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A Collision Avoidance Model for Crowded Environments

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1 Introduction

The problem of collision avoidance in static environments (path planning) was extensively studied for robot navigation. Avoiding collisions with multiple moving obstacles (trajectory planning) is a more difficult task. A general approach is to represent the situation in space-time coordinates: in such a space, the problem is to find a safe path avoiding the trajectories of the obstacles.

We developed such a method as part of a program simulating the behavior of pedestrian crowds. A path-velocity decomposition approach as in [1] did not appear realistic for human behavior, and more generally geometrical constructions of a complete trajectory such as in [2] did not seem applicable in our case. We tried to find a simple and intuitive method coherent with realistic hypothesis, but also scalable enough to be efficient when numerous obstacles must be avoided simultaneously.

2 Representation of Movements and Trajectories

A pedestrian walking in the street can deduce the position and the speed of other pedestrians from his visual perception. If we assume that pedestrians keep on walking at the same speed in the same direction, their trajectories in (x,y,t) space are straight lines.

Several strategies are possible to avoid a single trajectory (line) D in (x,y,t) space:

1. Minimizing the detouring by reducing the speed and yielding. In (x,y,t) space, the trajectory remains in a vertical plane and passes above D.
2. Maintaining the speed by yielding and deviating from the forecasted collision point.
3. Preserving time by accelerating in attempt to pass before the other pedestrian. In (x,y,t) space, the trajectory passes under D.

In the following, points belong to a three-dimensional space (x,y,z) with $z = V_Z.t$, where V_Z is an arbitrarily fixed constant and t is time. If a pedestrian's maximum velocity is V_M, and his acceleration not bounded, the points that can be reached after Δt are on a disk located $V_Z.\Delta t$ above the current position, and with a radius of $V_M.\Delta t$.

This disk as well as the trajectory to avoid $D = (P_0, \mathbf{V_0})$ are represented in figure 1. We also define points A and B as the intersections of the plane

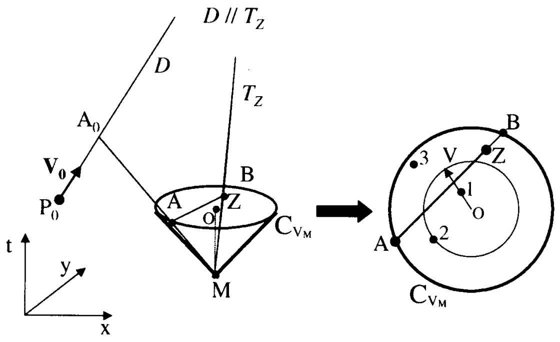

Figure 1: Disk of admissible displacements

$(M, \mathbf{MP_0}, \mathbf{V_0})$ with the circle C_{V_M}. A is the one which actually represents the intersection of D with the cone (this intersection is called A_0). The image of D on the disk is then the segment AZ, with $\mathbf{MZ} = \mathbf{V_0}$. Dots 1, 2 and 3 shown on the disk represent speed corresponding to the three avoidance behaviors we described before.

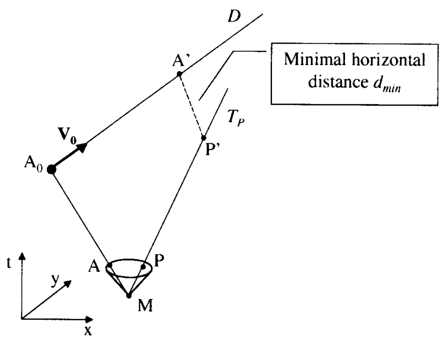

Figure 2: Shortest distance between D and T_P

Given a point P on the disk, it is possible to characterize the trajectory T_P obtained by adopting the speed corresponding to P, relatively to the line to avoid D by calculating:

- The minimal (horizontal) distance d_{min} between T_P and D (figure 2):

$$d_{min} = a.AP.|\sin\alpha| \qquad (1)$$

- The instant t_{min} when T_P and D are the closest:

$$t_{min} = \Delta t.a.(1 - \frac{AP}{ZP}\cos\alpha) \qquad (2)$$

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with $a = \frac{A_{0_Z}}{V_Z.\Delta t}$ and $\alpha = angle(\mathbf{PA}, \mathbf{PZ})$

From (1) it can be seen that points on the same line from Z correspond to a same d_{min} (figure 3). Intuitively, it means that the closer P is to Z, the further the collision point is, and the less deviation is required. If the pedestrian discards all movements that correspond to a d_{min} inferior to a fixed limit, it creates a triangular shaped forbidden area having Z for vertex, as shown in figure 3.

