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Modeling of shared space with multi-modal traffic using a multi-layer social force approach

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Abstract

In the field of traffic road design, the shared space approach aims to develop roads from mere traffic infrastructures to public spaces, compelling higher interaction between road users. In this paper we develop the fundamentals for a micro-simulation tool based on the Social Force Model, to represent the motion of road users in such layouts. Working with the observed behavior of users in a pedestrian-friendly intersection in the city of Braunschweig (D), a multi-layer structured model is developed, in which each layer is designated to handle different situations, from free-flow movements to user interactions in crowded situations. Visibility graphs and clothoid estimations are used for designing trajectories of road users for the free flow movement. Furthermore, an enhancement of the classical Social Force Model is provided in order to model long-range collision avoidance behavior. Finally, the enhanced simulation framework is validated by two observed scenarios, which include various conflicts between pedestrians and cars.

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Keywords: shared space; microscopic simulation; social force model; mixed traffic; trajectories of road users.

1. Introduction

The desire to give streets a social function and to reduce the dominance of vehicles has motivated planners and traffic engineers to consider new design approaches where motorized and non-motorized users share traffic spaces.

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Such a strategy of traffic integration – against the concept of separation – allows increasing the quality of public spaces, promoting social and recreational activities. The permitted passage of motorized vehicles contributes to this purpose by loading and unloading activities of consumer goods and people, and avoids overloading the traffic demand on adjacent networks. Therefore, shared space solutions must be designed carefully for the increased level of interaction between users and consequently the elevated number of conflict situations.

A street layout which implements the cohabitation of different traffic modes is said to have a *shared space design* and consists of a variety of physical features with the aim to reduce demarcation between road users.

Currently the choice of a particular shared space design does not take into account performance indicators like *Level of Service* or safeness. Appropriate micro simulation tools, which can reproduce the operation of shared spaces, are currently lacking. However, such tools would ideally provide precise performance outputs, namely “their efficiency (average road user delays and road capacity), safety (initial time-to-collision) and environmental impacts (emissions based on instantaneous speed and acceleration of vehicles)” (Anvari et al., 2015).

The challenge of our research project MODIS (Multi-modal Intersection Simulation) is to build a micro simulation framework, capable of simulating the movements of road users in shared spaces and calculating performance indicators, in order to evaluate the suitability of a particular solution. In this work the fundamentals of our approach are described starting from the observation of human behavior in a shared space environment. Calibration and validation of the proposed model will be part of future research. After the identification of relevant factors to describe the movement of users (Section 2), a multi-layer micro simulation framework is introduced, paying special attention to the development of Free-Flow Trajectories (FFTs) and the mechanisms of Long-Range Collision Avoidance (LRCA) (Sections 3, 4, 5). The results of the simulation framework are then visually compared to two representative observed situations involving pedestrians and cars (Section 6). Situations involving bicycles have not been analyzed in this work. Concluding remarks and future research directions are then presented (Section 7).

2. Observed behavior of users

For the purpose of modeling the behavior of road users, the motion of users in a crossroads intersection in the university district in Braunschweig (D) is analyzed. Although this intersection has a *Fahrradstrasse* (bicycle priority street) and a classical sidewalk, many shared space operational features are observed, namely the high level of interaction between different traffic modes, the negotiation of priority (including bicycles although they have right of way by law), and the presence of pedestrians standing still and interacting in groups.

Table 1 shows the time period and duration of the on-site survey and the observed volumes of road users, with an indication of the traffic detected in a 15 min. peak period during a lessons break.

