# Modelling Human Navigation: Cognitive Aspects of Obstacle Avoidance

Juan Purcalla Arrufi*

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**Abstract.** Modelling human walking—specially obstacle avoidance—has applications on simulating human behaviour in emergency situations or implementing human acceptable navigation on robots. We research a model for human walking navigation, focused on the problem of avoiding another walking humans—the model should straightforward generalise to the avoidance of standing humans. We partition each avoidance trajectory in three stages: initiation of the trajectory adjustments, performance of the trajectory adjustments, finalisation of the trajectory adjustments. This division poses some questions that we want to tackle in this paper. First, what event triggers the trajectory adjustments, so that they are initiated at a certain moment (in time-space). Second, how the trajectory adjustments are performed: humans have two strategies to modify their trajectory—change the walking speed or direction— thus, we would like to know what makes choose one strategy over the other or to choose a combination of both.

## 1 Objective

We intend to provide a numerical model of the human avoidance of obstacles when walking. The model deals with two crossing humans: one of them is the *interferer*, i.e., he does not change at all the course or speed of his trajectory, the other is the *avoider*. As they approach—at constant velocity—the avoider performs adjusts his trajectory in order to avoid collision and reach the goal, which could have been reached in a straight line, were the interferer absent.

The numerical model should, on the one hand, reproduce the experimental results of the initiation of the trajectory adjustments—essentially that the

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*Ph.D. supervisor Alexandra Kirsch; `alexandra.kirsch@uni-tuebingen.de`

smaller the crossing angle the latter the trajectory adjustment is initiated; and that the lower the speed the latter the trajectory adjustment is initiated. To that end we will use probabilistic inference based on a stochastic model for the interferer. On the other hand, the model should predict the way direction and speed adjustments are combined. A general result is that for obtuse angles pedestrians perform only direction adjustments; for acute–right angles pedestrians perform a speed adjustment in addition to the direction adjustment.

## 2 Motivation

Understanding and modelling human navigation—pedestrian dynamics—is a task which began about 20 years ago to be an own field in science. This fact was prompted, among others, by two events: the founding of *Gait and Posture*—one of the leading journals in human locomotion—, and the seminal work of Helbing on pedestrian dynamics. Now we have an extensive research in crossing situations of pedestrians, which has persuaded us to deal with these situations.

A human navigation model may equip a robot moving in human environments with an acceptable navigation behaviour, what we also call *human-aware robot navigation*. Our ansatz is following: the most direct way to achieve that robots navigate in a human acceptable way is to make robots mimic human navigation. Human-aware robot navigation embraces numerous tasks of daily importance: assistive tasks in domestic environments, patrolling and surveillance, service delivery in health care institutions. Despite all research on robotics in the last four decades, human aware navigation has been just recently established as a discipline—this topic began to increasingly attract the attention of the scientific community in the year 2000. Consequently, many areas in this discipline still need both satisfactory solutions and a solid formalisation.

Apart of the benefits for robotics, modelling human navigation on crossing situations builds on cognitive science. Indeed, on the one hand, we argue that the adjustment of the avoidance trajectory is triggered by inference processes—the probability of colliding based on the inferred position distribution of the *interferer*. On the other hand, we research the causes of the avoidance strategy: what makes the *avoider* choose the direction or speed change in different proportions.

## 3 Method

We consider three consecutive parts in the trajectory of the *avoider*: initiation, performance, and finalisation of the trajectory adjustments. For both the initiation and the performance of the trajectory adjustments we test following methods as possible explanation the experimental results, and therefore as explanation for human behaviour.

### 3.1 Initialisation of Trajectory Adjustments

In a crossing situation we hypothesise that the trigger of the trajectory adjustments is the probability of the crossing distance being below a certain value (e.g., 0.5). The computations are based on the inferred probability distribution of the interferer at the crossing time, $t_\times$. We assume that the trajectory of the *interferer* is predicted as a stochastic Gaussian process whose expected value depends on the current interferer's velocity, i.e., $\langle \boldsymbol{x}(t) \rangle = \boldsymbol{v}_0 t$. By means of sequential Monte Carlo prediction we can infer the interferer's probability distribution at the crossing time $t_\times$ and, consequently, the probability of the crossing distance to be below the minimal crossing distance; which would trigger the initialisation of the trajectory adjustments.

### 3.2 Performance of Trajectory Adjustments

We assume that pedestrians perform trajectory adjustments based on three principles that we explain below: distances between humans, human speeds (maximal, minimal, typical), trajectory smoothness. When we require these three principles to determine the trajectory jointly, we expect to reproduce the observed combination of direction and speed adjustments.

**Distances** For static situations the most basic approach is the theory of *proxemics* that defines the acceptable distance intervals for the type of relation the static interferer has to the avoider (*public*, *social*, *personal*, or *intimate*).

When considering a moving interferer, i.e., kinematic situations, research abounds in crossing situations. One of the most remarkable results states that humans aim to keep a crossing distance (CD) of about 0.8 meters. Humans begin to adapt their trajectory based on the crossing distance they predict; their predictions assumes constant linear motion based on the current positions and velocities of both humans, $k$ and $l$, $(\boldsymbol{x}_{k0},\, \boldsymbol{v}_{k0};\, \boldsymbol{x}_{l0},\, \boldsymbol{v}_{l0})$

$$\mathrm{CD}(\boldsymbol{x}_{k0}, \boldsymbol{v}_{k0}; \boldsymbol{x}_{l0}, \boldsymbol{v}_{l0}) = \min_{t \geq 0} \|(\boldsymbol{x}_{k0} + \boldsymbol{v}_{k0} t) - (\boldsymbol{x}_{l0} + \boldsymbol{v}_{l0} t)\| \tag{1}$$

**Walking and Running Speeds** The experiments of human locomotion have fixed the human values for walk speed: *slow* walking speed 1.15 m/s; *preferred* walking speed 1.41 m/s; *fast* walking speed 1.8 m/s; and *maximal* walking speed 2.3 m/s.

They have also found the limit for the transition into running modus, 2.05 m/s.

**Smoothness Requirements** Any trajectory is required to minimise the jerk's Root Mean Square (RMS) with certain boundary conditions in the interval $[t_1, t_2]$, e.g., $\boldsymbol{v}(t_1) = \boldsymbol{0}; \boldsymbol{x}(t_1) = \boldsymbol{0}$ and $\boldsymbol{v}(t_2) = \boldsymbol{0}; \boldsymbol{x}(t_2) = \boldsymbol{goal}$. Jerk minimisation is a general property of human motions: from arm displacements to walking trajectories.

We remark that this is a *global* (not local) requirement. It can only be fulfilled when the immediate future of the movement is, in some degree, predictable.

$$J = \langle j \rangle_2 = \left( \tfrac{1}{t_2 - t_1} \int_{t_1}^{t_2} \|\boldsymbol{j}(t)\|^2 \, dt \right)^{1/2} \quad \text{where } \boldsymbol{j}(t) = \dot{\boldsymbol{a}}(t) = \dddot{\boldsymbol{x}}(t) \tag{2}$$