MODELLING OF URBAN PEDESTRIAN ENVIRONMENTS FOR SIMULATION OF THE MOTION OF SMALL VEHICLES

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ABSTRACT
This paper has two aims. The first is to describe the results of initial experiments to understand the relationship between the speed of an electric scooter and the density of pedestrians. The second is to explain how subsequent experiments will be used to create a pedestrian model to better understand pedestrian-vehicle avoidance behaviour. The first aim has been achieved in Genoa by calculating the scooter velocity and associated pedestrian density. Then the design of future experiments, which will be carried out at the PAMELA Laboratory at UCL are described. The results of these additional experiments will be used as inputs to the SiVic simulator – this is able to simulate real-time driving of a PICAV. The SiVic simulator allows changes to the control system of the PICAV vehicle to be tested. The details of these additional experiments and the process of integrating these results into the SiVic simulator are described herewith.

Keywords: Pedestrian modelling; vehicle-pedestrian behaviour; Simulation

1. INTRODUCTION

A new form of public transport system is being considered as part a European project called PICAV (Personal Intelligent City Accessible Vehicle). This system will consist of a number of individual intelligent vehicles which can be hired on-demand by pedestrians, including those who are elderly and disabled, and used to access areas of the built environment which are otherwise inaccessible. These vehicles – PICAVs – will share the same space as pedestrians. Therefore it is important that the interactions between the pedestrians and the vehicles be understood so that a safe and efficient transport system can be developed. Also, the speed at which a PICAV can travel will be dependent on the density of the pedestrian flow in a particular street, which will subsequently affect the journey times of users and therefore the availability of PICAVs.

The first aim of this paper is to describe the results of initial experiments to understand the relationship between the speed of an electric scooter and the density of pedestrians. The results of this relationship will be used to inform minimum journey times for the fleet simulator. The fleet simulator is described in a separate paper at HMS Conference (Cepolina et al 2011).

The second aim is to explain how subsequent experiments will help to address the safety issues surrounding the use of PICAVs in the pedestrian space.
The paper is divided in the following way; section 2 reports the details and results of the Genoa experiments, section 3 describes the additional experiment which will be carried out at the Pedestrian Accessibility and Movement Environment Laboratory (PAMELA) facility and section 4 describes the SiVic simulator and the process of integrating the empirical data into this simulation environment.

2. A MODEL FOR THE PICAV SPEED-PEDESTRIAN DENSITY RELATIONSHIP

A series of video clips of an electric scooter travelling in a straight line were taken on the following two streets in Genoa, Italy: Via San Luca and Via di Canneto. These streets are pedestrian-only areas. The electric scooter was a standard electric scooter designed for disabled people, and not a PICAV unit as this is yet to be constructed.

The focus of this paper is on the analysis of the videos from via San Luca, which is typical of streets in the historical city centre of Genoa, with a number of shops on either side of the street and a street width of just over 2.5m. The surface of the street is also typical: cobbled stone. These videos were taken from a birds-eye point of view and took in an area of 18.75m2, which was divided in to 12 squares (6 squares long and 2 squares wide). The area was videoed in the morning, between 10:30 and 11:30 (i.e. during low pedestrian density), and in the evening, between 15:30 – 17:00 (i.e. during high density population). The maximum velocity of the scooter was set by limiting the power dial to mid-range. The analysis from these videos has led to a model which summarizes the relationship between the electric scooter velocity and the pedestrian density along the measured sections of the street. It is assumed for the purposes of this initial study that there is no difference in performance between the PICAV vehicle and the electric scooter used in the experiment. It is also assumed that pedestrians respond to the scooter in the same way they would to a PICAV vehicle.