Table 1. Time period of the on-site survey and observed volumes of road users. (* relative to the 15-min peak)

Location	Period	Road Users	Observed [n°]	Observed [%]
Intersection Pockelstrasse-Katharinenstrasse-Konstantin Uhde Strasse Braunschweig, Germany	04.06.2014, Wednesday, 12:30 - 13:45 (15 min peak: 13:00 - 13:15)	Pedestrians	1936 (715*)	69.4 (69.5*)
		Cyclists	634 (239*)	22.7 (23.2*)
		Cars, Trucks	220 (75*)	7.9 (7.3*)

The aim is to identify which factors are essential for determining the spatiotemporal evolution of the trajectories of road users. Firstly, the movement of road users differs according to their traffic mode. Vehicles have a high space requirement and limited degree of freedom, and in shared spaces usually behave respectfully towards weak users by decreasing speed and avoiding sudden steering movements as much as possible. On the contrary, pedestrians are able to make sudden changes of direction and speed without difficulty, due to their low walking pace. Finally, cyclists represent a unique hazard for both cars and pedestrians because of their unpredictable behavior resulting from a high degree of freedom combined with a slim outline. Apart from the diversity of traffic users, the streetscape and the level of interaction strongly influence the motion of users.

2.1. The streetscape

The layout of the streetscape suggests to road users how the space should be used. Beyond classical road signage other factors, such as geometrical measurement, road markings, materials and pavement, affect the speed of drivers (Marceau et al. 2007) and influence the motion of users. Moreover, the minimization of demarcation elements and traffic devices increases the perceived level of risk, leading users to a more respectful and precautionary behavior (Hamilton-Baillie 2008).



Fig. 1. (a) Aerial shot; (b) Functional subdivision: traffic zone (red), safe zone (green), shared zone (yellow).
Google Maps. Google, Geobasis-DE/BKG. 2009. Web. 01.03.2015

In order to consider the influence of the space on the behavior of road users, Schönauer et al. (2012a) propose a subdivision in sections (*straight sections* and *intersection areas*). In this work, a functional subdivision based on the principle of dominant road users is used (see Fig. 1b), including a *traffic zone* (vehicle dominant), a *safe zone* (pedestrian and cyclist exclusive) and a *shared zone* (all categories).

The clear identification of such zones is necessary for defining which users are permitted to use the space (e.g. cars are excluded from the safe zone). Moreover, the type of zone has an influence on the spatiotemporal evolution of the trajectory of users; we observe pedestrians using safe zones as a refuge when vulnerable to the movement of other users, and cars decelerating or accelerating when approaching or leaving the *shared zone*.

2.2. Level of interaction

The density of users in the space, hence the level of interaction between users, directly affects the motion towards their destination. Single users are only influenced by their personal perception of the space. Identifying these perceptions is necessary for calculating the free-flow trajectories (FFTs) assigned to each user in our model. FFTs are considered to be all trajectories where a user reaches the destination without any visible influence from other users. In order to investigate the relationship between FFTs and trajectories influenced by other users, we have studied five FFTs (in green) and non-FFTs (in red) for pedestrians (Fig. 2a) and cars (Fig. 2b) fixed origins and destinations[†]. The analysis highlighted some features of free flow (FF) behavior:

- Pedestrians try to reach their destination according to the principle of the shortest path while avoiding discontinuity points. This means that they opt for a smooth path, which allows to curve without modifying the walking pace. In such situations, the FFTs with the same origin and destination appear to congregate within a narrow range.
- Interaction with other users forces pedestrians to deviate from their trajectory, while usually avoiding stopping unless inevitable for safety reasons. A typical observed reaction is for pedestrians to stay in or move towards their closest *safe zone* when they judge the situation unpredictable.
- In Fig. 2 (b) green and red lines converge within the same range. This is because cars typically respond to conflict situations by decelerating or accelerating with little to no change of their trajectory.

[†] The Free-Flow (FF) behaviour was detected in the video by identifying road users who are crossing the area in solitude (no other road users), or wherever the presence of other agents could not reasonably influence the behaviour of the user under analysis.

