Pedestrian dynamics: Experiment and Simulation

22 October 2015 | Dr. Maik Boltes
Forschungszentrum Jülich, Germany
Division Civil Security and Traffic

- **Forschungszentrum Jülich (Research Centre)**
  *Research on energy and environment, information and brain*
  ~ 5500 staff member

- **Institut „Jülich Supercomputing Centre“ (JSC)**
  *Operating supercomputer of the highest performance class; simulating complex problems*
  ~ 200 staff member

- **Division „Civil Security and Traffic“**
  18 staff member (including 5 Ph.D. students, 3 graduate students)
  [http://www.fzj.de/ias/jsc/cst](http://www.fzj.de/ias/jsc/cst)
Division Civil Security and Traffic

- Interdisciplinary team focusing on models and simulations of complex systems with applications in civil security and traffic planning

Pedestrian Dynamics, Experiments and Analysis
Performing experiments for quantitative description of pedestrian dynamics

Pedestrian Dynamics and Traffic Simulation
Modelling of pedestrian dynamics, large scale evacuation, intermodal transport and mixed traffic

Fire Simulation
Modelling of fire and smoke spread in buildings or in common carriers using CFD methods
Overview

- Motivation
- Laboratory experiments
- Automatic extraction of trajectories
- Analysis results by example

- Simulation
- Validation and verification
- Open access
Motivation

- Exemplary disasters due to crowd crushes:

<table>
<thead>
<tr>
<th>Year</th>
<th>Place</th>
<th>Occasion</th>
<th>Deaths</th>
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<tbody>
<tr>
<td>1896</td>
<td>Moscow, Chodynka Feld (Russia)</td>
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[wikipedia.org/wiki/List_of_accidents_and_disasters_by_death_toll]

- Main reason: high pedestrian densities due to insufficient pedestrian facilities or inadequate crowd management
Motivation

- Exemplary *disasters* due to crowd crushes:

- **Main reason:** high pedestrian densities due to insufficient pedestrian facilities or inadequate crowd management
Motivation

- **Aims: Increase of**
  - **Safety**, e.g.
    Design of escape routes
    (stadiums, theaters, schools, ...)
  - **Comfort**, e.g.
    Design of transport infrastructures
    (stations, airports, trains, ...)

- **Tools and methods:**
  - Legal regulations (prescriptive method)
  - Guidelines and handbooks (macroscopic models)
  - Computer simulations (microscopic models)
Motivation

Knowledge of pedestrian dynamics is insufficient

→ Large uncertainties of quantitative results from simulation software

Evacuation time for a corridor:

[C. Rösch]
Motivation

Knowledge of pedestrian dynamics is insufficient

→ Non-negligible differences in guidelines
Motivation

Contradiction of data

May result from:

- Direction of flow (e.g. uni- and bidirectional)
- Measurement method
- Culture
- Population demographics
- Psychological factors (e.g. motivation)
- ...
Motivation

Reliable empirical data of pedestrian movement are necessary

→ analyze pedestrian dynamics for
  → model design
  → model calibration
  → model validation

Microscopic models need microscopic data
Laboratory experiments
<table>
<thead>
<tr>
<th>Year</th>
<th>Place</th>
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<th># Runs</th>
<th>Extraction</th>
<th>Marker</th>
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</table>
Laboratory experiments

In artificial environments
Laboratory experiments

In real environments
Laboratory experiments

Advantages:

- **Selective analysis** of parameters *without undesired influences*
- **Variability** of the experimental procedure
- Generation of **high densities** seldom seen in field studies
- Possibility to extract **microscopic trajectories** at high quality in space and time
Goal of extraction

- Individual trajectories
- Low spatial error
- Nearly no detection error

→ Calculability of all quantities describing the pedestrian dynamics at any time and any place
Automatic extraction of individual trajectories
Optical flow / Movement of crowds

[B. Krausz]  [S. Ali]
Motion capturing / Movement of body parts

[S. Schmidt]  [M. Becker]
Detection of people

Template matching

Histogram of oriented gradients

Deformable part-based model

[D. M. Gavrila] [E. P. Fotiadis] [Q. Delamarre]
Miss rate

<table>
<thead>
<tr>
<th>Features</th>
<th>Learning</th>
<th>Detection Details</th>
<th>Implementation</th>
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<td>MULTI FTR + MOTION</td>
<td>linear SVM</td>
<td>✓</td>
<td>MS</td>
</tr>
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</table>
Miss rate – Influence of detection errors

[P. Dollar]
Markers enables robust extraction

[S. P. Hoogendoorn]  [W. Daamen]  [S. Saadat]

[X. Liu]  [W. Song]  [S. Wong]
Markers enables robust extraction
Extraction of Trajectories

