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DOI:
https://doi.org/10.1088/1742-6596/1391/1/012171

Document Version
Final published version

Link to publication record in Manchester Research Explorer

Citation for published version (APA):
Liakou, M., & Kosmas, O. (2019). Analyzing museum exhibition spaces via visitor movement and exploration: The case of Whitworth Art Gallery of Manchester. Journal of Physics Conference Series, 1391. https://doi.org/10.1088/1742-6596/1391/1/012171

Published in:
Journal of Physics Conference Series

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To cite this article: Melpomeni Liakou and Odysseas Kosmas 2019 J. Phys.: Conf. Ser. 1391 012171

View the article online for updates and enhancements.
Analyzing museum exhibition spaces via visitor movement and exploration: The case of Whitworth Art Gallery of Manchester

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Abstract. To analyse the movement and exploration of visitors on museum exhibition spaces, agent based models that simulate their behaviour can be a useful tool. Such a model is proposed here, to which we use appropriate defined dynamical and social forces to describe their motions, while the resulting decision making procedure either preserves or creates groups of individuals. That proves to give realistic visitor motions to complex and multi level spaces while resulting the way they bypass obstacles, move to stairs or follow other groups on their way out. Simulation results are then used to analyse the exhibition spaces of the Whitworth Art Gallery throughout the motion flow of the visitors.

1. Introduction

Nowadays models that simulate pedestrians and their behaviour when moving in closed spaces have aroused great interest [1, 2, 3]. Those, which describe emergency and/or non-emergency situations, are usually employed from organisations to enrich their knowledge of visitors experience and behaviour. However, there have been obtained cases where the techniques used produce spatially and temporally limited empirical evidence and measurements [2, 4].

To understand the underlying causes and dynamics of pedestrian behaviour analysing emergent behaviours can be a useful too. To that end analytical models proved to be complicated, so agent based simulations have been introduced [2]. Aiming on how the environment can be adjusted so as to provide an improvement of human comfort and safety, pedestrians can be modelled as a collection of autonomous decision-making entities (agents) which are described to mimic different type of physical and social behaviours [2, 4].

In this present work we propose an agent-based model that simulates visitor behaviour in museum-exhibition spaces. As an extension of our previous work [2], that model defines visitors’ behaviour by introducing social forces as decision-making procedures. Based on dynamic and social forces that either preserve or create groups of individuals, the model introduced explains how agents bypass obstacles, move to stairs or follow other groups on their way out. We finally apply the proposed model for the case of the Whitworth Art Gallery, in determining how visitors behave and how dynamical models can be important in the level of service of museums and/or in the optimal exploitation of exhibition spaces.
2. Modelling pedestrian dynamics
Pedestrian behaviour in closed spaces under emergency situations, when using an agent based model, uses two main procedure steps. During the first one agents detect the closest exit while to the second one a mathematical model that described the dynamical equation for each one of them is defined. To that end, and having in mind that agents try always to reach their desired destination using the shortest possible path [1, 2], we can assume that our space consists of grid points \( \Omega \in \mathbb{R}^2 \). Those, together with its boundary \( \partial \Omega \), form a partition of the enclosed space that for each study case, while the closed space represent an area inside a room and the surrounding respectively its walls.

The shortest path that each agent has to follow on the way to the exit can be defined for every point using the equation \( ||\nabla u(x)|| = 1 \) for \( x \in \Omega \) and \( u(x) = 0 \) for \( x \in \partial \Omega \) [2, 5]. Although that equation may be computational expensive, many numerical approaches can give quick results. In our previous work [2] we have tested several techniques, but here we will restrict ourselves to the use of the fast sweeping method, see for example [6, 7, 8, 9, 10, 11].

In order to define a dynamical equation for each one of the agents that simulates their behaviour under emergency situations, their reactions will be defined by forces of different types [2, 5]. If we consider \( m_i \) being the mass of each \( i \)-th agent (\( 0 \leq i \leq n \), and \( n \) represents the total number of agents), the first force we need to define is the driving force \( F_d^i \). That plays the role of the main force and simulates each agents desire on moving towards the exit. In addition that must depend on agents position and velocity, with a physical constraint that forces them to move freely but not accelerate. As long as they reaches a pre-described speed they will continue with this speed toward the location of the door. I we denote \( e^i \equiv e^i(t) \) this desired direction and by \( v^i \equiv v^i(t) \) it’s desired speed at time \( t \) the driving force can be written as [1, 2]

\[
F_d^i = m^i v_0^i e^i - v^i, 
\]

where with \( v_0 \) we define the velocity which simulates agents motion under normal and nervous conditions. Trying to be close to reality, that will be bounded by two values that describe those conditions [1, 2].

