Measurement techniques for unannounced evacuation experiments

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Abstract There are many available measurement techniques for documenting people's movement patterns, but not all of them are appropriate for unannounced evacuation experiments. An unannounced evacuation requires that participants are not influenced beforehand. In addition, experiments are performed in all types of buildings and low ceiling height is often a problem. This paper describes three techniques that can be used for unannounced evacuation experiments, namely (1) filming from above – cameras with wide angle lenses, (2) triangulation with two cameras, and (3) distance measurement with a laser scanner. The description is based on the results from a research study in which the three measurement techniques were tested and evaluated. The study also involved collection of data in unannounced evacuation experiments.

1. Introduction

Many previous studies have examined the use of measurement techniques for documenting people's movement patterns [1,2,3,4,5]. Examples of proposed techniques include video recording [2], infra-red sensors [3] and radio frequency identification (RFID) [4]. Many of the techniques require that specific conditions are met in order to ensure high validity of the measurements. For example, the use of RFID requires that antennas are placed at appropriate locations and that tags are somehow planted in the crowd. A very common data collection technique is to film the movement of people from above with ordinary video or CCTV cameras. In order to get the best accuracy with this technique the cameras should be placed relatively high above the floor and point directly downwards. This basic method has been used numerous times to collect valuable data, such as data on the movement of people in open spaces during the Hajj [6].

Many existing measurement techniques require that specific conditions are met, e.g., that cameras are placed relatively high above the floor. These types of necessary preconditions may not always be possible to achieve in unannounced evacuation experiments, i.e., experiments where the participants are not informed about the evacuation beforehand. It is argued that an unannounced evacuation experiment is the best ways to get valid data because participants are not aware that they are taking part in an experiment [7]. From the viewpoint of the participants the situation is potentially a real emergency and they therefore act as they would have done in a real situation, e.g., similar walking speeds and movement patterns.

Unannounced evacuation experiments are most often performed in real buildings and very seldom in artificial laboratory environments. This means that the design of the building will influence the type of measurement techniques that can be used. One of the biggest difficulties is low ceiling height, which is a problem in almost all types of buildings. Low ceiling height makes it difficult to use the most basic method of filming the crowd from above. Instead it is often necessary to film the crowd from an angle. It is possible to get useful trajectory data even if the camera is not placed directly above [8], but these techniques are in some cases associated with big measurement errors [9].

Another limitation of unannounced evacuation experiments is that the participants can not be influenced beforehand. If they are influenced in any way, e.g., tagged or marked, they may suspect that something is going to happen, which would lead to low validity. Measurement techniques that rely on manipulation prior to the experiment, e.g., giving transmitters to people (RFID), will therefore not be appropriate for unannounced evacuation experiments.

The discussion above clearly illustrates that there is a need to develop and test techniques that can be used in unannounced evacuation experiments. In this paper, three techniques that were included in a study[1] at Lund University are described. The objective of the study was to explore the use of different measurement techniques for documenting people's movement patterns and to collect trajectory data using selected techniques. This paper describes the study and the three tested techniques, but collected data are not presented. The data will, however, be made publicly available at www.brand.lth.se/research in summer 2010.

2. Measurement techniques

The research study at Lund University began in autumn 2007 and was completed in spring 2010. One of the objectives of the study was to test and evaluate measurement techniques for unannounced evacuation experiment, but also to collect data. Experiments were performed both to calibrate the tested measurement techniques (calibration experiment) and to collect data (data collection experiment). A complete list of all experiments that were performed in the study can be found in Table 1.

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[1] The study was funded by Brandforsk, Sweden.

The first step of the study was to make an inventory of existing measurement techniques that could potentially be used in unannounced evacuation experiments. The two most important selection criteria were (1) that the technique would not require that the participants were influenced before the experiment, and (2) that the technique would be possible to use in spite of low ceiling height (ca 2.4 to 3.5 meters – standard ceiling heights in Swedish buildings). Based on the inventory three measurement techniques were selected for testing:

- Filming from above – cameras with wide angle lenses (*Standard method*)
- Triangulation using two cameras (*Triangulation*)
- Measurement of distance to people with a laser scanner (*Laser scanner*)

Only the actual measurement technique was evaluated in the study, and limited consideration was taken of the data acquisition process, i.e., how the data can be effectively collected and stored. Other studies have focused on such aspects as automatic data collection from video footage (see for example [1] and [6]), but this was not the focus of the present study. However, the three studied measurement techniques should ideally be combined with these types of automatic data collection methods to reduce the work load for the researcher.