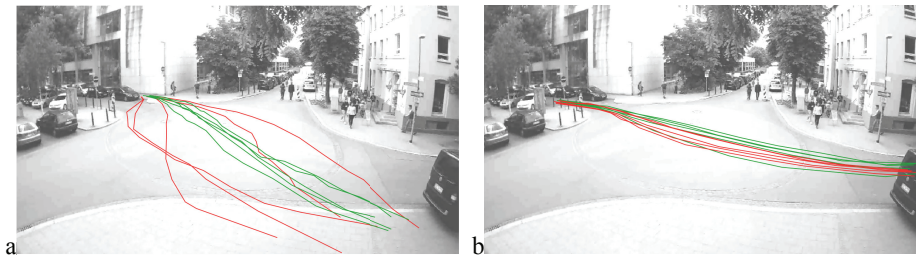


Fig. 2. (a) Trajectories of pedestrians; (b) trajectories of cars. Free flow (green), non-free-flow (red).

In non-free-flow conditions (i.e. situations with multiple users in conflict) the main objective of users is to arrive at their destination while avoiding collisions. For this purpose users forecast future collisions and a precautionary reaction is taken (LRCA mechanism). A common pattern in pedestrian behavior is to choose a new spatiotemporal trajectory (StT) by slightly modifying their FFT - in observed situations usually by swerving to the right - when two pedestrians are predicted to collide. The LRCA mechanism also applies in car-pedestrian conflicts, where one of the users decelerates in order to let the other user move across their path undisturbed (see Fig. 3).



Fig. 3. Car-pedestrian LRCA mechanism. (a) Eye contact; (b) Pedestrians decelerate; (c) Pedestrians move forward.

Sometimes a prior evaluation is not possible due to, for example, a high level of density. In this case, the amount of road users, and therefore possible collisions, prevents us from adopting a solely LRCA strategy. It could even happen that obstacles obstruct the visibility of users, reducing their danger perception, or that users are distracted, for example by mobile phones. In these cases, users are forced to perform significant modifications of their planned path, speed or both in order to avoid a collision. In Fig. 4 the presence of a building hinders the visibility of users. Due to the imminent conflict users are forced to react instantaneously by a Short-Range Collision Avoidance (SRCA) mechanism.



Fig. 4. Pedestrian's SRCA mechanism. (a) Users cannot see each other; (b) Conflict detection; (c) Conflict solving by immediate reaction.

When these two mechanisms of collision avoidance fail due to evaluation errors of users or misunderstandings in cooperative behavior, collision occurs.

3. A multi-layer microsimulation model approach

3.1. Background on modeling research

The simulation of traffic flow in shared spaces represents a unique issue in the context of traffic modeling. This is due to users not using fixed trajectories and the priority rules adopted by users, which are mostly influenced by geometrical and psychological factors, differing from those provided by road regulation.

In particular, two research projects have dealt specifically with these issues, namely the research at the Imperial College in London (Anvari 2012, 2014, 2015) and the research project MixME carried out in Austria (Schönauer et al. 2012a, 2012b) (Huang et al. 2011).

In both cases the authors have adopted the Social Force Model (SFM) based on the formulation of Helbing and Molnar (1995, 2000), which has shown good capabilities to represent pedestrian behavior and typical pedestrian problems like evacuation (Johansson et al. 2007). However, in order to deal with shared space problems, the SFM needs to be modified and extended. Some considerations are listed below.

- Shared spaces concern mixed traffic situations. The SFM must be adapted for other users (cars, bicycles, public transport). Anvari et al. (2012) adjusted the SFM for car dynamics and integrated a car-following model. Huang et al. (2011) developed a mechanical dynamic model for four-wheel motor vehicles with a PID controller for implementing turning behavior. Wischmeier and Rinke (2013) modified the repulsive force term of motorized vehicles to prohibit physical contact between them.
- As mentioned in section 2.2, FF conditions deserve particular attention. Users have a clear idea how to reach their destination including a preferred trajectory, speed, and intermediate destinations. Addressing this issue only to the driving term of the SFM leads to unrealistic behavior. Therefore the model must be able to calculate the FFTs of users for every origin/destination (O/D) pair. Anvari et al. (2012) used the flood fill algorithm for path planning, while Schönauer et al. (2012a) created an infrastructure model.
- It is a common human behavior to avoid dangerous conflict situations. This mechanism is not provided in the basic SFM, where other users only have certain effects on the movement when users are relatively close to each other. For this reason Anvari et al. (2015) introduced a conflict avoidance term in the SFM equation.
- Situations where a user gives priority to another for courtesy (i.e. in car-pedestrian conflicts) are typical scenarios in shared spaces. Schönauer et al. (2012) used game theory to solve this situation by designing a tactical model.

