

Using RFID to Evaluate Evacuation Behavior Models

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Abstract - In this paper, we present an object-oriented approach for using real-world location data for the evaluation of evacuation behavior models. When constructing a new building or planning how an existing one will be used, safe evacuation is extremely important. Currently many models exist to simulate a building evacuation, using information from the layout of rooms in conjunction with a model for human behavior. However, it is difficult to automatically validate these models, since the exit of each person from the area to be evacuated must be recorded by human observers, either in real time or later by looking at video. We believe that the evacuation behavior model of humans requires a comprehensive approach that integrates psychology and engineering frames of reference. We describe the system in detail, and do experiments to show that it works as designed. We also show how this data can be used to validate an existing evacuation model.

Keywords- Intelligent Agents, Software Engineering, Computational experiments

I. INTRODUCTION

During emergency evacuation one cannot expect rational behaviour from users. The environment cannot be used in the way it was designed due to the nature of emergency. Designs of emergency exits are still confined to cues in the form of signage, lights and sound. Real-world data provides useful insight and statistical information that will give us the opportunity to deal with many interesting technical issues, concerning the creation and implementation of human behaviour models. There are few models [2, 3, 4] that are calibrated and validated on real data. Gianluca Antonini, Michel Bierlaire and Mats Weber in their paper "Simulation of Pedestrian Behaviour using a Discrete Choice Model Calibrated on Actual Motion Data" [12], have proposed a model based on a discrete choice theory for pedestrian dynamic behaviour. Their model is calibrated using data from actual pedestrian movement taken from video sequences. In order to verify the quality of the calibrated model, they have developed a simulator based on it. Data collection for pedestrian movement is often a tedious process. Individuals must be manually identified from video footage, and their exit times and locations observed and recorded by a person. We propose using Radio Frequency Identification, or RFID, to gather this data automatically.

RFID is a technology for detecting the presence of individual tags with a unique identification number. At the

University of Michigan, we have been experimenting with many different technologies to automatically locate people and objects in the computer science building. RFID is one of the technologies we've experimented with, and found that it works well to track individual people wearing tags as they cross thresholds, such as the entrances and exits to rooms or buildings. We present here a system based on RFID readers and tags that can be used to track users as they enter and leave rooms. The system places readers above doorway thresholds, and asks users to clip tags to the front of their shirt to allow tracking. We record this information in a flexible way that allows it to be used to validate or create evacuation models.

Development of a model of individual behaviour and social interaction to understand the urban and enclosed environment is very complex. A theory for individuals as distinct objects, representing behaviours is required. From this comes the idea of agent-based modelling. There have been many models that consider multiple aspects of human behaviour to facilitate the consideration of human factors in the design process. But nearly all are primarily concerned with people movement and its effects on evacuation. The few existing models known for simulating human behaviour are EVACNET4 [5], EXIT89 [6], EXODUS [7,8], HAZARD I [9], EVAS [10].

Through our research into human behaviour in experimental evacuation studies, we have developed a research simulation model called AvatarSim [1] for simulating human behaviour during emergencies and it is based on the geometrical vector based approach [11]. The approach makes it possible to consider both detouring and speed modifications in the collision avoidance patterns. Also sub-goal system is developed to allow people to effectively navigate around obstacles [1]. The simulation was created in the Java programming language and can be displayed as a Java Applet- a multi-platform program that runs in a web page on any type of computer operating system with a Java enabled web browser.

II. SYSTEM AND SOFTWARE DESCRIPTION

The system we built consisted primarily of an RFID reader and antenna connected to a laptop running interface software and a small analysis program, with participants wearing RFID tags. A summary of the system is in Table 1.

A. EPC RFID Hardware

EPC RFID is a technology that has developed over the last several years as a way of detecting tags which are within the range of an antenna connected to an RFID reader, using standards developed by EPCglobal [13]. Each tag has a unique ID, allowing it to be tracked individually rather than simply counted. The reader periodically sends out, through its antennas, a request for all tags to report back their ID numbers. The antennas relay the responses to the reader, which processes the information and relays it to a computer, over a serial or network protocol. In the event that multiple tags are within the field of the same reader, or that multiple readers are scanning the same area, an ant collision protocol goes into effect which makes it possible for all of the tags to be seen by all of the interested readers.