Table 1. Experiments in the study at Lund University (autumn 2007 – spring 2010)

No.	Location	Year	Type of experiment	Description	Tested technique(s)
1	School of Economics and Management, Lund University, Lund, Sweden	2008 (Apr)	calibration, data collection	Movement on spiral stairs (balcony to ground level); *unannounced evacuation*	standard method, triangulation
2	IKEA, Helsingborg, Sweden	2009 (May)	calibration, data collection	Movement around a pillar and a display (furniture); *unannounced evacuation and normal use*	standard method, laser scanner
3	IKEA, Malmö, Sweden	2009 (Jun)	data collection	Movement around a pillar and a display (furniture); *unannounced evacuation and normal use*	standard method, laser scanner
4	Civil engineering building, Lund University, Lund, Sweden	2009 (Oct)	data collection	Movement through an opening; *unannounced evacuation*	standard method, triangulation
5	Civil engineering building, Lund University, Lund, Sweden	2009 (Oct)	calibration	Laboratory experiment to determine the accuracy; *no participants*	standard method, triangulation
6	Civil engineering building, Lund University, Lund, Sweden	2009 (Nov)	calibration, data collection	Movement through an opening (width varied); *announced evacuation (laboratory experiment)*	standard method, laser scanner

2.1 Standard method

Filming from above (called the standard method in this paper) is one of the most common measurement techniques. The technique is particularly useful if the cameras can be placed relatively high above the floor. However, problems arise when the ceiling height is low, which is the case in most buildings. For these types of settings it is often necessary to use an array of cameras and also to use optical lenses with short focal length (wide angle lenses). An example of images from an array of cameras is shown in Fig. 1. The images in Fig. 1 were taken during the initial calibration before the experiment at IKEA in Helsingborg, Sweden (experiment 2). By combining the images from the different cameras it was possible to trace the walking path of each participant in the experiment.

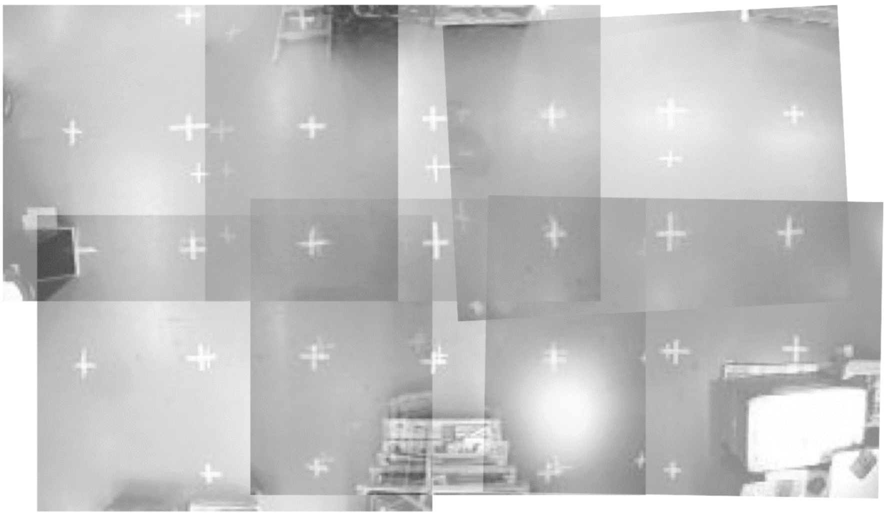

Fig. 1. Images from an array of cameras at IKEA in Helsingborg, Sweden (experiment 2)

As mentioned previously, the standard method often requires the use of wide angle lenses if the ceiling height is low. The cameras that were used in the study were therefore equipped with a wide angle lens in the experiments (see Fig. 2). The main benefit of using wide angle lenses is that a bigger area can be covered by the camera, but the big disadvantage is that the image becomes distorted. Fig. 2 shows the distorted image captured by a camera with a wide angle lens when filming a 2D grid with cells of equal size (0.10 m x 0.10 m).