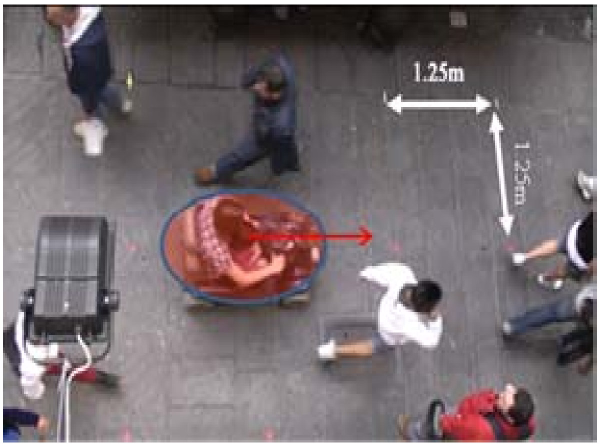

Figure 1: The electric scooter in the pedestrian area of Via San Luca

The analysis was performed by watching the video clips (Film No) and each run (Ride No) as timed from the moment the scooter entered the 18.75 m^2 area of interest until the moment it left. During this time the average pedestrian density was also recorded. Values of density are expressed as the number of pedestrians per square metre. Rides were completed in both upslope and downslope directions. Eight rides were filmed in the morning, and 36 in the afternoon. Usually, morning rides refer to low values of pedestrian density, while afternoon rides were characterised by high values of pedestrian density. The rides are the following. The entrance film time and the exit film time refer to the time reported in the video tape for when the scooter entered and exited the area of interest. It is expressed in this way: mm:ss:d. where mm = minutes ; ss = seconds ; d = decimal, i.e. 01:10:9 means: 01 minutes, 10.9 seconds.

2.1. The density-velocity model

The empirical data has been filtered to exclude three runs in the morning and three in the afternoon. These rides were different from all others as they required the scooter to avoid specific obstacles and so it did not travel in a straight line. The remaining rides have been used to create the relationship shown in figure 2, which shows the average pedestrian density on the x-axis and scooter velocity on the y-axis.

Several relationships between speed and density were explored using the statistical package R. The models explored were:

1. Linear model between scooter speed and pedestrians density.
2. Linear model between: scooter speed on one side; and on the other side pedestrians density plus an index being 1 if the scooter is going upslope and 0 if it is going downslope.
3. Polynomial models between scooter speed and pedestrians density, where s = speed, k = density. One such model could be e.g.:

   $$s = a\,k^4 + b\,k^3 + c\,k^2 + d\,k + e \qquad (1)$$

   where a, b, c, d, e are some coefficients.
4. Logarithmic and exponential model: e.g.

   $$s = a\,exp(k) + b \quad \text{or} \quad s = a\,ln(k) + b \qquad (2)$$

5. Discontinuous linear model: e.g. $s = a\,k + b$ where a and b have two values, e.g. there is a threshold in the density, called k_0; therefore: $a = a_0$ if $k < k_0$ and $a = a_1$ if $k \geq k_0$. Several values of k_0 have been explored.

The linear model $s = a\,k + b$ performed quite well, with an adjusted R-squared value of more than 0.55 and high level of significance for both the constant and the variable (the density). When the further models were investigated it was found that the increase in complexity of the model did not result in large improvements of the adjusted R-square value. Increased values were found (0.58 – 0.59), but as the increase in the R-squared value was so small when compared to the increase in complexity it was decided to use the linear model. This is defined by the following equation:

$$v = 1.57751 - 1.44677\,\rho \qquad (3)$$

where v is the velocity of the scooter (m/s) and ρ is the density of pedestrians (number of pedestrians /m^2).

