Towards Simulation Tools for Innovative Street Designs

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Research ranking in the UK:

- REF 2014: First in the “power” and “quality” indicators.
- Second best University in Civil Engineering.
- One of the longest established and leading centres for engineering-related transport teaching and research.
Transportation Research Group (TRG) in Brief

- Around 9 lecturers, 25 core staff, 20 PGR students and 35 PGT students.
- Current research awards: ~£8m:
  - ~£4m from EPSRC
  - ~£1m from EC
  - ~£3M from other Governmental Bodies (incl. Innovate UK)
- International links include Cornell, Delft, Gothenburg, MIT, Monash, Ningbo, Sydney and Tsinghua.
- Areas of research activity and expertise:
Intelligent Mobility

Intelligent Traffic Control Systems

Green Adaptive Control for Future Interconnected Vehicles

Integrating Connected & Autonomous Vehicles

Road Safety

Sustainable Mobility
“The majority of people will be living in cities by 2050.”

Shared Space, 1991

An entrance threshold

Single surface environments

Irregular parking

Green space and trees
Video available here: https://www.youtube.com/watch?v=qgYzyGvMqjo

Eröffnung "Shared Space" Sonnenfelsplatz 11.10.11
Shared Space Schemes:

- Austria
- Belgium
- Denmark
- Germany
- Netherlands
- Sweden
- United Kingdom
How can we evaluate new shared spaces before implementation?
Journey Planning Layer
Flood Fill Methods (1/2)

- **Euclidean Distance**
  \[ \Delta x = \sum_i |\delta x_i| \text{ and } \Delta y = \sum_i |\delta y_i| \]
  \[ D^E = \sqrt{\Delta x^2 + \Delta y^2} \]

- **Manhattan Metric**
  \[ D^M = \sum d^M_i = \Delta x + \Delta y \]

- **Chessboard Metric**
  \[ d^C_i = \max(|\delta x_i|,|\delta y_i|) \]
  \[ D^C = \sum d^C_i \]

Flood Fill Methods (2/2)

- **Combination**
  \[ d_i^m = d_i^M - d_i^C = \min(\delta x_i, \delta y_i) \]
  \[ D^m = \sum d_i^m = D^M - D^C \]
  \[ (D^v_2) = (\sqrt{2} - 1)(D^m) + (D^C) \]

- **Relative Error**
  \[ \epsilon_{Relative} = \left| \frac{D - D^E}{D^E} \right| \]

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Journey Planning Layer

Obstacle Avoidance and Way-finding Simulation:

(a) Without Distance Map
(b) With Distance Map

Operational Force-based Layer

- Red arrows: Social Interaction with the Boundaries
- Blue arrows: Social & Physical Interactions
- Green arrows: Social Interaction
\[
\frac{d\mathbf{v}_\alpha(t)}{dt} = f_\alpha^0 + \sum_\beta f_{\alpha\beta} + \sum_b f_{\alpha b} + \sum_\beta f_{\alpha\beta}^{\text{att}} + \sum_i f_{\alpha i} + \xi
\]
Geometrical Car Modelling

Car Modelling using a Geometrical Approximation of an Ellipse

\[ r_\gamma(\varphi_\gamma u) = \frac{w}{\sqrt{1-\epsilon^2 \cos^2(\varphi_\gamma u)}}, \text{ where } \epsilon = \frac{\sqrt{p^2-w^2}}{l} \]
Social Force Model for Cars

\[ \frac{dv_\gamma(t)}{dt} = f^0_\gamma + \sum_{\delta(\delta \neq \gamma)} f_{\gamma\delta} + \sum_{\alpha} f_{\gamma\alpha} + \sum_{b} f_{\gamma b} + \xi \]
Social Force Model for Cars

Driving Force:

\[ f_0^\gamma = \frac{v_0^\gamma \cdot e_\gamma(t) - v_\gamma(t)}{\tau_\gamma}, \text{ where } e_\gamma(t) = \frac{r_k^\gamma - r_\gamma}{|r_k^\gamma - r_\gamma|} \]

