C. M. Herr, N. Gu, S. Roudavski, M. A. Schnabel, *Circuit Bending, Breaking and Mending: Proceedings of the 16th International Conference on Computer-Aided Architectural Design Research in Asia,* 229-238.

REAL-TIME POROSITY

Combining a computer game engine with environmental sensors to better understand pedestrian movement in public/private space and in real-time

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Abstract. This paper describes the theoretical context, design, implementation and evaluation of a novel method for understanding pedestrian movement in public/private space. It examines the pedestrian counting and tracking methodologies of Space Syntax and proposes an alternative methodology that links sensors embedded in real-world environments and carried by pedestrians with an environment and avatars in a contemporary computer game. In this way observers are able to closely trail pedestrians without affecting their decision making. Results from a field trial are presented where the sensors and computer gaming technology were tested within a challenging real-world environment.

Keywords. Pedestrian movement; public/private; Space Syntax; environmental sensors.

1. Introduction

Artist/Architect Richard Goodwin coined the term Porosity as it relates to the public and private space of the city in 1996 (Goodwin et al, 2006). Goodwin classified a series of private spaces as types of public spaces. These spaces reach from conventionally public spaces (streets, footpaths, plazas) deep into private space via lobbies, atria, elevators, corridors, waiting and restrooms. He notes that if a visitor is able to spend 15 minutes in the restroom on the 14th floor of a building (on their way to an appointment with their accountant for example) then the restroom should be considered a 15 minute public space.

With support from the Australian Research Council Goodwin conducted a major study from 2003-5 which created a snapshot of the Porosity of three major buildings in Sydney, Australia (Goodwin et al, 2006). In that project he extended the work of Space Syntax (Space Syntax Limited, 2008) by recognising that not all spaces are equivalent in terms of public access. In many cases this would reshape the graphs of Space Syntax by altering the number and topological relationships of the spaces under consideration (reconsider, for example, the Space Syntax map of London and their analysis of the Tate Modern art gallery (Vaughan, 2007). The three dimensional effects of this delimiting of space by public access can be seen in Goodwin's 'Cactus Models' (Goodwin, 2007).

In contrast to Space Syntax, at the core of Porosity is its transformation over time; implicated by the constant testing and renegotiation of public and private space through human use and aspiration. Ultimately then, we need to extend the single snapshot of the Porosity of the city to a sequence of snapshots so that we can better understand the way people move through it over time. But as opposed to animation, where there is a predetermined narrative, these snapshots should be able to be interrogated from many different points of view, in real-time. To be useful for understanding dynamic situations they should also be recorded and represented in real-time.

The challenge of understanding the movement of people through space is a particularly compelling one; not least because of the complexities involved and the growing list of applications such an understanding could support (Sangwan, Qiu, and Jessen, 2005; Behzadan et al, 2008; Foxlin, 2005; Krumm et al, 2000; Yan and Forsyth, 2005; Hightower and Borriello, 2001; Rolland, Davis, and Baillot, 2000). The particular application motivating this research is to develop a better understanding of pedestrian movement through a major urban subway station so that the relevant agencies are better able to make decisions relating to the design of urban infrastructure.

The strength of Space Syntax could be inferred by the sheer number of research projects that have applied its methodologies in dozens of cities and buildings around the world. Time and time again studies have shown a correlation between Space Syntax's metrics and pedestrian movement observed on the ground. But for the authors gaps begin to appear when one looks closely at the observational methodology employed by these studies. Space Syntax methods come in three forms; gatecounts, static snapshots and trails. Recently Kostakos (2010) described all three methods but while these descriptions answer many questions several key areas remain vague. Over the years a great deal of criticism has been levelled at the theories of Space Syntax (Ratti, 2004).

Somewhat surprisingly Ratti's thorough account does not mention pedestrian measurement methodologies or the accuracy of Space Syntax pedestrian counts. The authors argue that each method is pragmatically flawed in some way and that by extension any correlation to data gathered is equally suspect.

