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Modelling shared space users via rule-based social force model

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ABSTRACT

The promotion of space sharing in order to raise the quality of community living and safety of street surroundings is increasingly accepted feature of modern urban design. In this context, the development of a shared space simulation tool is essential in helping determine whether particular shared space schemes are suitable alternatives to traditional street layouts. A simulation tool that enables urban designers to visualise pedestrians and cars trajectories, extract flow and density relation in a new shared space design, achieve solutions for optimal design features before implementation, and help getting the design closer to the system optimal. This paper presents a three-layered microscopic mathematical model which is capable of representing the behaviour of pedestrians and vehicles in shared space layouts and it is implemented in a traffic simulation tool. The top layer calculates route maps based on static obstacles in the environment. It plans the shortest path towards agents' respective destinations by generating one or more intermediate targets. In the second layer, the Social Force Model (SFM) is modified and extended for mixed traffic to produce feasible trajectories. Since car movements are not as flexible as pedestrian movements, velocity angle constraints are included for cars. The conflicts described in the third layer are resolved by rule-based constraints for shared space users. An optimisation algorithm is applied to determine the interaction parameters of the force-based model for shared space users using empirical data. This new three-layer microscopic model can be used to simulate shared space environments and assess, for example, new street designs.

1. Shared space background

Since the appearance of motorised transport, there have been discussions about the extent to which standardised and vehicle-dominated streetscapes have had a negative effect on the environment of public neighbourhoods. Hamilton-Baillie (2008) explains that individuals will tend to spend less time in public areas, if they perceive streets to be less attractive for their social interaction activities or transport movements. As a result, the quality of these spaces will decline and human activities will be transferred from public to private spaces. Hence, urban design is promoting shared space as an alternative to traditional designs (Hamilton-Baillie, 2008; Gaffikin et al., 2010; Dumbaugh and Li, 2011; Department for Communities and Local Government-UK, 2012; Schonauer et al., 2012a,b).

Space sharing (see Table 1) has been initiated by the woonerf (living playground) concept in the Netherlands in the late 1960s. A woonerf is a residential street, designed to provide safe and pleasurable areas for pedestrians (specifically children), and where pedestrians are given priority over motor vehicles. In particular, a woonerf street is designed without a clear

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Notations

Variables	Explanation
A	interaction strength
$\boldsymbol{a}$	acceleration
$a^{\mathrm{Centrifugal}}$	centrifugal acceleration
B	interaction range
B'	acceleration interaction range
B''	braking interaction range
c	cost function
d	distance between the centre of two shared space users
d_c	safe distance
d_γ	minimal distance of a car
$d(v_{\gamma\delta})$	speed-dependent safe distance between two cars
d^{CPA}	minimum distance between the agents at their closest Point of Approach (CPA)
$\boldsymbol{d}$	desired destination vector
D^{C}	chessboard distance between two points
$D^{\mathrm{Euclidean}}$	Euclidean distance between two points
D^{M}	Manhattan distance between two points
D^{V2}	variant 2 distance between two points
δ_{xi}	horizontal distance between two point
δ_{yi}	vertical distance between two points
Δx	horizontal distance between two agents
Δy	vertical distance between two agents
$\Delta v_{\gamma\delta}$	velocity difference of two cars
v^{min}	minimum velocity change
ξ	fluctuation force
e^0	desired direction
F	form factor
$\boldsymbol{f}^{repulsive}_{\gamma(\gamma-1)}$	repulsive force between car $\gamma$and the car ahead $(\gamma - 1)$
$\boldsymbol{f}_{\alpha\beta}$	interaction/repulsive force between pedestrian α and pedestrian β
$\boldsymbol{f}_{\alpha b}$	interaction/repulsive force between pedestrian α and boundary b
$\boldsymbol{f}_{\alpha\delta}$	interaction/repulsive force between pedestrian α and car δ
$\boldsymbol{f}_{\delta\gamma}$	interaction/repulsive force between two cars
$\boldsymbol{f}^{conflict}$	conflict avoidance force
$\boldsymbol{f}^{following}$	car-following force
$\boldsymbol{f}^{ph,friction}$	friction physical force
$\boldsymbol{f}^{norm}$	pushing physical force
$\boldsymbol{f}^{ph}$	physical force
$\boldsymbol{f}^{soc}$	social force
$\boldsymbol{f}^{tan}$	tangential force
$\boldsymbol{f}^0$	driving force
$2l$	length of a car
L	distance between the front and the rear axle
λ	form factor constant
n	normalised vector
φ	angle between the desired direction and centre of another agent
ψ	steering angle
q	effective factor
r	radius
r_α	radius of a pedestrian
$r_{\alpha U}$	sum of the radii of a pedestrian α and another agent U
s	clearance
t	time
τ	relaxation time or reaction time
τ'_γ	braking time of car γ
Θ	function depending on its argument
T_γ	safe time headway
U	shared space user (pedestrian or car)
v^0	desired speed
v^{opt}	optimal speed