1. Calibration
2. Detection
3. Tracking
4. Height Detection
Calibration

- **Model of pinhole camera with distortion** maps homogenous real world coordinate \( x \in \mathbb{R}^4 \) to pixel coordinate \( u \in \mathbb{R}^3 \):
  - **Intrinsic param.**: focal length \((f_x, f_y)\), distortion center \((c_x, c_y)\)
  - **Extrinsic param.**: position \( t \in \mathbb{R}^3 \), orientation of the camera \( R \in \mathbb{R}^{3\times3} \)
  - **Distortion coefficients**: tangential \( p_1, p_2 \), radial \( k_1, k_2 \)

\[
\begin{align*}
  u &= g_{A,k_1,k_2,p_1,p_2,R,t}(x) = Ad((R \cdot t)x), \quad A = \begin{pmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{pmatrix} \in \mathbb{R}^{3\times3} \\
  d(\begin{pmatrix} u \\ v \\ 1 \end{pmatrix}) &= \begin{pmatrix} u(1 + k_1 r^2 + k_2 r^4) + 2 p_1 u v + p_2 (r^2 + 2u^2) \\ v(1 + k_1 r^2 + k_2 r^4) + p_1 (r^2 + 2u^2) + 2 p_2 u v \\ 1 \end{pmatrix}
\end{align*}
\]

[D. C. Brown, Close-range camera calibration]
Calibration (intrinsic)

- **Automatic calculation** of the parameters minimizes the distortion error for \( j \) characteristic points \( g_{ij} \) and their corresponding modeled positions \( g_\*(x_j) \) of a known pattern in \( i \) pictures with different points of view:

\[
\sum_{i=1}^{n} \sum_{j=1}^{m} \| g_{ij} - g(A,k_1,k_2,p_1,p_2,R,t(x_j)) \|
\]

[ Z. Zhang, A flexible new technique for camera calibration ]
Calibration (extrinsic)

2D/3D point correspondences / calibration points
- At least 4 point correspondences needed
- 3D points not all in one plane
- Iterative algorithm calculates the translation and the rotation of the camera
Calibration (multiple views)

Field of view influenced by
- Focal length of lens
- Pitch of camera
- Height of ceiling
Calibration (overlapping camera grid)

- Larger observation space
- Smaller field of view $\rightarrow$ less occlusion
- Complex calibration
Detection

- Oriented isolines of same brightness
- Approximation with ellipsis
- Identification by size, position, shape
Detection

- Colored hats
- HSV color space
- Closing, opening
## Detection

**Application depending marker:**

<table>
<thead>
<tr>
<th>Marker</th>
<th>Robustness Detection</th>
<th>Accuracy Position</th>
<th>High Density</th>
<th>Additinal Information</th>
<th>Needed Resolution</th>
<th>Expense Production</th>
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<tbody>
<tr>
<td>![Image]</td>
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<tr>
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<td>+</td>
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<tr>
<td>![Image]</td>
<td>+</td>
<td>++</td>
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<tr>
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<td>![Image]</td>
<td>0</td>
<td>++</td>
<td>+</td>
<td>++</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Tracking

Translation of $\vec{d}$ of pixel region in successive frame

$$p_i'(t_{j+1}) = p_i'(t_j) + \vec{d}$$

$$e_i(t_j) = \arg\min_{\vec{d}} \sum_{\omega} \sum_{\omega_x=-\omega}^{\omega} \sum_{\omega_y=-\omega}^{\omega} \left( B_j(p_i'(t_j) + (\omega_x, \omega_y)^T) - B_{j+1}(p_i'(t_j) + \vec{d} + (\omega_x, \omega_y)^T) \right)^2$$
Determine position

Head camera distance
Determine position

Position error $e_h$ caused by height difference $d_h$

$$e_h = |d_h \tan \alpha|$$
Determine position

Disparity $u_1 - u_2$ between point of views of stereo camera for measuring head distance

$$z'_0 = \frac{bf'}{u_1 - u_2}$$
Disparity $u_1 - u_2$ between point of views of **stereo camera** for measuring head distance

$$z_0' = \frac{bf'}{u_1 - u_2}$$
Analysis results by example
Smoothing

- With step detection, frequency analysis, height waves, convex hulls, ...
- For elimination of local position error or swaying
Smoothing

- With step detection, frequency analysis, height waves, convex hulls, ...
- For elimination of local position error or swaying
Voronoi density

\[ \rho_{\text{Voronoi}} = \frac{\int_A p(r) \, dx}{|A|} \]

mit \( p(r) = \begin{cases} \frac{1}{A_i} : x \in A_i \\ 0 : \text{else} \end{cases} \)
Profile of quantities

- **Velocity**
  \[ < v >_v = \frac{\iint v_{xy} \, dx \, dy}{\Delta x \cdot \Delta y} \]

- **Density**
  \[ < \rho >_v = \frac{\iint \rho_{xy} \, dx \, dy}{\Delta x \cdot \Delta y} \]

- **Specific flow**
  \[ J_s = \langle \rho \rangle_v \cdot \langle v \rangle_v \]
Influence of culture to the velocity

[Graph showing data points for India, German I, and German II.]