However, the authors suggest that the trailing methodology is the most robust of the three but that it too suffers from a lack of scalability. The desire to link individual level mechanisms with population level observation has promoted a drive towards pedestrian simulation by researchers in this area (Penn and Turner, 2001; Batty, Jiang, and Thurstain-Goodwin, 1998; Ratti, 2004). Pedestrian simulation may overcome the limit of scale but sacrifices the depth of information gathered and seems counter to the noted strength of Space Syntax; it aims to explain how cities *are* rather than how they should be (Kostakos, 2010).

On the surface it would seem that to trail more pedestrians one simply requires more observers. While it's clear that to have 500 observers following 500 pedestrians is not only impractical it would skew the behaviour patterns that arise from mechanisms such as flocking. The question becomes; how might one be present in a space alongside the pedestrian being trailed without actually being there and affecting the results?

In response to this question the authors have designed a system that captures the location of multiple pedestrians via Radio Frequency wireless sensors and translates them in real-time into a modified computer game environment that replicates their physical environment. In such an environment observers are able to trail pedestrians, observe them from many different points of view and are even able assume the pedestrians point of view ... all without a bodily presence in the real space, along with the influences that might create. Following preliminary testing within a laboratory environment the system was trialled within a major public space for further evaluation. This paper will describe the design and implementation of the system in detail and report on its current performance. The paper will conclude with notes on future work.

2. Aims of the research

In support of the overall goals of the Real-Time Porosity project, to record, represent and analyse Porosity in real-time (so that this understanding might influence architectural and urban design), the key aim of this experiment was to test an alternative to the trailing methodology developed by Space Syntax. For this experiment the researchers developed a novel link between the computer game engine CryENGINE2 and a Radio Frequency (RF) tracking system developed by the CSIRO. Previous research (Lowe and Goodwin, 2010) tested this linkage in a conventional office environment where the RF tracking technology was known to perform well.

3. Wireless ad-hoc system for positioning:

As is commonly understood GPS works well when the item to be tracked is visible from the sky but is severely limited in most indoor scenarios. In these circumstances other tracking, or localisation, systems are required. A number of techniques have been attempted and include video (Yan and Forsyth, 2005, Krumm et al, 2000), computer vision, inertial sensors (Foxlin 2005), WLAN (Behzadan et al, 2008), and RFID (Sangwan, Qiu, and Jessen, 2005); however none has been sufficiently successful. Video based techniques suffer from low resolution and perform poorly in crowded environments due to targets being obscured. Inertial techniques fail after a short time interval due to uncorrected sensor drift. Techniques using RFID require significant setup of infrastructure and techniques based on received signal strength have poor accuracy and don't adjust to changes in the environment; which are continual in environments of interest. That leaves as the only possible candidate the class of tracking techniques based on measurement of time of arrival (TOA) of radio signals. Up until now these have generally been rejected due to the difficulty of performing highly accurate measurements of TOA in indoor environments. Indoor environments, particularly in areas such as subway stations, suffer from multipath reflection whereby radio receivers obtain multiple copies of a transmitted signal due to reflections of the transmitted signal from multiple surfaces in the environment. These have varying delay and phase and combine to corrupt the original signal at the receiver.

The CSIRO has developed world leading technology that is able to perform accurate TOA based localisation in challenging radio propagation environments using low-cost hardware. This platform is called WASP (Wireless Ad-hoc System for Positioning) and was developed for applications including tracking athletes for performance monitoring and training, tracking fire fighters in large buildings to enhance their safety and tracking vehicles and people in underground mines for enhanced safety and productivity. Another feature of the WASP platform is that it was developed for rapid deployment in unknown environments. This set of features makes WASP ideally suited to the current application.

A radio localisation system consists of devices (often called tags) attached to the person being tracked, and devices (often called anchors or base stations) positioned at known locations that form the reference for tracking (these are analogous to the satellites in a GPS system). The hardware has been previously described in (Hedley et al, 2007) and the processing algorithms were presented in (Humphrey and Hedley, 2008) and (Hedley, Humphrey, and Ho, 2008). The remainder of this section provides a brief overview of WASP.

