Automated Routing in Pedestrian Dynamics

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1 Introduction

« big picture: micor-/macroscopic models, cell automata/ODE-based, take a closer look in next chapter »

2 ODE based Model

« Explain different types (social force (2nd order), velocity based (1st order)) »

« velocity based have a sub-group using floor-fields (Dietrich's) »

« yet another model? »

3 Modelling

In the latter, a new approach in modeling is described,

- aiming for the avoidance of faulty interaction of pedestrians and walls
- while maintaining the positive characteristics of row-formation, stop-and-go waves and such - like seen in pedestrian crowd behavior/experiments/reality. (split up into more sentences).

In many of the existing models (using mathematical formulations in the continuous space/domain), agents breach wall-surfaces and get stuck inside of walls . This undesired phenomenon shows the challenge in calibrating forces and parameters of a model, so that agents show natural behavior while not getting overlapping in extreme situations. Especially in situations of high crowd density, e.g. when facing bottlenecks, overlapping can occur. The model or the data-post-processing needs to find a special treatment of this artifacts in the data. It leads to problems in counting, flow-calculation, simulation-stop-criterium and such.

There are three mechanics used in the model to avoid “overlapping/clipping” in the vicinity of walls (include a figure for each):

1. The routing of pedestrians makes use of the eikonal-equation, computed with an inhomogeneous speed-function, $s(x)$, whose resulting floor-field[1] favors keeping a distance to obstacles, walls and corners.
2. The angle between an agent’s moving-direction and the wall-surface-perpendicular affects the moving speed if and only if the agent’s moving vector includes a component geared towards the wall.
3. If an agent’s distance to a wall drops below a fixed parameter, he is redirected to move parallel to the wall if and only if the agent’s moving vector includes a component geared towords the wall.

In order to keep the model simple, repulsive wall forces as seen in Social Force Models are omitted. An analogy to repulsive pedestrian forces though is used to keep agents from colliding with each other. The model differs from SFMs, as in SFMs, other agents repulsive forces are transformed into acceleration vectors and from there into a velocity component, which is part of the agent’s velocity. In this model though, repulsive forces are not treated as Newton mechanics teaches us, but are only used to factor the repulsive pedestrian effect into a direction component. The magnitude on the other hand is effected by the other agents only to a certain degree (as discussed below).

Definitions:

[1] see chapter **Eikonal Equation, Safe Navigation using the Floor-field**

$$
\begin{array}{llllllll}
d & : \Omega & \ni \vec{x} & \longrightarrow & d(\vec{x}) & \in \mathbb{R} & := & \text{distance to the closest wall} \\
P & : \mathbb{R}^2 \times \Omega & \ni (\vec{v}, \vec{x}) & \longrightarrow & P(\vec{v}, \vec{x}) & \in \mathbb{R}^2 & := & \text{orth. proj. of } \vec{v} \text{ onto closest wall of } \vec{x} \\
v_{ff} & : \Omega & \ni \vec{x} & \longrightarrow & v_{ff}(\vec{x}) = \vec{v}_{ff} & \in \mathbb{R}^2 & := & \text{floor-field at position } \vec{x} \\
g & : \mathbb{R}^2 & \ni \vec{v} & \longrightarrow & g(\vec{v}) & \in \mathbb{S}^2 & := & \text{proj. onto the unit-sphere in } \mathbb{R}^2
\end{array}
$$

Variant Model:

$$
\begin{aligned}
\Delta \vec{x}_n &= \Delta t \cdot \vec{v}_{n,res} \\
\vec{v}_{n,res} &= \begin{cases}
\left(1 - \frac{1}{2}\left[(\hat{v} \cdot (-\nabla \hat{d})) + |(\hat{v} \cdot (-\nabla \hat{d}))|\right]\right) & P(\vec{v}_n) \quad : \quad d(\vec{x}) < 0.1 \\
\left(1 - \frac{1}{2}\left[(\hat{v} \cdot (-\nabla \hat{d})) + |(\hat{v} \cdot (-\nabla \hat{d}))|\right]\right) & \vec{v}_n \quad : \quad 0.1 < d(\vec{x}) < 0.2 \\
 & \vec{v}_n \quad : \quad d(\vec{x}) > 0.2
\end{cases} \\
\vec{v}_n &= 0.8 \cdot \vec{v}_{n-1,res} + 0.2 \cdot g\left(g(\vec{v}_{ff}) + g(\sum \vec{v}_{repP,i})\right)
\end{aligned}
$$