3.2. Layer structure

Given these considerations, a layer-structured simulation framework based on the SFM, where each layer is assigned to one of the standard traffic situations described in section 2.2., is developed. The FF layer (layer 1) provides a computation of the best trajectory the user would use according only to the streetscape (buildings, obstacles, parked cars). The LRCA and SRCA layers (layer 2 and 3) specifically address solving conflict situations.

In the presented simulation framework the SFM structure of Helbing and Molnar (2000) with the modifications of Johansson et al. (2007) is adopted by adding a new term $\vec{f}_{iCA}(t)$ to include the LRCA mechanism:

$$m_i \frac{d^2 \vec{x}_i(t)}{dt^2} = \vec{f}_i(t) + \sum_{j, j \neq i} \vec{f}_{ij}(t) + \sum_b \vec{f}_{ib}(t) + \vec{f}_{iCA}(t) \quad (1)$$

The unmodified SFM formulation consists of the first three terms, namely the driving term $\vec{f}_i(t)$, the repulsive effects from other users $\vec{f}_{ij}(t)$ and from fixed obstacles $\vec{f}_{ib}(t)$. For detailed explanations on the particular SFM terms please refer to Höcker (2010) or Wischmeier and Rinke (2013).

3.3. FF layer

Under FF conditions, road users wish to reach their destination following the shortest path, according to static obstacles and infrastructure (Anvari et al. 2015). Moreover, the general tendency is to opt for a smooth path that avoids suddenly changing direction or changing pace (section 2.2). In order to represent this, a FF layer implementing both these principles is included in the design of the model.

A graph-based model is developed to automatically compute a path through the streetscape, considering the streetscape's functional subdivision (section 2.1). For this purpose the concept of visibility graphs, widely used for the navigation of robots (De Berg et al., 2000), is adopted for the navigation of road users by transforming obstacles and non-accessible zones to polygons. On a weighted visibility graph generated from the polygon vertices the Dijkstra algorithm is performed to find a shortest path for each traffic mode between each O/D pair. To model the human behavior of keeping a certain distance away from obstacles and to take the width of the user into account, all inner path vertices are transposed a certain distance from the corresponding polygon.

After the identification of this path a realistic smooth path is computed by an edgewise calculation of point-to-point clothoids. Clothoids are widely used as transition curves for the design of highways or railroads and allow for driving without instantaneous steering. Since the video analysis has shown a general tendency for pedestrians to favor smooth and uniform FF trajectories, which allows a constant speed while steering, the clothoid approach can be deemed to be reasonable even for this user category. Bertolazzi and Frego (2014) developed an algorithm for computing clothoids between two points using four parameters (start/end-point and -angle). Finally the FFT is generated by assembling all particular clothoids. The result is shown in Figure 5b for pedestrians using the same O/D pair of Fig. 2a.

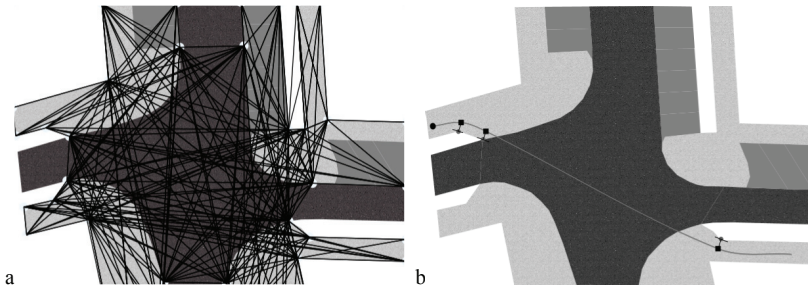


Fig. 5. FFT calculation. (a) Visibility graph for pedestrians, (b) FFT computed by clothoids between translated points of the shortest path

Despite FFTs generally appearing with a certain variance, in this application only one fixed path for every O/D pair is considered. The study of their distribution and calibration from real observations is part of future research.