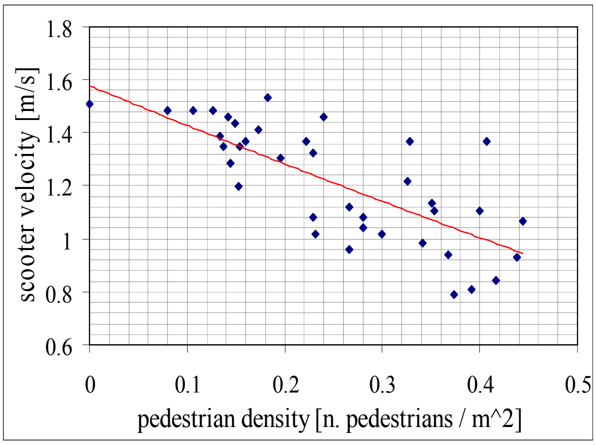

Figure 2: Pedestrian density – scooter velocity model

One drawback to the empirical work undertaken is that it was difficult to get a full range of densities and thus it was not possible to test varying velocities or driving strategies. For this reason a series of experiments will be run at PAMELA to test these various variables so that a fuller model can be developed. The next section will describe the details of these experiments and how they fit into the larger scope of the PICAV project, both in terms of vehicle design and also fleet dimension and management.

3. MODELLING OF URBAN PEDESTRIAN ENVIRONMENTS

A series of experiments are currently underway at the Pedestrian Accessibility and Movement Environment Laboratory (PAMELA). The experiments will add to the range of data for the vehicle velocity-pedestrian density model. They will also enable a *pedestrian model* to be developed, which will be used to understand pedestrian-vehicle avoidance behaviour (see Figure 3). A large part of the analysis will involve the use of automatic pedestrian tracking; the algorithms for this will be developed as part of this project, but are not described in this paper. The results of the pedestrian model will be fed into the SiVic simulator (described in section 4.1) and used to generate people within the simulator that can react in a *real* way to a scooter. This will then enable human-machine driving interfaces to be tested for various types of people e.g. elderly and disabled people.

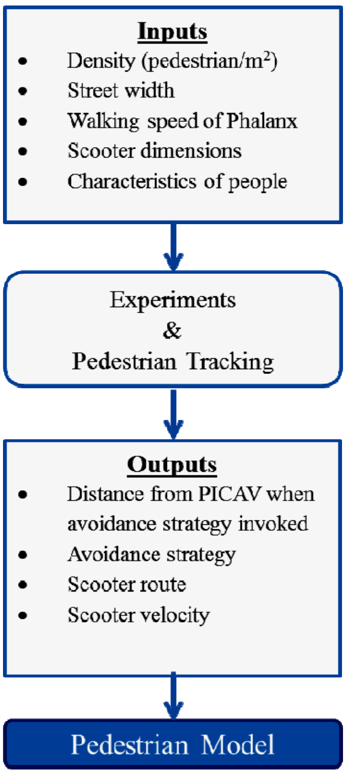

Figure 3: Flowchart of pedestrian modelling process

The PAMELA facility will now be described in section, followed by experimental methodology and a description the SiVic simulator.

PAMELA is part of the Accessibility Research Group (ARG) at University College London (UCL). It is a purpose-built unique space in which the pedestrian environment can be reproduced in detail. It consists of 82m2 of moveable platform, which can be raised/lowered/tilted to create the desired topography. The laboratory is explained in greater detail in Childs et al. (2007).

For these experiments, PAMELA is configured with 3 lanes: 1.2m, 1.4m and 3.6m wide. The interactions will be explored by asking a phalanx of people to advance towards a scooter along on of the lanes. The phalanx will consist of 9 people placed in three rows of three, in order to represent the widest controllable set of interactions between the crowd and the vehicle and between the members of the crowd (see Figure 4).