3.1 Variant Model

« short (!) overview over the model-modules »

The model can be sectioned into these modules:

- Floorfield
  - reading geometry
  - creating grid
  - distance-field
  - enhanced floor-field
- Intra Crowd Repulsion
- Direction-Calculator
- Anti-Overlapping
- Speed Calculator

3.2 Eikonal Equation

The "Eikonal Equation" in a domain Ω, subset of $\mathbb{R}^n$,

$$\begin{aligned} |\nabla u(x)| &= F(x), x \in \Omega, \\ \text{s.t.} \quad u|_{\partial\Omega} &= 0 \end{aligned}$$

yields "first-arrival-times" $u(\vec{x})$ in a spacial domain, provided a target region within the domain as input. A valid interpretation of "first-arrival-times"-isolines is to picture a wavefront at a given time t, originating in the target region ($t = 0$) and propagating throughout the spacial domain Ω while flowing around any obstacles (see figure 3.1).

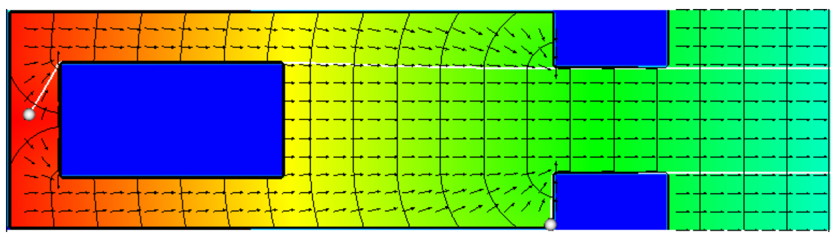


Figure 3.1:

Given a discretization of the domain Ω and the target region $\partial\Omega$, the solution to the Eikonal Equation can be approached (angenähert) by using the Fast-Marching Algorithm. The algorithm provides a first order approximation, yet sufficient for our cause (pedestrian navigation). Computing-time of Fast-Marching is independent[2] of the complexity of obstacles and walls.

The negative gradient $-\nabla u$ of the "first-arrival-times" will be a useful tool in the routing of pedestrians/agents to the target region used as part of the algorithm's input. The Fast-Marching algorithm is described in the appendix in detail for further reference.

We will refer to the result of the Fast-Marching Algorithm as "floor-field". To successfully use these floor-fields, we will discuss and analyze a modification, which gives us a smooth floor-field, as proposed in roboticslab.uc3m.es.

[2] Fast-Marching completion-time depends mainly on the length of the wavefronts. If the geometry leads to small lengths, as in geometries with large amounts of narrow corridors, completion time decreases.

3.3 Safe Navigation using the Floorfield

When using the plain approximation to the Eikonal Solution, agents anticipate a non-smooth pathway that leads very close to walls (see white trajectories in figure 3.1). In most of the models for pedestrian dynamics, pedestrians, which are very close to walls or obstacles, could overlap with them in rare occasions. Agents might leave the valid domain and find themselves captured inside walls or obstacles. In the model described in this paper, we aim to fix that problem. In reality, we can observe, pedestrians avoiding walls and obstacles and keeping a certain distance.

Therefore, it is desirable to define a modified quality of an optimal route, which accounts for a minimal arrival time and a safe pathway. Safe in respect to avoiding the vicinity of walls and obstacles if and only if possible. If a space is very crowded (high density), then agents should make use of the given space even if that means getting close to walls.

This crowd behavior, described above, is commonly achieved with adding a repulsive characteristic to walls.

In the "social force model", the walls will have a repulsive force pointing perpendicular to the wall-surface, aiming to keep agents away from the wall. These forces need to be calibrated to work as intended.

Smaller forces might not be strong enough to avoid overlapping with the wall if an agent is in between a wall on one side and many other agents on the other side . The agents on the other side affect that one agent, forcing him towards the wall, while the wall itself acts on the agent in the opposite direction.

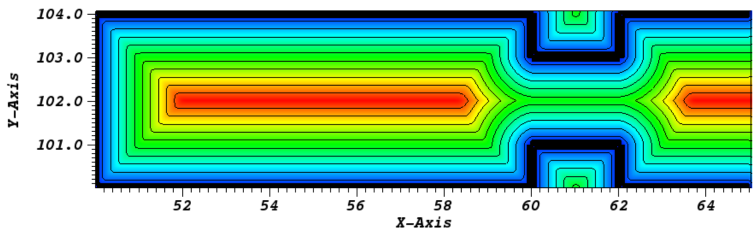
If the repulsive wall forces are too strong, pedestrians will not use the space close to a wall, even if the domain is very crowded.