In this layer the driving term is oriented in accordance with the direction of the FFT (Eq. 2). The setting of a FF speed allows the calculation of the future position of the user, which is especially useful for conflict detection.

$$\vec{f}_i(t) = \frac{v_i^0(t) \cdot \vec{e}_i^0(t) - \vec{v}_i(t)}{\tau_i}, \quad \text{with} \quad \vec{e}_i^0(t) = \overline{FFT}(s_i(t) + v_i^0(t) \cdot \Delta t) - \vec{x}_i \quad (2)$$

where $v_i^0(t)$ is the desired speed of the pedestrian i , $\vec{v}_i(t)$ is the actual velocity and τ_i is the relaxation time, as in the formulation of Helbing and Molnar (1995). The vector $\vec{e}_i^0(t)$ is directed to the desired position along the trajectory taken into account the actual distance traveled $s_i(t)$, the desired speed and the global time step Δt .

4. Collision avoidance mechanisms

A four-step algorithm to solve conflict situations, which has been implemented in our simulation framework, is presented in the following sections.

4.1. Perception of opponent trajectories

In order to reproduce human perception, it is assumed that every user (further referred to as the ego user) monitors other users who are in their field of vision (competitive users or CUs). Each user’s field of vision is determined by their traffic mode. When a CU enters this field, the ego user makes an estimation of the CU’s trajectory by extrapolating the last observed midpoints of the body p_i at time t_i using a Lagrangian polynomial. The resulting curve will later be referred to as Competitive Users Predicted Spatiotemporal Trajectory (CUP StT). The use of the time t as a parameter for the Lagrangian polynomial implies a description of the speed of the CU.. The set of observation points is reduced by the Ramer–Douglas–Peucker (RDP, Ramer (1972), Douglas & Peucker (1973)) algorithm (see Fig. 6a., observed positions of CU) to avoid inaccurate curvature. The degree of the curve is then limited to four, as high degrees can lead to oscillations of Lagrangian curves, by only using the last four points of this reduced set for the extrapolation. A mathematical description is given in Formula 3 in which p_i represents the observed position of CU at time t_i . The key ideas are summarized and illustrated in Fig. 6.

$$CUP\ StT(t) = \sum_{i=0}^n p_i \cdot L_i^n(t), \text{ with } L_i^n(t) = \frac{\prod_{j=0, j \neq i}^n (t - t_j)}{\prod_{j=0, j \neq i}^n (t_i - t_j)} \tag{3}$$

4.2. Conflict detection and Distance Function

In order to determine whether the motion would result in a collision the FFT of the ego user is compared to the predicted behavior of CUs. For this purpose, the distance between the ego user i and the CU j within the next ten seconds is computed by the following function.

$$DF(t) = d(FFT(s_0 + v_0 \cdot t), CUP\ StT(t)) - (r_i(\angle(i, j, t)) + r_j(\angle(j, i, t))) < SD \tag{4}$$

FFT is a function of the path length s and has to be converted to a function depending on t . Therefore the time t is multiplied by a desired velocity v_0 of the ego user and added to the walked path length s_0 . The term $r_i(\angle(i, j, t))$ describes the distance from the center of user i to their circumference in the direction of user j at time t . The term r_j is the analog measurement for the CU.

This distance function is evaluated at discrete time steps starting from the current time. A conflict is detected at time TIC (time to imminent conflict) if $DF(TIC)$ is lower than a minimal safety distance (SD) for the first time. The safety distance depends on the type of both users, e.g. 0.1 m for a pedestrian vs. pedestrian conflict (PP), and takes into account the sense of security of each user.

Fig. 6 shows a traffic situation where a conflict is detected, including the related distance function.