Fig 1: EPC RFID Readers

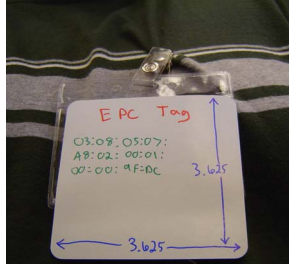


Fig 2: EPC RFID tags

Readers (refer Fig 1) and tags (refer Fig 2) for EPC RFID systems are widely available and relatively inexpensive, which makes them suitable for use on a large scale. We chose a Matrics RFID reader and tags for our system [14]. Traditionally, RFID technology has been used to track goods, not people. While there are certainly economic and cultural reasons for this, there is also a significant technological one: tags are very difficult to read when they are in close proximity to materials that absorb a large amount of radio frequency energy, such as water, which makes up most of the human body. In earlier experiments, we found tags to be unreadable from more than a few inches away when stuck directly on a shirt or inside a pocket. We found that getting the tag just a fraction of an inch away from the body makes a drastic difference, and so we affixed the tags to a ¼ inch thick piece of foam, clipped to participant's shirt.

In order to keep the antennas from interfering with normal walking habits, where possible we place them above drop ceilings. Orienting the antennas in the obvious way—pointing

them straight down—give poor results, probably since having the tags and antennas perpendicular exposes just a fraction of the tag's surface area to the antenna's field. Parallel to the tags seems to give the best results, but requires awkward antenna placement, since they must be at chest-height in front of the wearer. Pointing the antennas towards the door at approximately a 45 degree angle seems to give good results. It also adds a component of directionality; since the signal will not pass through the human body, if the tag is worn on the front of a person's shirt, it will only be seen when the wearer is facing towards the antenna. This helps us track users entering and exiting rooms: since users generally walk forward, careful antenna placement helps us to distinguish entrances from exits.

The Matrics system we used allows setting the power level of each antenna. We used this capability to tune the power level of the antennas until the tags could be seen just as the wearer left the room, but not while they were inside the room near the door. We found in earlier experiments that the readability of the tags depends on a number of factors, such as how the tag hangs on the body, so this tuning was an inexact science, and was accomplished largely through trial and error.

B. Software

To drive the RFID hardware, we developed and used the freely available *rfid-perl* [12] suite of modules and programs. This software provides a consistent interface to RFID systems, and currently has drivers for Matrics and Alien [15] systems, the two major EPC RFID systems. It provides real-time access to the data from the reader, making it suitable for the tuning and informal testing of configurations. The data can also be recorded, for later offline analysis.

The data provided by *rfid-perl* is a complete log of all data seen by the reader, output in a straightforward and consistent format. A user entering or exiting a room will typically be sighted several times by a variety of antennas. In order to process this data into a few discrete events, we wrote a simple program to read through the recorded data, and output room exit times. This program consolidated multiple reports from the exiting antenna into a single exit event, occurring at the time of the first sighting. It also recognized a manually inserted marker statement, indicating the time when everybody was in the room.

III. EXPERIMENTS

To do preliminary validation of our system, we did a set of small, proof-of concept style experiments. We monitored the exits of 5 participants from two doors of a classroom here at the University of Michigan.

A. Setup

We installed our Matrics RFID reader above the drop ceiling between the two exits from the classroom. We attached antennas, and placed two of them in the ceiling directly outside of the classroom doors, about 3 feet away, aimed

TABLE I
System and Software Summary

- **RFID Reader:** Matrics EPC RFID reader.
- **Antennas:** two 28.25 x 12.5 inch 900MHz antennas above drop ceilings in the halls, about 3 feet from the exits, pointed towards door at about a 45 degree angle.
- **Tags:** 3.625 x 3.625 inch Matrics EPC RFID tags mounted on a ¼ inch Styrofoam backing, clipped to fronts of shirts
- **Software:** Reader connected to laptop running *rfid-perl* software; a small custom-written program summarizes RFID readings into exit events.

towards the door at an approximately 45-degree angle. We tuned the power levels of the antennas so that users were consistently detected leaving the room, but were generally not detected inside the room near the doorway. The RFID reader was connected using RS-485 and USB to a laptop computer *rfid-perl*.

Tags were attached to a ¼ inch foam backing then clipped to the shirts of our five participants, all University of Michigan graduate students. The participants were asked to disperse throughout the area surrounding the classroom until instructed to “Go,” at which time they entered the classroom as they would if going to class. We waited a brief time, and then asked them to “Evacuate,” and they exited the classroom as they would during a fire alarm. We recorded by hand the time of the “Go” instruction, the time when everybody was in the room, the time of the “Evacuate” instruction, the time when everybody had evacuated the room, and which exit each person chose. We repeated this for 4 trial runs.

