' walking speed was fairly constant during the central portion of the trial across all different conditions. Further, the walking speed was not affected by how the goal and the obstacles were placed. In contrast, the subjects' angular accelerations were significantly affected by the configuration of the goal and the obstacles. In particular, their results indicated that:

1. Angular acceleration increases linearly with goal angle and decreases exponentially with goal distance.
2. Angular acceleration decreases exponentially with both obstacle angle and obstacle distance. However, it does not decrease with goal angles.
3. Maximum turning rate toward a goal increases with goal angle.

Figure 1 is taken from [3] to illustrate their definitions of terms, including how goal angle, goal distance, obstacle angle, and obstacle distance are defined.

To model these observed phenomena, Fajen and Warren used a second order dynamics system (Equation 1) which linearly combines a damping term, a goal term, and multiple obstacle terms for deciding the character's angular acceleration ($\ddot{\phi}$).

$$\ddot{\phi} = -b\dot{\phi} - k_g(\phi - \varphi_g)(e^{-c_1 d_g} + c_2) + \sum_{i=1}^{\#obstacles} k_o(\phi - \varphi_{o_i})e^{-c_3|\phi - \varphi_{o_i}|}(e^{-c_4 d_{o_i}})$$

Equation 2

In Equation 1 $(\phi - \varphi_g)$ is the goal angle, and $(\phi - \varphi_{o_i})$ are the obstacle angles (see Figure 1 for detailed illustration.) $-b\dot{\phi}$ is the damping term, which decreases the angular acceleration $\phi^{\cdot\cdot}$ linearly with current turning speed $\dot{\phi}$. $-k_g(\phi - \varphi_g)(e^{-c_1 d_g} + c_2)$ describes the effect of the attractor. $\ddot{\phi}$ increases linearly with goal angle $(\phi - \varphi_g)$ and decreases exponentially with goal distance d_g. $k_o(\phi - \varphi_{o_i})e^{-c_3|\phi - \varphi_{o_i}|}$ reflects the finding that the angular acceleration decreases exponentially with obstacle angle $(\phi - \varphi_{o_i})$. $(e^{-c_4 d_{o_i}})$ reflects the finding that the angular acceleration decreases exponentially with obstacle distance. Further, they identified the values of the constants, such as b, c_1, etc. by fitting the model to the data from human subjects.

2.2. Approaching Dynamic Target

Fajen and Warren studied how people move towards a moving target. Figure 2 illustrates their definitions of terms for the study. This figure is taken from their original paper [4].

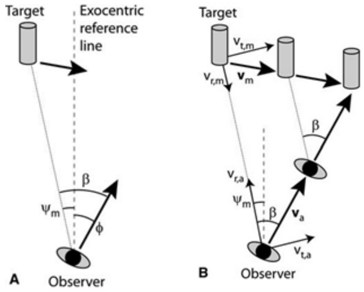

Figure 2 Definition of Terms for Approaching Moving Target

Using data from human subjects, their study tested four different strategies, some of which are often used for driving steering behaviors in game AI [1, 2].

The first strategy is the pursue strategy. The character tries to travel directly toward the target. In doing so, the character will keep turning to bring the target-heading angle β to zero. The remaining three strategies are all interception strategies.

1. Required interception angle: directly calculate the intercept angle $\hat{\beta}$, and then bring the difference between the current target-heading angle β and the required angle $\hat{\beta}$ to zero.
2. Constant target-heading angle: try to arrive at a constant target heading angle by making $\beta^{\cdot}$ zero.
3. Constant bearing: bring the change in the target's bearing direction to zero. This strategy can be implemented by either making the bearing direction $\dot{\varphi_m}$ zero, or making $\dot{\beta} - \dot{\phi}$ zero.

Their results indicate that the constant bearing model fits human subjects' data best when the target moves at a moderate speed (3-5o/s).

This model can be formally expressed using either Equation 2 or Equation 3.

$$\ddot{\phi} = -b\dot{\phi} - k_m(\dot{\beta} - \dot{\phi})(d_m + c_1) \qquad \textbf{Equation 2}$$

$$\ddot{\phi} = -b\dot{\phi} + k_m\dot{\varphi_m}(d_m + c_1) \qquad \textbf{Equation 3}$$

Equation 3 requires an accurate estimation of bearing direction $\dot{\varphi_m}$. To do that, the character needs to have a visible external reference frame, such as a fixed background or distant landmarks. Without such external reference frame, Equation 2 can still be used, which only requires egocentric reference frames.