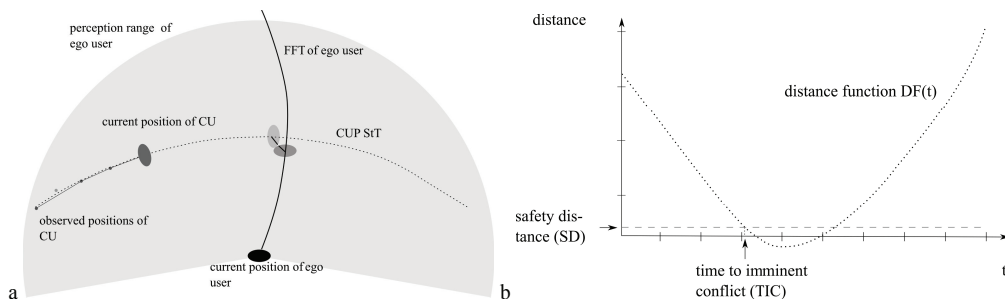


Fig. 6. Example of conflict detection; (a) current and predicted situation; (b) distance function DF

In Fig. 6a the process of conflict detection is given. The ego user observes five positions of CU and extrapolates the trajectory (CUP StT) neglecting the second point after running the RDP algorithm. In Fig. 6b the distance function $DF(t)$ for this particular conflict is shown. The DF is evaluated at discrete time steps. At TIC, the value of DF is lower than SD and a potential conflict is detected. Note that the conflict detection algorithm uses information only from the point of view of the ego user. This modeling approach allows for users in the simulation to misinterpret the conflict situation, which is intended to help describe observed behavior.

4.3. Conflict classification

Once a conflict is detected, it is initially classified based on the TIC. If the TIC is higher or equal than two seconds, the conflict is classified as long-range, and it is reasonable to assume that the ego user adopts a preventive reaction. Otherwise the conflict is classified as short-range. Long-range conflicts are then further classified based on the traffic modes involved. This work focuses on single conflicts among pedestrians (PP) and single conflicts between pedestrians and cars (CP). Multiple conflicts and those involving additional traffic modes are part of future research.

4.4. Conflict reaction

While for short-range conflicts the SFM works in its unmodified formulation, in the case of long-range conflicts the model is modified as shown in Table 2.

Table 2. LRCA mechanism. Road users involved and reactions implemented.

Conflict name	Road Users involved	Reaction	SFM modification
PP	Pedestrian vs pedestrian	Choose a new FFT	Changing the direction of the driving term
CP	Car vs pedestrian	Decrease/increase the speed	Adding $f_{ICA}(t)$ in the direction of motion

A conflict between pedestrians (PP) is solved by the computation of a new trajectory avoiding the conflict point and crossing the trajectory of the CU at a safe point (SP), located at a certain distance from the conflict point. Depending on the conflict angle, two points on the CUP StT, exactly two seconds before or after the conflict time, which in combination with the average pedestrian speed results in a sufficient distance from the conflict point. A visual explanation is provided in Fig. 7a. If two conflicting agents head towards each other, the SP used is the point to the right hand side of the ego user, which is the usual behavior observed.

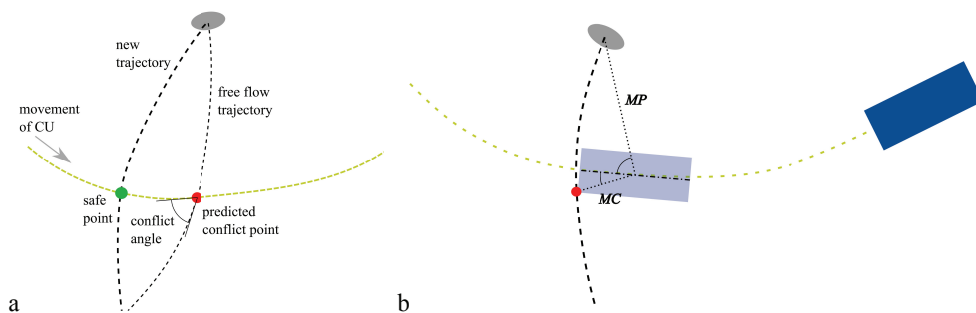


Fig. 7. Implementation of LRCA mechanisms. (a) PP; (b) CP.