In the experiments where the standard method was used (experiments 1 to 6) a grid was first marked on the floor. This grid was then filmed for a short time period before it was removed. In the analysis of the video footage the grid was then used to determine the position of each participant as he or she moved through the area of interest. This was a relatively simple task for the experiments at IKEA (experiments 2 and 3), but was much more difficult for the other experiments (experiments 1, 4 and 6). The reason for this was that the population density was low in the experiments at IKEA which made it easy to determine exactly where the people were standing (called original approach, see Fig. 3). The density was much higher in the other experiments which made it difficult to see exactly where people were standing. An alternative approach was therefore used for cases with high population densities (see Fig. 3).

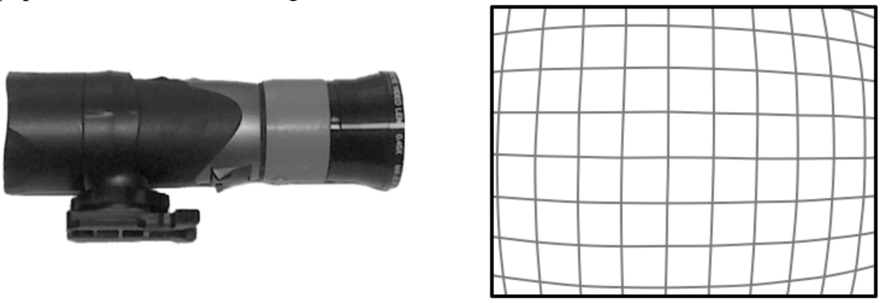

Fig. 2. Camera used in the experiment (left) and the distortion of the image with a wide angle lens (right)

The first step of the alternative approach was to determine exactly where the camera was pointed in the experiment. The direction of the camera was calculated based on the grid that was marked on the floor in the beginning of the experiment. Once it had been determined exactly where the camera was pointed it was also possible to calculate the vector from the camera to a person, namely to the centre of the upper torso of the person (between the shoulders). In these calculations the distortion of the image (see Fig. 2) was taken into account.

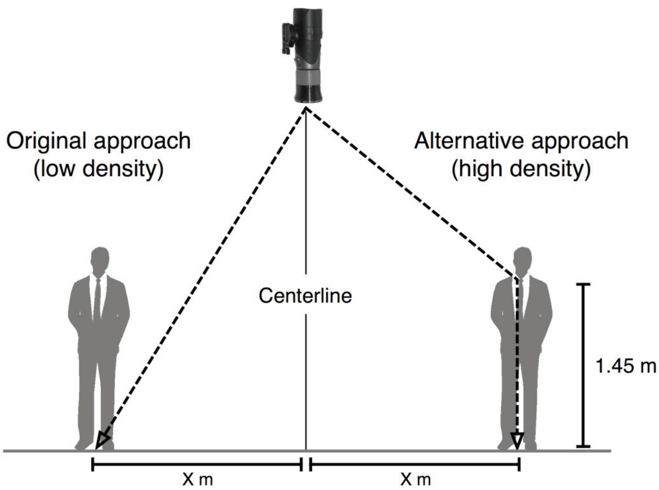

Fig. 3. The approach used to determine the position of each participant for low densities (experiment 2 and 3) and high densities (experiment 1, 4 and 6)

Finally, it was determined where the vector crossed the horizontal plane at the height of 1.45 meter, which approximately corresponds to the shoulder height of a person (Fig. 3). The point of intersection provided a reasonable estimate of the position of the person. This approach is similar to the calculation procedure used in the computer program called Persias [8].

2.2 Triangulation

The second measurement technique that was evaluated in the study involved triangulation using images from two video cameras. In the experiments the two cameras were placed close to the ceiling to get the best possible overview of the crowd. The position of the cameras and their direction was carefully documented since this information is important for the triangulation calculations. In most cases, wide angel lenses were used and the cameras were placed at a height of approximately 2.3 to 2.5 meters. Fig. 4. shows the location of the cameras in one of the experiments at Lund University (experiment 4).