[U. Chattaraj]

[JÜLICH FORSCHUNGSZENTRUM]
Influence of motivation to the velocity

[J. Lukowski]
Flow as a function of bottleneck width
Density profile

- Bidirectional
- Unidirectional
- Unidirectional with bottleneck

[J. Zhang]
Density in front of bottleneck
Specific flow profiles
Flow as a function of bottleneck length

![Image showing flow as a function of bottleneck length with graphs and images of different bottleneck lengths.](image URL)
Flow as a function of density / flow direction
T-junction
T-junction

Experiment and Simulation
Simulation
Pedestrian dynamics simulation

Open source framework for pedestrian dynamics simulations “Jülich Pedestrian Simulator”
www.jupedsim.org
Simulation level

**Strategic level**

- Determination of the final destination and strategy to reach the goal
  - Parking, train station
  - Quickest path, known path

**Tactical level**

- Determination of intermediate destinations
  - Walk, do not push, take left exit, lift,…

**Operational level**

- Locomotion system
  - Go, stop, slow down, swerve…
Tactical level

1. Goal and Strategy
2. Move to next destination
3. New Location / Jam
4. Evaluate the situation based on the strategy
5. Change trip if necessary
Tactical level: Quickest path based on visibility

[Kernloh et al. “Modelling dynamic route choice of pedestrians to assess the criticality of building evacuation”, 2012, ACS.]
Tactical level: Information propagation

Both exits are open

Agents with the same color share the same information
Tactical level: Reaction in case of fire
Operational level: Force based models in continuous space

- Equation of motion

\[
m_i \dddot{\vec{R}_i} = \vec{F}_i = F_{i}^{\text{drv}} + \sum_{j \in \mathcal{N}_i} F_{ij}^{\text{rep}} + \sum_{w \in \mathcal{W}_i} F_{iw}^{\text{rep}}
\]

\[
\mathcal{N}_i := \{j : \| \vec{R}_j - \vec{R}_i \| \leq r_c \wedge i \text{ "feels" } j\}
\]

\[
\mathcal{W}_i := \{w : \| \vec{R}_w - \vec{R}_i \| \leq r_c\}
\]

- Parallel update

\[
\begin{pmatrix}
\vec{R}_i(t + \Delta t) \\
\vec{v}_i(t + \Delta t)
\end{pmatrix} = \begin{pmatrix}
\vec{R}_i(t) \\
\vec{v}_i(t)
\end{pmatrix} + \int_t^{t+\Delta t} \begin{pmatrix}
\vec{F}_i(t)/m_i \\
\vec{v}_i(t)
\end{pmatrix} dt + \begin{pmatrix}
\vec{R}_i(t) \\
\vec{v}_i(t)
\end{pmatrix}
\]
Operational level: Generalized Centrifugal Force Model

- Velocity dependent space requirement

\[ d(v) = a + b \cdot v \]

[Chraibi et al, "Generalized centrifugal force model for pedestrian dynamics", Physical Review E 82, 046111 (2010)]
Operational level: Gradient model field

Simulation

Pedestrians: 3154  Time: 0 Sec
Hybrid simulation – coupling with macroscopic simulation
Verification and validation of models
Verification and validation of models

- **Verification**
  - Make sure the implementation is correct
  - Test if the implementation of the underlying model is correct
  - (Unit testing)

- **Validation**
  - Test the realism of the model
  - Comparison with empirical data
  - Fundamental diagram, flow, field observations, ...
Nest test with PEDFLOW (PED14)

corner

pre-movement time

const. velocity

bi-direct

[Michelle Isenhour, US Military Academy]
RiMEA (14 tests)
Jülich benchmarks
Open Access
CV Software

- **Name:** PeTrack (PEdestrian TRACKing)
- **URL (download, help):** http://ped.fz-juelich.de/petrack
- **Language:** English
- **License:** free
- **Operating Systems:** Windows, Linux, ...
- **Programming Language:** C++
- **Used Software Libraries:**
  - *User Interface:* Qt, Qwt
  - *Image Processing:* OpenCV, Triclops (PointGrey)
Database

- After finishing thesis about experiments all data (videos, trajectories, documentation) published publicly available
- [http://ped.fz-juelich.de/database](http://ped.fz-juelich.de/database)
Pedestrian dynamics simulation

Open source framework for pedestrian dynamics simulations “Jülich Pedestrian Simulator”
www.jupedsim.org
New Journal

Collective Dynamics
– open access and free of charge for authors –

The journal Collective Dynamics (CD) focuses on research in the field of pedestrian dynamics, vehicular traffic and other systems of self-driven particles, such as molecular motors, animal groups or agents. The journal is a forum for all scientists working on fundamental (empirical as well as theoretical) research or concrete applications. Articles should be written in a way that makes them accessible to a wide range of scientific disciplines. As a peer-reviewed journal, Collective Dynamics publishes scientific papers that should reflect original, previously unpublished work, but may also report on systematic reviews of published research and other pedagogical articles (e.g. lecture notes).

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Andreas Schadschneider & Armin Seyfried
Thank you!
Collaboration

[Company SL-RASCH, Saudi Arabia]

[University Tokio, Japan]

[Monash University, Melbourne, Australia]