It is a difficult task, to find a set of parameters, that work as desired in a broad set of situations and geometries.

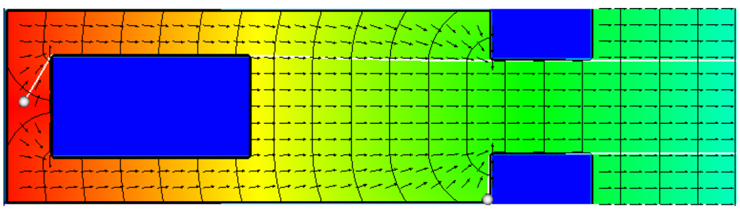
Instead of modeling the repulsive character of walls (seen as the avoidance of walls by pedestrians) via repulsive wall forces (social force model), we modify the floor-field in a way, that pathways avoid the vicinity of walls to a certain, adjustable degree, thus integrating this repulsive character into the navigation/routing.

How can an agent "avoid" the close vicinity of any wall or obstacle?

3.4 Distances-Field



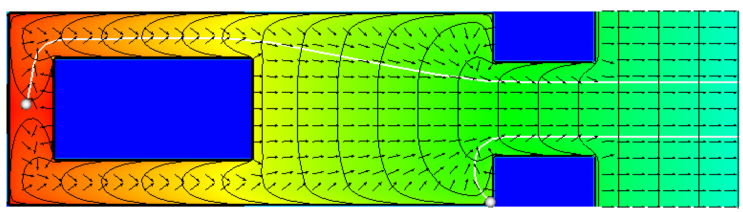
« explain the pre-step incl. the threshold "cut-off"; have some nice pictures »



the floor-field

⇓

is modified to:



3.4.1 Cost of a “full” preprocessing step

« the effort is doubled - but useful information is gained, that can be used in more than one way. »

Close to all time of the needed computation spent on the goal, the prohibition of overlapping, is spent in a preprocessing step before the actual simulation starts and therefore does not effect the real-time factor. A factor, which is a promintent metric, when comparing different models.

3.4.2 Distances-Field and repulsive Wall-Forces

« optional? describe in short that the distance field takes responsibility for not clipping in two ways: redirect in wall-distance < 0.2; modify floor-field to avoid walls »

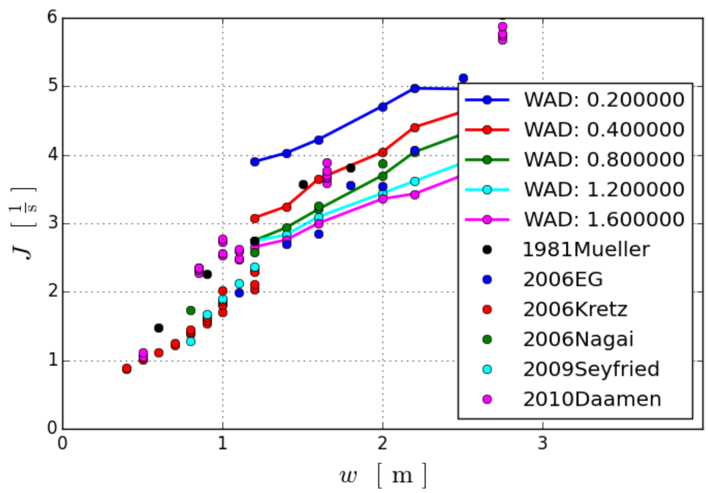
« move this section »

3.5 Idea of Separation of a Moving-Vector into Direction and Magnitute

3.5.1 no clipping

3.5.2 Recycling the Distances Field (neg. Gradient must be saved)

4 Testing



5 Outlook

5.1 Floor-field

5.1.1 Multiple Goals

The floor-field is a useful tool in routing of pedestrians through any geometry.

5.1.2 Multiple Floors

Neighboring Relations

5.2 Usage in JuPedSim

5.3 Floor-fields in Triangulated Domains

5.4 Parallelization

6 Appendices

6.1 Fast-Marching Algorithm

6.2 Classes and their Relations

6.3 Code Snippets

7 Bibliography