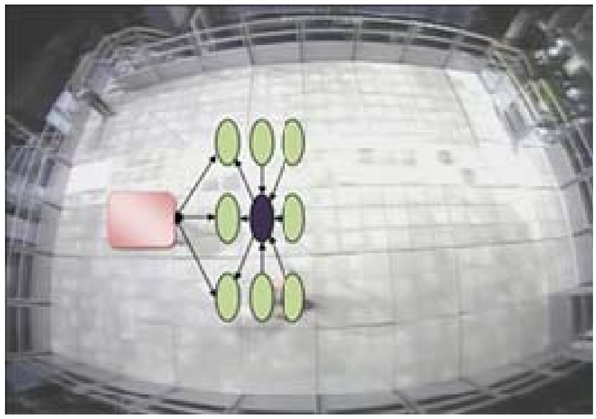

Figure 4: PAMELA laboratory configuration

The experiments will present the pedestrians under different density conditions in terms of the space within which they are set (to represent different street widths). The spacing between each pedestrian at the outset of each experiment is maintained constant (0.7m longitudinal, 0.3m transverse) in order to retain the same inter-pedestrian interactivity as far as possible. The phalanx will be instructed to proceed at different speeds towards the scooter and recordings made of the various routes taken by the pedestrians to avoid the vehicle. The spacing between each pedestrian is expected to change as a result of the interactions with the vehicle and these differences will be measured. In the first experiment the vehicle will be stationary, but in subsequent experiments the vehicle will proceed towards the phalanx at different speeds. There will be a total of six experiments (directions refer to the orientations inferred in Figure 4):

Table 1: PAMELA experiments: movement conditions

Experiment	Scooter movement	Phalanx movement
1	Stationary	Left
2	Right	Right
3	Right	Left
4	Right	Down
5	Right	Down, Up
6	Right	Left, Right

At present it is anticipated that the input parameters for the PAMELA experiments will be: Density (pedestrians/m^2), available space for dispersal (street width), walking speed of the phalanx, size of scooter, initial intended speed of scooter, characteristics of people. The outputs would be: dispersal profile of phalanx, dispersal profile of the central pedestrian (show in black in Figure 4), route of the scooter, and speed changes of pedestrians and scooter. Each pedestrian will be instructed to act individually i.e. they will not be travelling in groups. Therefore any platooning which does occur will occur due to the experimental conditions as opposed to social circumstances.

These outputs will form the basis for the calculation for pedestrian *viscosity*, something which will be used to calculate trip times in a later section of the project. They will also be used to develop general rules (heuristics) of pedestrian avoidance mechanisms. These heuristics will be used to program pedestrians in Sivic.

Furthermore, the level of service (LOS) of the footway for the pedestrians will be calculated. This will be done by measuring the space available to pedestrians (m2/person), the flow rate of the pedestrians (person/minute/m).

3.1. Process for pedestrian model

The pedestrian model will be constructed by creating a database of trajectories and velocities for each pedestrian and the scooter. This will be done using a combination of OpenCV and Python. The database will then be analysed to create a number of heuristics for modelling vehicle-pedestrian interactions in the built environment.

3.1.1. Automatic pedestrian tracking

The interactions will be recorded and evaluated using a combination of OpenCV and Python. OpenCV is a *library of programming functions for real time computer vision* and Python is *an interpreted, interactive, object-oriented, extensible programming language*. In the PAMELA experiments each of the pedestrians will wear a different colour hat to aid with automatic video detection and tracking. This will aid the automatic detection of people's routes. This should make creating the algorithms easier.

3.1.2. Pedestrian model

The pedestrian model contains all of the velocities and trajectories of the pedestrians and the scooter from the PAMELA experiments. These paths are used as an input to the simulation described in section 4. From these velocities and trajectories a set of heuristics will be created. They will include the minimum, mean and maximum distances from the scooter at which pedestrians begin to change their trajectory when approaching a vehicle given the following inputs: pedestrian density, speed of the vehicle and pedestrian characteristics. Finally a plot of average scooter speed against pedestrian density will be created so that accurate trip times can be measured.

4. SIMULATION OF THE MOTION OF SMALL VEHICLES

4.1. SiVIC (Gruyer 2005)

This simulator is a virtual sensors prototyping platform developed by the laboratory LIVIC (IFFSTAR). Its objective is to reproduce faithfully a real road scene, the dynamics of a vehicle and the operation of the onboard sensors.

Its main feature is to enable the same interactions as the ones onboard a real vehicle: steering wheel, acceleration, braking, etc. This can allow us to prototype some driving assistance solutions, to test this application in dangerous situations without any material risk to users, vehicle or other people and to reproduce scenarios.