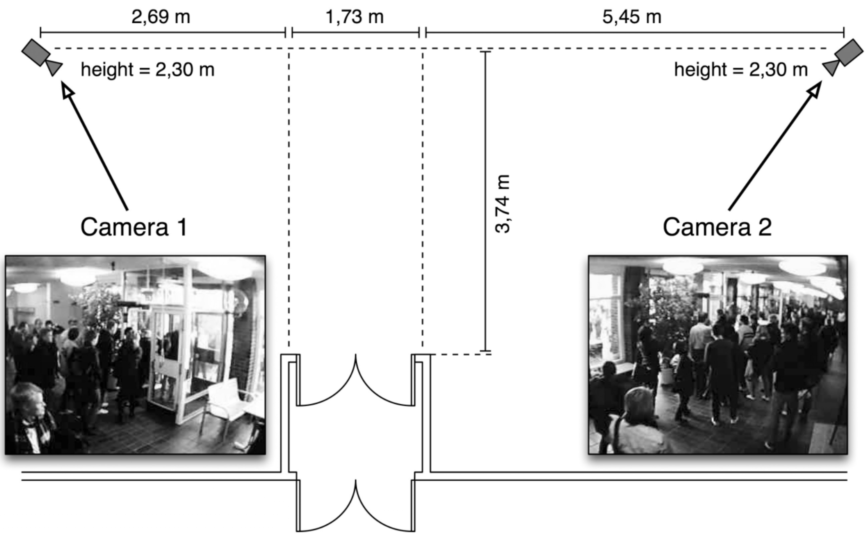

Fig. 4. Triangulation with two video cameras (experiment 4)

In order to find the position of a person the person was first identified in the images from both cameras. The line that extended from each camera to the person (the head of the person) was then identified, taking the distortion of the image into account. Finally, the person's position was determined by finding the intersection between the two lines. In most of the experiments, triangulation generated results with reasonable accuracy. The main advantage of the technique is that it does not only provide the position (x- and y-coordinates) but also the height of the person (z-coordinate). However, a serious disadvantage is that it is often difficult to correctly identify a person in the two images, which is partly due to the fact that people are often obscured by others.

2.3 Laser scanner

The third measurement technique involved measurement of the distance to people with a laser scanner. The scanner that was used in the study was a LMS221 from SICK [10]. LMS221 performs measurements of the distance in a plane (2D) and the maximum scan frequency is 75 Hz. The field of view is 180° and the angular resolution can be set to 0.25°, 0.5° or 1.0°. LMS221 uses the time of flight of laser light (infrared "eye-safe" laser) to calculate the distance. The laser light (pulse) is sent from the scanner via a rotating prism and is then reflected back to the scanner when it encounters an object. The output from LMS221 can be presented as a scan line that displays the distance to obstacles, e.g., people (see Fig. 5).

The laser scanner was used in two different ways in the study. In the experiments at IKEA (experiments 2 and 3) the scanner was fitted in a pillar and scanned along a horizontal plane (Fig. 5). The height of the plane was 1.3 meters above the floor, which corresponded to the height of the torso for most of the adult participants. In the experiment at Lund University (experiment 6) the scanner was instead attached to the ceiling and scanned along a vertical plane in the door opening. A similar approach has been applied by Walkow [5] who used two scanners to also get information about the speed and direction of travel.

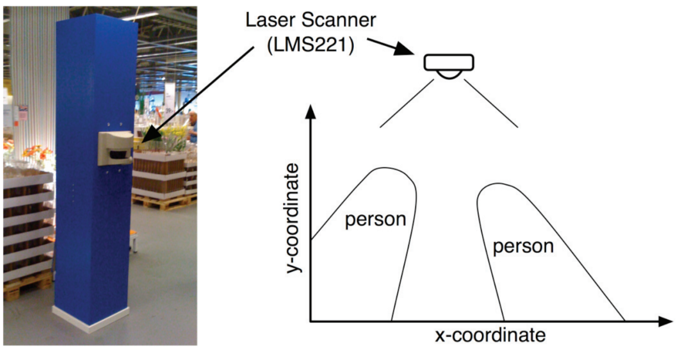

Fig. 5. LMS221 in a pillar at IKEA (left) and a distance profile from the scanner (right)

The laser scanner generated highly accurate data. One limitation of the approach used at IKEA (horizontal plane) is that it can only be used for low densities. Also, the approach that was used in the experiment at Lund University (vertical plane) needs to include an additional scanner to provide more useful data.

3. Conclusions

All three measurement techniques were able to estimate people's position with reasonable accuracy. However, all techniques were also associated with limitations that need to be considered. Difficulties typically arise when the population density is high, since people are easily obscured by others. This problem can partially be addressed with multiple cameras/scanners, but this option was not explored in the present study. Based on the study it is concluded that all the tested techniques can be used in unannounced evacuation experiments. Measurement of the distance with laser scanners is the technique that is believed to have the greatest potential and therefore should be developed further. More specifically, it should be investigated if and how may scanners can be used together to track walking paths and to collect trajectory data.

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