People Tracking with Social Force-Based Motion Prediction

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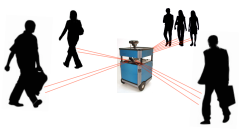
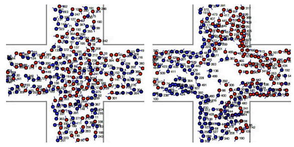
Motivation and Idea

- People tracking is a key technology for robots to safely and efficiently interact and cooperate with humans
- Pedestrian models developed in the cognitive science and quantitative sociology communities are being used for evacuation dynamics, building design or crowd behavior analysis
- **Idea:** Use pedestrian models for more realistic human motion prediction in people tracking





Example simulation of crowd behavior in a crossing using the social force model. Two groups of pedestrians (red and blue) traverse the crossing to reach the opposite corridor. Over time, lanes in a twirl-like pattern emerge in a bottom-up fashion as the most efficient motion strategy (left t = 0, right t = 2 min).

Theory

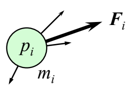
- Pedestrian model according to Helbing et al. [1,2]: Interactions between pedestrians are described by using the concept of a **social force**
- **Social Force:** Models the influences from the environment, other people, and an incentive to act

Basic equation of motion for pedestrian p_i with mass m_i

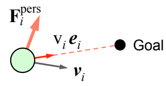
$$\frac{d}{dt}\boldsymbol{v}_i = \frac{\mathbf{F}_i}{\mathrm{m}_i}$$

Main conception: Human motion is explained by the superposition of different forces

$$\mathbf{F}_i = \mathbf{F}_i^{\mathrm{pers}} + \mathbf{F}_i^{\mathrm{soz}} + \mathbf{F}_i^{\mathrm{phys}}$$

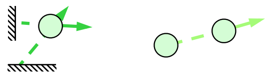


Personal Motivation Force: Incentive to reach a certain intended velocity v_i and direction $\boldsymbol{e}_i$



$$\mathbf{F}_i^{\mathrm{pers}} = m_i \frac{\mathrm{v}_i\,\boldsymbol{e}_i - \boldsymbol{v}_i}{\tau_i}$$

Social Forces: Repulsive effects from other individuals P and the environment O



$$\mathbf{F}_i^{\mathrm{soz}} = \sum_{j\in\mathcal{P}\setminus\{i\}} \mathbf{f}_{i,j}^{\mathrm{soz}} + \sum_{o\in\mathcal{O}} \mathbf{f}_{i,o}^{\mathrm{soz}}$$

$$\mathbf{f}_{i,k}^{\mathrm{soz}} = a_k\ e^{\left(\frac{\mathrm{r}_{i,k} - \mathrm{d}_{i,k}}{b_k}\right)}\,\boldsymbol{n}_{i,k}$$

Physical Constraints: Hard constraints from other individuals P and the environment O

$$\mathbf{F}_i^{\mathrm{phys}} = \sum_{j\in\mathcal{P}\setminus\{i\}} \mathbf{f}_{i,j}^{\mathrm{phys}} + \sum_{o\in\mathcal{O}} \mathbf{f}_{i,o}^{\mathrm{phys}}$$

$$\mathbf{f}_{i,k}^{\mathrm{phys}} = c_k g\left(\mathrm{r}_{i,k} - \mathrm{d}_{i,k}\right)\boldsymbol{n}_{i,k}$$

Integration into People Tracker

- Multi-Hypothesis Tracking (MHT) approach by Reid [3], Cox et al. [4], Arras et al. [5]
- Tracking with range data from a 2d laser scanner
- Track representation: $\mathbf{x}_t = (\ x_t \ \ y_t \ \ \dot{x}_t \ \ \dot{y}_t\ ) = (\ \boldsymbol{x}_t \ \ \boldsymbol{v}_t\ )$
- Static environment represented as a short term memory of laser points

Old: constant velocity motion model

$$p\left(\mathbf{x}_t \mid \mathbf{x}_{t-1}\right) = \mathcal{N}\left(\mathbf{x}_t; A\,\mathbf{x}_{t-1}, A\Sigma_{t-1}A^T + Q\right)$$

New: social force motion model

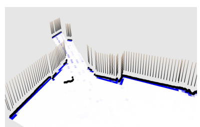
$$p(\mathbf{x}_t \mid \mathbf{x}_{t-1}, \mathcal{P}, \mathcal{O}) = \mathcal{N}(\mathbf{x}_t; \xi(\mathbf{x}_{t-1}, \mathcal{P}, \mathcal{O}), J_\xi\,\Sigma_{t-1}\,J_\xi^T + Q)$$

Superimposed force

$$\xi\left(\mathbf{x}_{t-1}, \mathcal{P}, \mathcal{O}\right) = \begin{bmatrix} \boldsymbol{x}_{t-1} + \boldsymbol{v}_{t-1}\,\Delta t + \frac{1}{2}\frac{\mathbf{F}}{\mathrm{m}}\Delta t^2 \\ \boldsymbol{v}_{t-1} + \frac{\mathbf{F}}{\mathrm{m}}\Delta t \end{bmatrix}$$

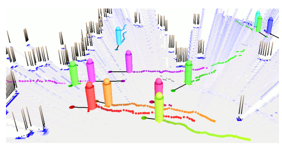
Falls back on constant velocity model for $\mathbf{F} = 0$, that is, no external stimuli or deviation from intended direction and velocity

Static objects: represented as occupancy probabilities in a grid from the last K laser scans (a short term memory)

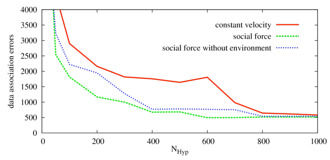


Experiments and Conclusions

- Comparison with baseline model of constant velocity and direction on two large-scale data sets
- With the new model, the system requires fewer hypotheses to reach the same tracking accuracy or, given more hypotheses, makes between 30% to 50% **fewer data association errors**
- Improvement mainly due to influences from other people, not from the environment



Twelve of 150 tracks from the outdoor experiment in the city center of Freiburg showing people as cylinders. The static objects (walls, a fountain, other obstacles) are visualized as vertical lines. The social force motion model results in a better occlusion handling ability of the tracker



Total number of data association errors as a function of the number of tracker hypotheses. The comparison with the baseline motion model of constant velocity and direction shows that the influence from the static objects is weak compared to the influence from other individuals

References

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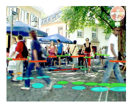

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