Physica A 438 (2015) 272–285

Contents lists available at ScienceDirect

Physica A

journal homepage: www.elsevier.com/locate/physa

On oscillations in the Social Force Model

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HIGHLIGHTS

- The Social Force Model of pedestrian dynamics is investigated for oscillations.
- A proof is given that approaching a destination a pedestrian oscillates forever.
- Approaching another person it depends on parameters; oscillations can be avoided.
- Elliptical specification II shows fewer oscillations than circular specification.
- Oscillations can be utilized to verify correct software implementation.

ARTICLE INFO

Article history:
Received 4 October 2014
Received in revised form 14 May 2015
Available online 10 July 2015

Keywords:
Pedestrian dynamics
Pedestrian simulation
Social Force Model
Oscillations

ABSTRACT

The Social Force Model is one of the most prominent models of pedestrian dynamics. As such naturally much discussion and criticism have spawned around it, some of which concerns the existence of oscillations in the movement of pedestrians. This contribution is investigating under which circumstances, parameter choices, and model variants oscillations do occur and how this can be prevented. It is shown that oscillations can be excluded if the model parameters fulfill certain relations. The fact that with some parameter choices oscillations occur and with some not is exploited to verify a specific computer implementation of the model.

1. Introduction

The Social Force Model of pedestrian dynamics is a model that aims at describing the movement of pedestrians with the predominant purpose of simulating pedestrian movement on computers. The force of pedestrian β on pedestrian α typically has the form

$$\vec{f}_{\alpha\beta} = A_\alpha w() e^{(-g())} \hat{e}_{\alpha\beta} \tag{1}$$

where $g()$ is a function which grows with increasing distance between both pedestrians and can depend on the velocities of one or both pedestrians. The function $w()$ suppresses forces the more pedestrian β is located outside the current walking direction of pedestrian α.

The Social Force Model has first been introduced in 1995 [1]. This variant later was called "elliptical specification I". A second variant (circular specification) has been proposed in 2000 [2] and a third variant (elliptical specification II) in 2007 [3]. The difference between the three variants lies mainly in the way the velocities of two interacting pedestrians are considered in the computation of the force between them. The 1995 variant considers only the velocity of the pedestrian who exerts the force. The 2000 variant does not at all consider velocities (only the distance between pedestrians) and the 2007 variant considers the relative velocity between both pedestrians (the pedestrian who exerts the force and the pedestrian on whom

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http://dx.doi.org/10.1016/j.physa.2015.07.002
0378-4371/

the force acts). For the analytical considerations in this paper mainly the simplest variant from 2000 will be considered. Nevertheless it will also be discussed how results will change qualitatively if the variants as of 1995 or 2007 are applied.

Under "oscillations" in this paper unrealistic artifacts in the trajectory of a pedestrian approaching another pedestrian, his destination or a wall is understood. The occurrence of oscillations in the sense of this contribution has been discussed in a number of contributions [4–7] and it is often claimed that oscillations cannot be avoided in the Social Force Model, but that they just can be made small. In this paper it will be shown that this is not correct and exact conditions for the value of the model parameter such that oscillations occur will be derived.

In the remaining of the paper first a single pedestrian approaching a destination is investigated, then a pedestrian approaching another pedestrian who is standing still and finally two pedestrians approaching each other. In each case the model is reduced to one dimension and the noise term is set to zero. In the first section on approaching a destination the problem will be shown to be most severe as with certain conditions oscillations cannot be prevented and continue infinitely long. At the same time – as will be argued – for this case it is not very relevant, as there are simple, pragmatic solutions. The second and third cases yield restrictions to the choice of parameters which can produce realistic, oscillation-free behavior.

2. A pedestrian approaching a destination

In this section we are interested in and discuss the equations of motion and their solution of a single pedestrian approaching a destination coordinate (i.e. a point) where he is required to come to a standstill. We assume that in the beginning the pedestrian is walking with his desired speed v_0 straight towards the destination coordinate, so there is no tangential component of the walking velocity. Then we can describe the pedestrian as walking from positive x coordinate into negative x direction towards the destination which is at $x = 0$. Since the 1995, 2000, and 2007 variants of the Social Force Model only differ in the force between pedestrians and not the driving force term all results of this section hold for all three variants.

We assume for now, that the desired velocity is always some externally given v_0 and is always pointing from the pedestrians current position towards $x = 0$. This assumption is the simplest one and it can be questioned—as we will do below. With it , it is obvious that there will be oscillations around $x = 0$. Our intention here is to investigate the quantitative details of these oscillations.

In general the equation of motion for this pedestrian reads

$$\ddot{x}(t) = \frac{-\text{sign}(x(t))v_0 - \dot{x}(t)}{\tau} \tag{2}$$

where τ is an external parameter which typically has values between 0.1 and 1.0 s.

We require the pedestrian not only to reach $x = 0$, but also to stand still there as arrival condition. Because the pedestrian has a speed larger 0 (or, considering walking direction: smaller 0) he will walk over the destination and be on the left (negative) side of x coordinates. There the desired velocity points into the direction of positive x coordinates. So we have for the time following the moment when the pedestrian is at $x = 0$:

$$\ddot{x}(t) = \frac{v_0 - \dot{x}(t)}{\tau}. \tag{3}$$

This is solved by

$$\dot{x}(t) = v_0 - a e^{-\frac{t}{\tau}} \tag{4}$$

$$x(t) = b + v_0 t + a\tau e^{-\frac{t}{\tau}} \tag{5}$$

where a and b are integration constants which need to be determined by initial conditions.

We choose $t = 0$ at the moment when the pedestrian is at $x = 0$. Then $\dot{x}(t = 0) = -v_0$. However, for later usage we want to set here more general $\dot{x}(t = 0) = -u$ and remember that for our particular case $u = v_0$. With the two conditions $x(0) = 0$ and $\dot{x}(0) = -u$ we can determine the values of the integration constants:

$$a = v_0 + u \tag{6}$$

$$b = -(v_0 + u)\tau. \tag{7}$$

So we have

$$\dot{x}(t) = v_0 - (v_0 + u)e^{-\frac{t}{\tau}} \tag{8}$$

$$x(t) = v_0 t - (v_0 + u)\tau \left(1 - e^{-\frac{t}{\tau}}\right). \tag{9}$$

Now we can compute the time t_{turn} when the pedestrian stops (and turns around) $\dot{x}(t_0) = 0$ and the position $x(t_0)$ at which this happens:

$$t_{turn} = \tau \ln \frac{v_0 + u}{v_0} \tag{10}$$

$$x(t_{turn}) = \tau v_0 \left(\ln\left(1 + \frac{u}{v_0}\right) - \frac{u}{v_0}\right). \tag{11}$$