We recorded the output of the *rfid-perl* monitoring program during these runs, and afterwards ran our simple analysis program on the data to get a list of who exited from which door, and at which time.

B. Results

To see how accurately our system recorded what happened in the real world, we compared our notes about who had exited through which door with the output of our analysis program. The results are presented in Table II.

For the most part, the results from the RFID system accurately reflected reality: in our experiments, the first two trials had 80% accuracy, and the last two had 100% accuracy. The tag worn by Participant 3 was not detected by any antennas at all during the first two trials, while the other tags were detected an average of 12 times per run during these two trials. That leads us to believe that this tag was not behaving reliably; unfortunately our sample size was too small to know whether this was an anomaly or a problem that needs to be addressed.

TABLE II:
RFID-measured final exit times and human-observed “all clear” times

Participant	Trial 1		Trial 2		Trial 3		Trial 4	
	Real Exit	RFID Exit	Real Exit	RFID Exit	Real Exit	RFID Exit	Real Exit	RFID Exit
User 1	1	1	2	2	2	2	2	2
User 2	2	2	1	1	2	2	2	2
User 3	2	-	2	-	2	2	2	2
User 4	2	2	2	2	2	2	2	2
User 5	1	1	2	2	2	2	1	1
Accuracy	4 / 5 80 %		4 / 5 80%		5 / 5 100%		5 / 5 100%	

times per run during these two trials. That leads us to believe that this tag was not behaving reliably; unfortunately our

sample size was too small to know whether this was an anomaly or a problem that needs to be addressed.

IV. SIMULATION AND VALIDATION

AvatarSim is based on multi-agent technology and we are interested in exploring the enhancement model of agent’s behaviour with more “human-like” decision making strategies than are presently available. Our aim is to build a model that would exhibit more realistic simulation behaviour. The issue of validation of a model is extremely important. The agents we are designing in some sense are unpredictable, in the same way people are. The question then arises is as how to differentiate between agents that are human-like and those that behave in other ways.

In this case a descriptive form of validation is most appropriate. i.e. to take data from studies of real humans and compare with the agent behaviour. We have designed AvatarSim model to predict the outcomes by predicting behaviour. If the behaviour of individual agents in a small-scale can be validated, we hope that the results will be scalable. For validating AvatarSim we are considering number of methods:

- Human-in-loop testing, where one of the agents in a system takes place of a human and evaluates whether or not the agents would behave as another human would.
- Analysis of a data trace of a human through RFID detection and comparing it with agent model.
- Comparison of a trace of an agent performing an evacuation task with one from a human performing the same task.

For all these methods, the complexity lies in explaining the differences. For example we can’t expect exactly the same trace from two different people on a complex task. Similarly we can’t expect the same trace from one of the agent and a human. Perhaps behavioural experts are in best position to make a judgment, with their diverse knowledge and background in human behaviour.

The fig 4 shows an evacuation behaviour simulation for AvatarSim that is modelled based on real time experiment conducted inside a class room at University of Michigan to depict behaviour of people inside a room. Fig 4 depicts a simple 3800mm X 7500mm room layout with benches and tables as static obstacles and moving people as dynamic obstacles. In the simulation an input file is used to define the number of avatars, min and max speed, wait time etc. There are two exits (goal 0, and 1). Until the simulation is complete (all the people exit the class room), the applet continues to update the number of people exited inside the class room. The rate of flow (people/sec) for each goal also gets updated. The dynamic line graph in the applet helps in visualizing and comparing the rate of flow of avatars in .1 time interval for all exits (goals). The graphs for Avatar Simulation aids in providing real-time visualization of rate of flow of avatars for each goal as the time progresses.



Fig 3: Evacuation scenario using RFID tags

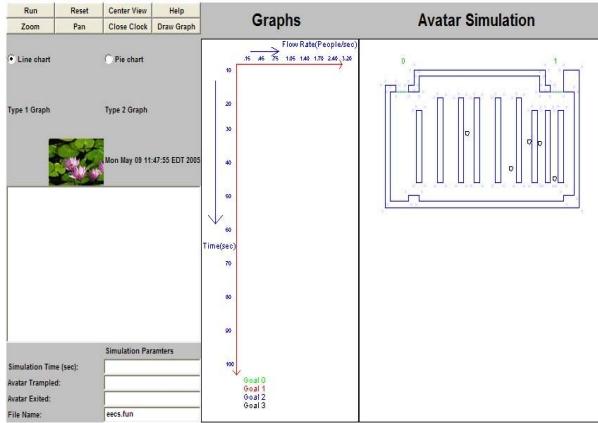


Fig 4: AvatarSim Simulation modelled on the RFID tag experiment.