In both Equation 2 and Equation 3, d_m denotes the distance between the target and the character. The effect of the distance term $(d_m + c_1)$ is to increase the influence of the moving target as target is further away from the character. Fajen and Warren pointed out that without such term, the agent will make sluggish turns toward distant targets.

3. Computational Extensions and Preliminary Results

The two models described in the previous section (Equation 1 and Equation 2) have been implemented in the Unity game environments for driving virtual characters' walking behaviors. The constants in the equations take the default values suggested in Fajen and Warren’s work. Figure 3 shows the simulation environment. Because these algorithms only specify the path for the character to follow, a generic talking animation clip is played while the character is moving.

Figure 3 Simulation Scenario

The simulation works well when simulating a single character's movements. The character's moving trajectories resemble the trajectories of human subjects in Fajen and Warren’s works when approaching either a stationary or a moving target.

An interesting observation is that if the character comes towards two obstacles that are on either side of its intended path, near to each other, it may go around both of them instead of straight between them, which would be the optimal path computationally. Empirical studies using human subjects are needed to investigate whether this is just an artifact of the model or truthfully reflects how people walk.

Two computational extensions have been made for applying Equation 1 to a wider range of scenarios.

3.1 Extension I

In Fajen and Warren’s model [3], both the goal and the obstacles were simulated using thin cylinders in the virtual environment, and are treated as abstract locations in the models. The width of the cylinders is trivial compared to the subjects' body widths. However, such thin obstacles are rare in real world, and hence in game environments. Most of the time, the obstacles are of similar size or wider than the characters' bodies. In fact, an obstacle can be much wider than the character and still not block the character's view of the target and other obstacles. For example, people can walk around the corner of a building to reach their targets.

One possible solution suggested by Fajen and Warren [3] is to treat the obstacles as a finite set of smaller obstacles. This approach has been tried out in this project. The obstacles were discretized into fine rectangular segments. The centers of the segments were treated as the location of the obstacles. This algorithm enables the character to go around wide obstacles most of time. However, in some cases, the sum of the forces generated by the segments directed the character to go directly through the obstacle. Future work has been planned to further investigate this issue.

3.2 Extension II

A crowd is a group of people. A crowd simulation was created by applying Equation 1 to each individual character, and treating everyone else as obstacles. The simulation works well in general. The characters avoided each other while attempting to get towards their own goals. When the characters were given the same goal, a nice flow will emerge that almost would resemble something one would see at a busy mall.

The emergent behavior where multiple characters bump up to each other and then walk shoulder-to-shoulder has also been observed. This is possibly due to the fact that the algorithm assumes stationary obstacles, and therefore the characters will never cut backwards to avoid where other characters will be instead of where they are. On the other hand, in crowd simulation, it is unrealistic for each character to know the moving directions of other characters around him/her because everyone is constantly changing their directions. Future work is needed on finding an efficient algorithm for resolving this issue.

4. Planned Evaluations

The goal of this work is to create human realistic simulation of locomotion for virtual characters. Therefore, the ultimate criteria for evaluating the project is whether people think such characters are more realistic and behavior more naturally.

Future work has been planned to formally evaluate the effect of having such characters on user experience. The effect will be evaluated under different contexts because the same walking behavior may seem/feel differently in different context. In particular, I propose to vary the following factors and study their effects on the player’s experience:

1. Display type: head mounted display vs. computer screen vs. big projector screen
2. Perspective: first person perspective vs. third person perspective with a top down view of the scene
3. Interaction type: no interaction vs. physical interaction vs. social interaction
4. User’s agency: whether the user is allowed to walk around freely in the scene.

The general hypothesis is that the more immersed the user is, the more likely the user will find the characters driven by our new algorithms being more realistic than those driven by traditional path finding and steering algorithms. A possible exception is the condition of third person perspective with a top down view of the scene. Because the user can clearly see each character’s goal and obstacles, it is easier for the user to “simulate” how the character should walk in his/her mind, and therefore it is easier for him/her to tell whether the character walks like a real human.

I also plan to evaluate the more general hypothesis that the new talk behavior in characters will have a positive impact on the user’s experience of presence in the virtual world. I am interested in investigating the effect on both the user’s experience of being physically present in the virtual world and being social present with other intelligent entities, and whether using such characters will affect the way the user interacts with the virtual world, including the virtual characters.

Acknowledgements

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