Two versions of the WASP hardware have been built, and are shown in Figure 1. Both have the same radio and signal processing electronics, however the larger node (115 x 90 x 55 mm excluding external antenna) has a larger 6.5 Ahr battery for longer life and greater connectivity options, while the small node (90 x 50 x 25 mm) has a 1.9 Ahr battery and a compact internal patch antenna. The radio operates in the 5.8 GHz ISM band with a transmit power of up to 100 mW and the receiver has a noise figure of 5 dB.

Figure 1: WASP node hardware, with tag on left and base station on right.

The accuracy achieved by the WASP depends upon the particular radio environment, however in indoor environments under line of sight conditions median error is usually better than 0.25 m. A custom communication stack was designed to support the particular requirements of accurate tracking and it also provides a data network with date rates up to 8 Mbps so that location data, and potentially other information, can be transported to a computer monitoring and recording the trial, and providing a real time display of tracked locations.

The technical requirement of the trial was to record the location of several research assistants wearing tags while moving about the subway station for subsequent analysis. The WASP setup required the installation of a number of fixed base stations around the station and required the location of these nodes. The location was determined by finding their XYZ coordinates in the previously constructed computer game environment of the station. The anchor nodes were positioned to be inconspicuous in the environment with a distribution supporting accurate tracking. This required that from any location on the station that there was a line of sight to at least four anchor nodes; satisfying this requirement lead to the installation of 14 base stations.

To enable the real-time display of the location of the targets in the gaming environment a monitoring computer connected to the WASP network was connected via Ethernet to an adjacent high performance computer. This computer was ran the gaming engine that displayed the tag (and hence target) locations.

4. Interfacing with the computer game engine using the Flow Graph Plugin System (FGPS):

Tracking the pedestrian is the first part of an alternative technique required to capture the deep information that a researcher would get by in person trailing. The second part is to translate that data into a form whereby the researcher is able to be co-present with the pedestrian being trailed. The use of contemporary computer gaming technologies for visualising, navigating and interacting with spaces and other users has been well documented and suits these purposes (Lowe and Goodwin, 2009; Sun, De Vries, and Dijkstra, 2007; Conroy Dalton, 2001; Shiratuddin and Thabet, 2002; Germanchis, Pettit, and Cartwright, 2005; Laing et al, 2007; McGrath and Hill, 2004). For this research the authors developed a unique extension of a contemporary computer game by linking AI controlled character movement within the computer game environment with pedestrians carrying RF sensors.

Game editors for Unreal Tournament 3 (UnrealEd by Epic Games) and Crysis Wars (Sandbox2 by Crytek) are provided by the developers and enable the creation of environments (or mods) that may be accurate facsimiles of real-world environments. In addition these two game editors provide a visual scripting mechanism to enable the creation of complex forms of interactivity (in Sandbox2 this is called the Flow Graph). In addition to modifying environments the community of modders for Crysis Wars have modified the Flow Graph within Sandbox2; one particularly significant mod is called the Flow Graph Plugin System (FGPS) (Ryan, 2009). The FGPS provides a mechanism for the game engine to read data from XML formatted files. The authors took advantage of this to link characters controlled by AI within the game environment to XYZ location data of pedestrians provided by RF sensors. To our knowledge this innovation remains unique. The link between the location data in the XML file and the AI controlled characters is as follows; the Flow Graph reads the XML file once per second then repositions a target with the XYZ coordinates it finds there and finally instructs an AI controlled character to head toward the target. Please follow the link below to download the necessary files, and setup instructions, to replicate this part of the experiment: www.russelllowe.com/publications/caadria2011/caadria2011.htm

Following this loop the AI controlled character may not reach the target before the target is repositioned (the WASP system is capable of providing coordinates at 20 Hz and in this field trial was delivering coordinates at 5 Hz) so there is, in effect, some smoothing of the data that is dependent on the 'physical' speed of a character in game. There is currently a one second lag between the pedestrian's position and the position shown by the computer game but this is an arbitrary interval and can be adjusted to provide the best balance between AI smoothing and short lag time.