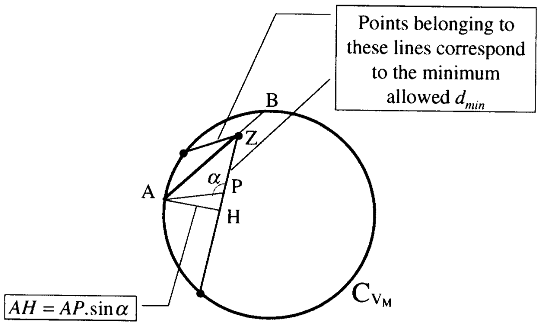

Figure 3: Forbidden area

3 Algorithm for Collision Avoidance

Safe movements are defined as those outside the forbidden area constructed as explained in 2. The pedestrian's current speed is represented by point V and the point leading to the goal at his favorite speed is G (see figure 4).

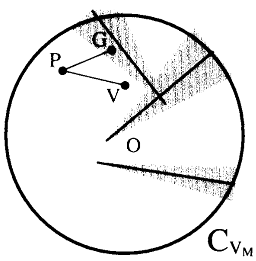

Figure 4: Evaluation of a movement P

To choose among safe movements, the cost of a point P is defined as:

$$K_1 \frac{GP}{2.r_M} + K_2 \frac{angle(OV, OP)}{180} + K_i \frac{|OP - OV|}{2.r_M} \quad (3)$$

with

$$i = \begin{cases} 3 & \text{if } OP \geq OV \\ 4 & \text{if } OP < OV \end{cases}$$

K parameters are constants: K_1 represents the cost of moving away from the goal, K_2 the cost of changing direction, K_3 the cost of accelerating, and K_4 the cost of decelerating.

Using this method, the pedestrian can select his next step. The process can then be iterated (without modifying the forecasted trajectories) to plan a n-step trajectory.

4 Implementation and Evaluation

From experimental data, the pedestrians' maximum walking speed was set to 2 m/s and their favorite speed to 1.5 m/s. The simulation time step was set to $\Delta t = 0.1$ s. The algorithm was tested using situations involving many potential conflicts (for instance, 12 pedestrians in small groups of 1 to 3 individuals whose trajectories cross at a same central point).

We studied the influence of n and d_{min} on the regularity of the trajectories, which is characterized by the "energy" used by the pedestrian:

$$E = \sum_i |\mathbf{A_i}.\mathbf{\Delta M_i}| \quad (4)$$

where $\mathbf{A_i}$ is the acceleration and $\mathbf{\Delta M_i}$ the displacement during the step i.

The choice of n results of a tradeoff between predictive potential (with a small n, only a few steps ahead are planned, which make the simulation unstable since the forecasted trajectories are not reliable) and accuracy (it is useless to plan a large number of steps since the environment will not evolve according to the hypothesis used for the prediction).

d_{min} represents the safety distance around obstacles: if it is too large, useless detours are made, whereas collisions occur if is too small.

The best trajectories are obtained for $n = 20$, which corresponds to planning the trajectory for the next 2 seconds, with a safety distance $d_{min} = 0.85$ meters. We also found that $K_1 = 5$, $K_2 = 2$, $K_3 = 2$, and $K_4 = 1$ gave an average behavior; modifying from one unit any of the K_i brings results coherent with the signification of the parameter.

5 Conclusion

In this paper, we presented an algorithm for collision avoidance that was implemented in a simulation of pedestrian behavior. It proved to be efficient even in difficult situations when multiple obstacles must be avoided. However, it is only a general algorithm and it would also be necessary to implement situation-specific methods to solve conflicts as a human pedestrian does.

References

[1] Kamal Kant and Steven Zucker, "Planning collision-free trajectories in time-varying environment: a two-level hierarchy", Proceedings of the 1988 IEEE International Conference on Robotics and Automation, pp. 1644 1649.

[2] Takashi Tsubouchi, Suguru Arimoto, "Behavior of a mobile robot navigated by an 'iterated forecast and planning' scheme in the presence of multiple moving obstacles", Proceedings of the 1994 IEEE International Conference on Robotics and Automation, pp. 2470 2475.