CP conflicts are usually solved differently. Because of the obvious imbalance in the physical characteristics between opponents users display a more prudent behavior. In these circumstances, users no longer try to maintain their cruising speed, and opt to accelerate, decelerate or stop. This behavior is implemented in the SFM by adding a collision avoidance force in the direction of motion, namely f_{ICA} . The determination of whether the user decelerates

is based on an analysis of their alignment to the conflicting user. If a user assumes that at TIC the CU will have already crossed their trajectory, he will decelerate to let the CU pass. Otherwise the pedestrian user will accelerate while the car user will simply continue at their earlier speed.

The relative position between the conflict point and the car is determined by comparing the vectors MC (from the midpoint of the car to the conflict point) and MP (from the midpoint of the car to the current position of the pedestrian) to the longitudinal axis of the car. Figure 7b provides an example where a pedestrian is already close to leaving the car's path at conflict time. In this situation the motorist will resolve the conflict by decelerating.

5. Simulation framework

The steps of our simulation framework are described in the conceptual flowchart in Fig. 8. A description of each step is briefly presented below.

When the simulation starts, the geometry of the scenario and the associated visibility graph for each traffic mode is computed. Afterwards O/D points and demands as well as users are inserted and the FFTs are computed as described in section 3.3. Starting the simulation, the following main actions are computed every time step.

- **Preliminary operations.** This step includes the generation of new users from the origin points, and their orientation according to their FFT. Furthermore the impulsive and repulsive forces according to Eq. 1 are calculated.
- **Conflict detection, classification and reaction.** As described respectively in sections 4.2, 4.3, and 4.4.
- **Move object.** The resulting acceleration vector from the SFM equation is integrated twice by numeric integration methods and the new position of the user is computed.
- **Subsequent actions.** This step includes evaluation methods and removing users from the simulation who have reached their destination.

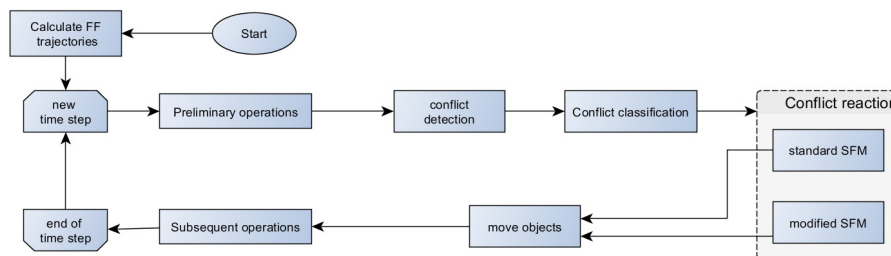


Fig. 8. Conceptual flowchart of the simulation steps

6. Application and results

Two examples from recorded behavior have been chosen to demonstrate the performance of the proposed model. In the first case a conflict situation between two pedestrians is solved via smooth deviation of one pedestrian from their FFT. In the second case three distinct car-pedestrian conflicts are observed and solved in different ways. Figs. 9 and 10 show a significant moment in each scenario, represented in both the simulation (a) and in reality (b, camera positioned northwest), as well as the comparison between the completed observed and simulated trajectories (c).

An example for the individual assumption of potential conflicts is given in Fig. 9. Pedestrian B recognizes a potential conflict in the two trajectories so decides to cross the street behind pedestrian A. The simulation reproduces this behavior (Fig. 9c). The comparison of observed and simulated trajectories in Fig. 9a shows that, due to the computation of the safe point, pedestrian B swerves too far in the simulation. In reality both pedestrians keep a smaller safety distance to another and nearly meet. Since the general behavior is reproduced to a satisfactory extent, the intensity of the reaction has only to be calibrated more precisely.