With the agents placed inside the room according to observations made during the RFID tag experiment, we found that the evacuation times were similar for the four simulation runs. The time required for escape is an essential part of performance-based design. Also important are the interactions between pre-movement and behaviours for all individual occupants. Once a warning has been given to the building occupants, evacuation scenario with a series of initial behaviours (the pre-movement time) followed by movement into and through escapes routes (the travel time) is observed. The characteristics of agents are similar in all the four simulation runs and we have observed different simulation times if the same experiment is run on multiple occasions. The agents show the some sense of unpredictable ness as people do. The comparative data is shown in table III below.

TABLE III
Simulation times from RFID and AvatarSim

S. No.	Simulation Time through RFID tags (sec)	Simulation time through AvatarSim (sec)
1.	28.6	21.2
2.	21.2	18.3
3.	22.1	28.2
4.	27.2	19.4

The simulation was tested in several sample situations and it shows that the parameters of the algorithm could be adjusted

to obtain a realistic and efficient collision avoidance behaviour and evacuation behaviour. However, some enhancements are to be still implemented before this model can realistically describe the complex patterns characteristic of crowd behaviour.

V. CONCLUSIONS

Based on our experiments, we conclude that RFID is an effective tool for recording individual room exits in an evacuation. We were able to detect which exit each person left through, as well as the time they left, with good reliability. The results were gathered automatically by the system, and once the software was written, required very little time to process. Because of this efficiency and because adding more users requires little additional cost or time, we expect this technique to be very useful for large-scale evacuations, such as a multi-storey office building or a stadium.

We were also able to reliably and efficiently tell which user evacuated through which door. The ability to uniquely identify users makes it possible to correlate an evacuee with information about that individual, such as demographic data or that person's familiarity with the area being evacuated. Our system also recorded exit times, which are useful for quickly and accurately calculating the flow of people through the doors, and figuring out how long it took individuals to get out of the building.

By incorporating experimental data into the AvatarSim model, it was found that the evacuation time was comparatively same for the five simulation runs. The parameters like speed, mass, wait-time of the agents in the model could be adjusted to produce real-time simulations. We also compared the performance time required for escape through the exits for the agents to the real-time experiment and found that that the parameters of the algorithm could be adjusted to obtain a realistic simulation. We hope that the results of AvtarSim will be scalable if the behaviour of individual agents in a small-scale can be validated. With additional sensors, it would be possible to track a user's progress through a large building. Both of these could provide useful insights into evacuation-patterns.

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VI. FUTURE WORK

The next step is to conduct similar experiments on a larger scale, with a larger area being evacuated and with more participants. That would further validate our system and model, and help us learn more about its abilities and limitations. Larger scale data would also be useful for validating computer evacuation models, both our own and others. Finally, combining more data with information about the individuals evacuating would allow us to look for patterns in evacuations, and possibly lead to new models, either through intuitions gained from looking at the data, or else through a statistical analysis of the data itself.

By using additional sensors, we expect we could gather additional location information that would be useful for additional insight into evacuation patterns, and to correlate other location information to evacuation information. For example, sensing a user entering a stairwell on a particular building floor would let you know which floor they were coming from, and knowing the times when they entered the stairwell and left the building allows a more detailed model to be analysed or created. Another example is correlating entrance data with exit data, to see whether a user is more likely to evacuate through the same door they entered through.

Other location sensing systems are available which provide more precise location information, at the expense of higher per-user costs. Two notable systems we may investigate in the future are UbiSense [20] and Ekahau [21]. Ubisense provides sub-meter location accuracy, enough precision to closely monitor a user's path during an evacuation. It would be able to record false starts and other in-room movement, and also track how many people are near a room's exits. Ekahau provides 3-5 meter accuracy, and would be useful for tracking in a larger building or stadium, where this level of accuracy is useful for plotting a user's rough course through a building. Location information from systems like these could provide an even richer set of location information to analyze evacuation models and create new ones. However, the costs would be prohibitive for extremely large-scale experiments.

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