The pedestrians in the field trial included members of our research team and members of our research partners, no members of the public were tracked in this study. Our pedestrians were tracked either singly or walking in pairs, in single file. The tests were conducted over four non consecutive days in July/August 2010. Three of the tests were outside of peak commuter periods (10am-2pm) with one during the evening rush hour (4pm-8pm). Estimated numbers of pedestrians on the platforms ranged from 100 people, off peak, to approximately 1000 people at peak. The performance of the tracking algorithm was quantitatively evaluated as follows. A person carried the node in a straight line parallel to the edge of the platform with a distance from the edge of approximately one metre. These pathways enabled benchmarking with known geometries.

5. Results, discussion and conclusion

The location of the node was tracked by WASP, and for each computed location the distance from a line one metre from the edge of the platform can be determined. This provides the errors perpendicular to the line, and under the reasonable assumption that the errors are isotropic, the errors parallel to the line have an identical distribution so we can estimate the total tracking error. The median error was 0.38 m, and 90% of the locations had an error of less than 1.05 m. The distribution of errors for this data had a large tail as there are a number of locations in this complex environment from which blockage by building structures prevented line of sight signals to sufficient anchor nodes to obtain a good geometrical dilution of precision (GDOP).

Due to the direct 1:1 relationship between dimensions in the virtual environment and those in the real world environment the XYZ positions of the targets inherit the level of accuracy delivered to them from the WASP monitoring computer. The smoothing effect created by the AI generated pathway serves to reduce error margins when the pedestrian is moving in a straight line, but may result in the avatar cutting corners from the pedestrian's pathway as they turn corners. This departure from the true path is limited by distance a pedestrian travels between each interrogation of the XML data by the computer game engine.

The ad hoc installation of sensors did cause some anxiety amongst the travelling public and could reasonably have been expected to alter their normal navigational patterns. But to achieve sufficient localisation accuracy in cluttered environments it was necessary to built a custom system, however with the development of standards and consumer electronics in the future it will be possible to track the mobile phones carried by most pedestrians. Future WLAN standards, such as 802.11ac already in development, will utilise many times the radio bandwidth of current standards. As mobile phones increasingly provide WLAN connectivity it will be possible to track the pedestrians using the high bandwidth WLAN signals from the mobile phones that they carry and a fixed infrastructure of custom anchor nodes. This will mitigate greatly the impact that carrying such a device would have on the navigational decisions of the pedestrian.

Recently a virtual world platform called Blue Mars (Blue Mars, 2010), which uses a version of the Crysis Wars game engine, advertised an option for over 4000 concurrent players. Future work will investigate this platform as an opportunity for expanding the numbers of pedestrians in the study (as well as the use of mobile devices, such as the iPad, to interrogate the resulting movement patterns). Other opportunities include feeding additional environmental data into the positioning algorithm. This research and the field trials demonstrated an alternative methodology to manual pedestrian counting, static snapshots and trailing. In addition to providing accurate positioning of pedestrians it provides an opportunity to be present in the space without being physically present in the real world environment. Further opportunities exist to extend the work into areas relating to hazardous environments (construction site visits for example) and other sensitive operational environments (such as the emergency departments in health care facilities). With massively multiplayer online environments such as Blue Mars utilising cloud computing to deliver compelling virtual worlds to mobile computing devices the future for automated pedestrian analysis using real world sensors and computer gaming technology looks very bright.

Acknowledgements

The research is jointly funded by the Australian Research Council (ARC LP 0991589), the University of New South Wales (UNSW), the Emergency Information Coordination Unit (EICU) and the Commonwealth Scientific and Industrial Research Organisation (CSIRO).

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