Interaction Forces Considering the Geometric Model of Cars:

\[ f_\gamma U(t) = f_{\gamma U}^{soc}(t) + f_{\gamma \delta}^{\text{following}}(t) \]

Socio-psychological Force:

\[ f_{\gamma U}^{soc} = A_{\gamma U} e^{\frac{r_{\gamma U} - d_{\gamma U}}{B_{\gamma U}}} n_{\gamma U} F_{\gamma U} \]

\[ F_{\gamma U} = \left( \lambda_\gamma + (1 - \lambda_\gamma) \frac{1 + \cos(\varphi_{\gamma U})}{2} \right) \cdot q \]
Form Factor and Effective Factor

Rearview Vision considered by the Form Factor for Vehicles
Forward Vision considered by the Form Factor for Vehicles

Side Mirror Vision
Moving Direction

BLIND SPOT
Forward Vision
BLIND SPOT

Rearview Mirror Vision
Form Factor for Anisotropic Behaviour

\[ q = 1, \text{ if } -\vartheta^0 \leq \varphi \gamma \alpha \leq \vartheta^0 \text{ and } (180^0 - \vartheta^0) \leq \varphi \gamma \alpha \leq (180^0 + \vartheta^0) \]
\[ q = 0, \text{ otherwise} \]
Social Force Model for Cars

Trajectory simulation of an obstructed car and the following car according to:
(a) the social force
(b) the deceleration force

Deceleration Force:

\[ f_{\gamma \delta}^{\text{following}} = -\frac{\nu_0}{\tau_\gamma} e \frac{d(v_\gamma) - d_\gamma}{B^{I} \gamma \delta} - \frac{\Delta v_\gamma e}{\tau_\gamma} \Theta(\Delta v_\gamma), \]

where
\[
\Theta(\Delta v_\gamma) = \begin{cases} 
1, & \text{if } (\Delta v_\gamma) > 0 \\
0, & \text{otherwise}
\end{cases}
\]
Social Force Model for Pedestrians in Shared Spaces

\[ \frac{dv_\alpha(t)}{dt} = f_\alpha^0 + \sum_{\beta(\beta \neq \alpha)} f_{\alpha\beta} + \sum_b f_{\alpha b} + \sum_\gamma f_{\alpha\gamma} + \xi \]
Rule-based constraints layer
Rule-based constraints layer

Relation between Steering Angle and Moving Speed

\[ \psi_\gamma = \arctan \frac{2l \cdot a_{\gamma \text{Centrifugal}}}{|v_\gamma|^2} \]

for \(0 < |v_\gamma| \leq 5.3 \text{ m/s}\),
\[ \psi_\gamma \leq 30^\circ \]

for \(5.3 \text{ m/s} < |v_\gamma| \leq 8.9 \text{ m/s}\),
\[ \psi_\gamma \leq \arctan \frac{2l \cdot a_{\gamma \text{Centrifugal}}}{|v_\gamma|^2} \]
Driving trajectory simulation of a turning car:
(a) without steering angle constraints
(b) with steering angle constraints

Speed change of a turning car as a result of steering angle constraints
Rule-based constraints layer

Optimal Manoeuvre for Conflict Avoidance:

Adding a minimum velocity change $\Delta \vec{v}^{\text{min}} = \vec{v}^{\text{opt}}(t) - \vec{v}(t)$ will avoid conflicts.

$$c \left( v_x^{\text{opt}}(t), v_y^{\text{opt}}(t) \right) = (v_x^{\text{opt}}(t) - v_x, q_1(t))^2 + (v_y^{\text{opt}}(t) - v_y, q_1(t))^2$$

The optimisation problem incorporating all these constraints can be formulated as follows:

**Minimize** \( c \left( v_x^{\text{opt}}(t), v_y^{\text{opt}}(t) \right) \)

**Subject to** \( v_U^{\text{min}} < v_U^{\text{opt}} < v_U^{\text{max}} \)

\( d_{\gamma \alpha}^{\text{CPA}} > r_\alpha + r_\gamma (\varphi_{\gamma \alpha}) \)

Distance to reach the CPA > Minimum acceptable distance

A conflict avoidance force \( \vec{f}_U^{\text{conflict}} = \frac{\Delta \vec{v}^{\text{min}}}{\tau_U} \) is calculated and added to the sum of forces.
Rule-based constraints layer