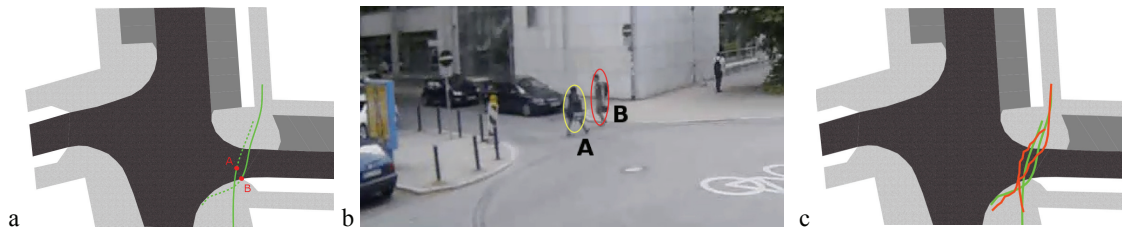


Fig. 9. Comparison of a pedestrian vs. pedestrian conflict. (a) simulation; (b) observation; (c) simulated (green) vs. observed trajectories (red).

An example for the individual assumption of potential conflicts is given in Fig. 9. Pedestrian B recognizes a potential conflict in the two trajectories so decides to cross the street behind pedestrian A. The simulation reproduces this behavior (Fig. 9c). The comparison of observed and simulated trajectories in Fig. 9a shows that, due to the computation of the safe point, pedestrian B swerves too far in the simulation. In reality both pedestrians keep a smaller safety distance to another and nearly meet. Since the general behavior is reproduced to a satisfactory extent, the intensity of the reaction has only to be calibrated more precisely.

In the second case the collision avoidance mechanism for CP conflicts (Section 4.4.) is validated. Fig. 10b shows a critical moment for the pedestrian group in the scenario (idealized as one person in the simulation). After letting the first car pass the group decides to walk before the second car. The second car then detects a conflict and decides to decelerate until the conflict is solved. The reactions of both the pedestrian group and the second car are the same in the simulation as in reality, as can be seen in Fig. 10c.

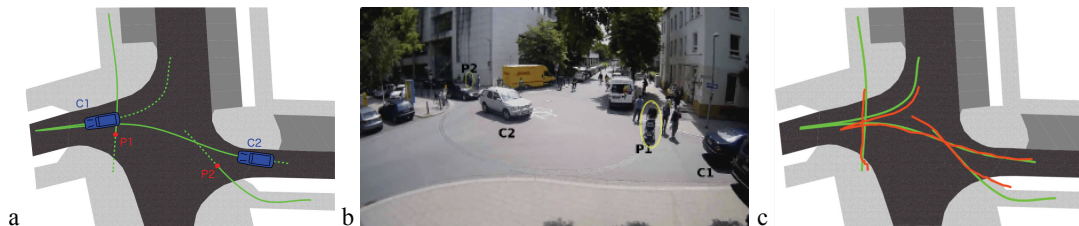


Fig. 10. Comparison of a pedestrian vs. car conflict. (a) simulated (green) vs. observed trajectories (red); (b) observation; (c) simulation.

In both scenarios the simulation shows realistic behavior. All users detect the conflicts using the CUP StT and the dynamic recalculation of this trajectory as well as the decelerating and accelerating process leads the users to solve the conflicts in a realistic manner.

7. Conclusions and future work

This work presents a new methodological approach to simulate the operation of shared spaces. The analysis of video footage has highlighted the need to treat free-flow condition specifically and to integrate a collision avoidance mechanism to realistically simulate the movement of road users. A social force based model has been developed in a three-layered structure, where each layer is dedicated to different traffic situations (FF, LRCA, SRCA). The model has shown good capabilities to represent simple conflict situations involving pedestrians and cars.

Future research will concern itself firstly with calibration and validation issues with the aim of finding statistical criteria to evaluate and improve the accuracy of the proposed approach. This can be done using genetic algorithms to find the best parameter configuration for the conflict detection and collision avoidance mechanisms. Secondly, the model must be extended in order to include multiple conflict situations between users, and to integrate bicycle and public transport. Finally, the simulation of traffic activity over longer time periods will allow for the calculating of performance indicators, such as time delay and number of conflicts, leading to the evaluation of the Level of Service and safety inherent in a specific streetscape.

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