To deal with complex scenarios, the simulator has a set of functionalities, such as onboard proprioceptive sensor model (odometer, accelerometer, gyrometers, ...) and exterior sensors (cameras, laser scanner, ...) and a management module of dynamic events. Pedestrians have been added to the SiVic environment and given velocities and trajectories of real pedestrians. These have been taken from the Genoa experiments.

4.2. Couplage of SiVIC and RTMaps (Gruyer 2006)

RTMaps is a fast prototyping software for real time multi sensor applications. It can easily retrieve and merge data from different sensors. Moreover, we can write and create easily computer programs using these data. Gruyer et al. (2006) have realized a coupling between SiVIC and RTMaps. This allows us to retrieve with RTMaps the data from a simulated sensor and test this on different scenario applications created with RTMaps. One of the RTMaps features is to test applications with data recorded during experiments. Then we can directly install these applications in the vehicle. The coupling between RTMaps and SiVIC allows us to test these applications with more and more complex scenarios as soon as we can create them in SiVIC. Once the application is validated on the simulator, we can directly test them in the vehicle. For this, we can use exactly the same computer programs written for RTMaps.

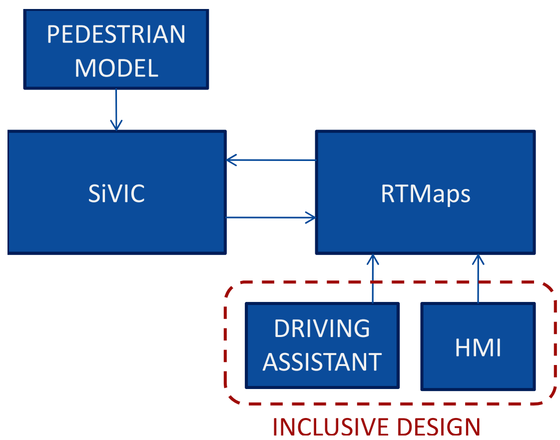

Figure 2: Inclusive Design process

This allows us to investigate different approaches to assistance for the driver of the vehicle, including the HMI, before taking the step of placing a person in the vehicle.

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AUTHORS BIOGRAPHY

Catherine Holloway graduated from the National University of Ireland, Galway in 2004 with a B.E. Industrial Engineering & information Systems (Design stream). She worked as a research & development engineer for Medtronic for 2 years before beginning her PhD with the Accessibility Research Group (ARG) at UCL. She completed her PhD on the effect of crossfall gradients on wheelchair accessibility in 2011 and is currently working as a post-doctoral researcher in ARG on the PICAV project.

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Professor Nick Tyler is the Chadwick Professor of Civil Engineering and Head of the Department of Civil and Environmental Engineering at UCL.

Nick works with clinical, engineering, social science, arts and humanities researchers in order to explore exactly how a person interacts with their immediate environment. Nick's research portfolio amounts to some £20 million in funding from Research Councils, industry and government and he has established research projects in Latin America, Japan, China and the EU as well as in the UK. Nick invented the Pedestrian Accessibility and Movement Environment Laboratory at UCL and as developed a line of research which is leading the world in terms of evaluation of built environments in terms of actual measurable impacts on humans. Nick was the Director of the MRC Symposium on Healthy Ageing and the Physical Environment in Beijing in 2010.

Nick is the Director of the UCL CRUCIBLE Centre, which is an interdisciplinary Research Centre for Lifelong Health and Wellbeing, funded by four Research Councils. He is a member of the UCL Council, the Joint Board of Moderators of the Engineering Institutions of the UK, the EPSRC Transformational Research Advisory Group and Member of the HM Treasury Infrastructure UK Engineering and Interdependency Expert Group. He currently has 7 PhD students (4 FT, 3 PT). Completions in the last 5 years are: Cognitive approach to accessible information systems (2002 – 2010), Microscopic simulation of pedestrians in 3D environments (2002 – 2009), Bus rapid transit systems and feeder routes – a micronetwork approach (2003 – 2009), Biomechanics of wheelchair propulsion.

Nick is a Fellow of the Institution of Civil Engineers and a Fellow of the Royal Society of Arts.