(a) Simulation of the interaction between a car and pedestrian without conflict avoidance force

(b) Simulation of the interaction between a car and pedestrian with conflict avoidance force
Determination of the Interaction Strength $A$:

$$\frac{dv}{dt} = \frac{\vec{v}_\alpha - v_\alpha^0 \cdot \vec{e}_\alpha^0(t)}{\tau_\alpha} - \frac{A_\alpha}{m} e^{d_{\alpha B}/B_\alpha}$$

Maximum deceleration of human beings:

$$0.2g (g = 9.8 \frac{m}{s^2}) \Rightarrow B_\alpha = 0.5$$
Calibration and Validation

1. Input: Initial Parameters for A and B.
2. Output: Trajectories, Velocities, Accelerations and Decelerations
3. Output: Calibrated parameters for A and B.

- Using the hybrid model, an error measure related to deviation from our simulated position to the actual position from the observation will be calculated.
- With this error measure we can iterate a calibration process that will find an optimal set of simulation parameters.
Calibration and Validation

\[ E = \frac{\left\| r_U^{\text{simulated}}(t + T) - r_U^{\text{tracked}}(t + T) \right\|}{\left\| r_U^{\text{tracked}}(t + T) - r_U^{\text{tracked}}(t) \right\|} \]
Observation Results

Trajectories of pedestrians (in white) and cars (in red) in New Road, Brighton
Observation Results

- The mean speed of pedestrians is $1.08 \frac{m}{s}$ ($\sigma = 0.70 \frac{m}{s}$) that is close to the Weidmann estimation of $1.38 \frac{m}{s}$ for the 'optimal energy level'.

- The mean speed of cars on New Road is about $2.14 \frac{m}{s}$ ($\sigma = 1.79 \frac{m}{s}$) and drivers do not speed up more than $10. \frac{m}{s}$
Observation Results

- Pedestrians accelerate and decelerate at the rate of $-0.005 \frac{m}{s^2}$ ($\sigma = 0.59 \frac{m}{s}$) which is matching Weidmann estimation for the immediate change of acceleration (less than 20% of the g-force).

- Acceleration and deceleration rate is about $-0.04 \frac{m}{s^2}$ ($\sigma = 1.22 \frac{m}{s}$) for cars.
Calibration Results for Shared Space in New Road, Brighton

(a) 
(b) 
(c) 
(d)
Calibration Results for Shared Space in New Road, Brighton

- Mean = 0.4539
- σ = 0.4539

- Mean = 0.3058
- σ = 0.2850
Calibration Results for Shared Space in New Road, Brighton

- Real Car Speed [m/s]
  - Mean: 3.89
  - σ: 3.33

- Simulation Car Speed [m/s]
  - Mean: 2.7808
  - σ: 2.4367
Inputs

- Street plan: an outline of desirable design elements with their dimensions in the street space.
- Start and destination point of all users (e.g. pedestrians, drivers).
- Desired speed and acceleration for all agents.
- Max speed and acceleration for all agents.
Evacuation time and desired speed relationships in the design stage so as to achieve solutions for optimal design features before implementation.

Faster-Is-Slower simulation: (a) clogging at the exit and (b) evacuation time of 200 people versus desired velocity.
Potential spots for conflicts in order to avoid peaks of density and pressure at critical locations.
Visualising the trajectories of pedestrians and cars

Trajectories of 150 pedestrians and 26 cars (a) perspective view and (b) top view
• Traffic demand of all road users
Road users’ speed and acceleration histograms

Speed and acceleration histograms of (a) Pedestrians and (b) Cars on New Road (Brighton, UK)
Development of a new microscopic model for the simulation of shared space schemes to:

- achieve solutions for optimal design features;
- gain knowledge about efficiency or safety challenges;
- make emission and exposure assessments for new street designs.

What is next?

Safety investigation of the shared space model.

Modelling cyclists behaviours in shared spaces.

Modelling human-autonomous cars interactions.

Video mapping and spatial augmented reality.
Many thanks for your attention.

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