To simulate the behaviour of agents that following the same direction on their move towards the same exit, we can define repulsive forces from the surrounding walls as [1, 2]

\[
F^i_w = \sum_{w \in \partial \Omega} \left\{ \left[ A^i e^{(r_i - d^i_w)/B^i} + kg (r_i - d^i_w) \right] n^i_w - \kappa g (r_i - d^i_w) (v^i t^i_w) t^i_w \right\},
\]

where \( d^i_w \) denotes the distance between the wall and the \( i \)-th pedestrian, \( r_i \) is the size of the pedestrian, \( g(x) \) stands for a function which is zero if the argument is negative and equal to the argument if it is positive. In addition \( A^i, B^i, k \) and \( \kappa \) are constants, \( n^i_w \) is the normal vector between the pedestrian and the wall and \( t^i_w \) is the tangential vector between the pedestrian and the wall. If we consider the terms, then the first term is the typical force to the wall, then next term is a friction term given that the pedestrian touches the wall and the last term is the tangential velocity term also given that the pedestrian touches the wall [1, 2].

Furthermore, when moving in crowded places, agents would preferably like to keep some distance between them. That behaviour can be simulated through a social force acting between \( i \)-th and \( j \)-th agents as [1, 2]

\[
F^s = \sum_{i \neq j} \left\{ \left[ A^i e^{(r^i_j - d^i_j)/B^i} + kg (r^i_j - d^i_j) \right] n^i_j + \kappa g (r^i_j - d^i_j) (v^i_j - v^i) t^i_j \right\},
\]

where \( r^i_j = (r^i + r^j) \), the last term is the friction due to the relative velocity difference as we also saw to the wall.
Finally, if we take into account that in closed spaces visitors come mostly in rather small groups (students, families or friends) we have to include a parameter as a social behaviour not only for agents walking close to each other, but also for individuals intentionally walking side by side [2, 3]. A natural way is to consider that groups operate independently avoiding the close proximity with members of neighbouring groups that may lead to group merging. To this aim, we proposed a force

\[ F_g^i = -\mu^i v^i, \]  

where the parameter \( \mu^i \) describes the strength of the social interaction between group members.

Last, if we now assume that we are dealing with deterministic trajectories, Newton’s second law of motion for the resulting force acting upon each agent will give [2]

\[ F_{d}^i + F_{s}^i + F_{w}^i + F_{g}^i = m_i \frac{d^2x_i}{dt^2}, \]

where the forces of the left hand side are defined in (1), (2), (3) and (4) respectively.

3. Simulation results for the case of Whitworth Art Gallery

The proposed model has been tested for the closed space scenario of the Whitworth Art Gallery in Manchester. To that we consider that 80 visitors are initially distributed randomly around museum items in the first floor of the gallery. We further assume that a mass \( m = 70\text{kg/visitor} \) is rather uniformly distributed at a site \( r^i \in [0.25, 0.35] \) and that their flow velocity (in m/s) is \( 0.75 \leq v_0 \leq 1 \).

The snapshot in Figure 1, represents the initial moment, right before the evacuation scenario. In order to check the performance and reliability of the proposed model, we further consider the constants of equation (5) to take the values: \( t^i = 0.5s, A^i = 2 \cdot 10^3N \) and \( B^i = 0.08m \) for \( i = 1, \ldots, n \) (here \( n = 80 \)). We furthermore, utilise the values \( k = 1.2 \cdot 10^5\text{kg/s}^2 \) and \( \kappa = 2.4 \cdot 10^5\text{kg/m} \), see [1, 3, 5].

4. Conclusion and future work

In the present we propose a model for simulations of pedestrian behaviour in closed spaces. That is based on the social and dynamical behaviour of individuals through interactions between themselves and the physical space respectively. The new model can describe group behaviour,
combines real and non-physical physical forces the same mathematical expression. Preliminary results obtained for the case of the Whitworth Art Gallery in Manchester indicate that the proposed model can simulate group behaviour of different scales and numbers in complex and multi level spaces. Results prove that the model can be very useful in determining how visitors behave, which can be important in the level of service of museums and/or in the optimal exploitation of exhibition spaces. Finally, a future extension of the model can be formulated, in order to consider more psychological factors like groups that merge.

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