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Estimating Pedestrian Accident Exposure: Automated Pedestrian Counting Devices Report

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# ESTIMATING PEDESTRIAN ACCIDENT EXPOSURE

## Automated Pedestrian Counting Devices Report

March 2007





The mission of the UC Berkeley Traffic Safety Center is to reduce traffic fatalities and injuries through multi-disciplinary collaboration in education, research, and outreach. Our aim is to strengthen the capability of state, county, and local governments, academic institutions, and local community organizations to enhance traffic safety through research, curriculum and material development, outreach, and training for professionals and students.

## ESTIMATING PEDESTRIAN ACCIDENT EXPOSURE

### Automated Pedestrian Counting Devices Report

Prepared for CalTrans under

Task Order 6211

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# 1. PREFACE

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## 1.1. Purpose of the Review

Automated methods are commonly used to count motorized vehicles, but are not frequently used to count pedestrians. This is because the automated technologies available to count pedestrians are not very developed, and their effectiveness has not been widely researched. Moreover, most automated methods are used primarily for the purpose of detecting, rather than counting, pedestrians (Dharmaraju et al., 2001; Noyce and Dharmaraju, 2002; Noyce et al., 2006).

Automated pedestrian counting technologies are attractive because they have the potential to reduce the labor costs associated with manual methods, and to record pedestrian activity for long periods of time that are currently difficult to capture through traditional methods. Data input and storage may also be less time consuming than with manual methods.

On the other hand, the capital costs of automated equipment may be high; specialized training may be required to operate it; and automated devices are generally not capable of collecting information on pedestrian characteristics and behavior. For these reasons, automated devices are not appropriate for all pedestrian data collection efforts.

The choice between which method is more appropriate to collect pedestrian data must be based on the accuracy level desired, budget constraints, and data needs specifications.

## 1.2. Automated Counting Technologies

Much of the research on automated pedestrian tracking devices has focused on pedestrian detection, not pedestrian counting. Extensive reviews of pedestrian detection technologies were conducted by Noyce and Dharmaraju (2002) and by Chan et al. (2006). Technologies include piezoelectric sensors, acoustic, active and passive infrared, ultrasonic sensors, microwave radar, laser scanners, video imaging (computer vision).

Of the technologies listed above, those most adaptable to the purpose of pedestrian counting are: infra-red beam counters; passive infrared counters; piezoelectric pads; laser scanners; and computer vision technology. None of these devices are widely used for the purpose of counting pedestrians outdoors, but all have some potential to be adapted for that purpose.

This report describes each of these technologies in detail, and discusses some of the technical strengths and weaknesses of each method. It is important to be aware that technical limitations are only one consideration among many when choosing an appropriate counting device. The device “packaging,” such as the method and location of installation may be equally important. For example, the location and accessibility of the device may create liability issues or promote vandalism.



## 2. BACKGROUND

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Automated pedestrian counting capabilities have been developed for a variety of purposes such as traffic planning, retail customer volume statistics and security monitoring. Most of the existing products are developed for indoor environments (e.g. shopping mall, casino, subway station and building entrance etc) or outdoor environments with low density pedestrians (e.g. trails and parks). A few projects have attempted to compare alternative technologies for use in the same environment, but most of published references have focused on individual technologies.

Central London Partnership (CLP) has conducted a project on automatic pedestrian counting technologies to better understand and potentially demonstrate existing products in the outdoor London environment (CLP, 2005). They identified and are testing three commercially available pedestrian counting technologies: computer vision, passive infra-red and vertical laser scanners. They are also conducting manual pedestrian counts to verify the results obtained from automated technologies.

Schneider et al. (2005) presented case studies of pedestrian and bicycle data collection efforts in local communities. Although the purpose of the study was not to evaluate different automatic pedestrian counting technologies, it includes case studies involving different automated counting methods, such as passive infra-red, vertical laser scanner and piezoelectric pad. These devices were used largely in low-density pedestrian environments such as bicycle and pedestrian paths.

The Minnesota DOT sponsored the evaluation of a variety of commercial off-the-shelf (COTS) bicycle and pedestrian detectors as part of a broader project to evaluate traffic detection systems (SRF Consulting Group, 2003). Their report included an extensive literature review on bicycle and pedestrian detection technologies, and they tested four such systems under low volume conditions on a bicycle and pedestrian pathway. Their tests showed that three systems were 100% accurate (one video, one passive IR and one combined ultrasound and passive IR), while one system was 93% accurate (active IR), however they were only presented

with one target bicycle or pedestrian at a time, in a simple environment without any significant disturbances.

The University of North Carolina also tested a variety of COTS pedestrian detectors for their ability to automatically trigger walk signals (Hughes et al., 1999). They discussed the issues involved in automatically triggering walk signals, but did not emphasize the strengths and weaknesses of the different detection technologies (Hughes et al., 2000). An analogous study in Israel was reported by Hakkert et al. (2001), again focusing on pedestrian detection but with only passing references to technical performance limitations of the two detection systems that were tested. Note that all of these evaluations have addressed the need for simple detection of pedestrian presence (Is there a pedestrian here?), but not counting how many pedestrians are present or crossing.

The following sections describe technologies that have potential to count pedestrians in an outdoor environment:

- ✓ Infra-red beam counters
- ✓ Passive infrared counters
- ✓ Piezoelectric pad
- ✓ Laser scanner
- ✓ Computer vision

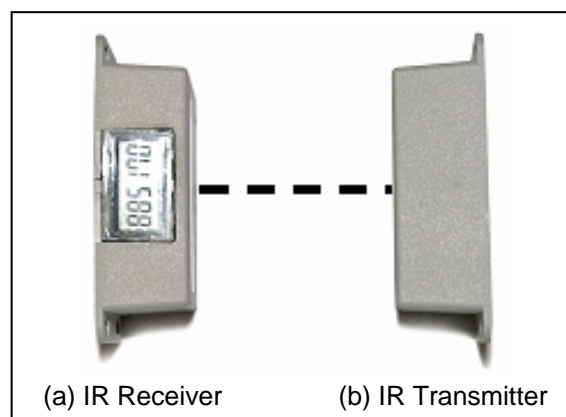
### 3. INFRA-RED BEAM COUNTERS

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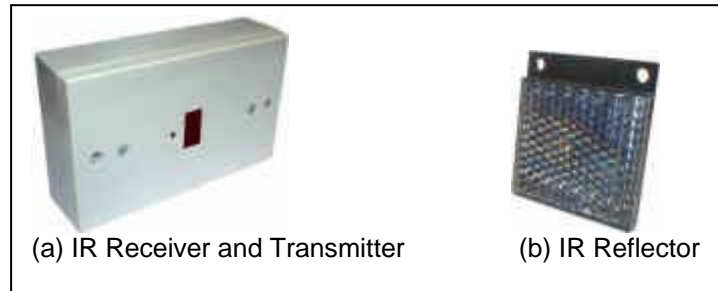
Infrared beam counters are one of the most popular types of commercially available counters. The counter is a simple device with low power consumption that can be powered by batteries. It is a popular pedestrian counter for indoor settings.

An infra-red light beam counter is composed of following components: an infra-red beam transmitter, an infra-red beam receiver and a data logger. The transmitter emits a constant infrared beam that is intercepted by the receiver at an appropriate position. When the beam is interrupted by a solid object passing through, a count is registered by the data logger. Infrared beam counters typically operate at a range of around 30 meters.

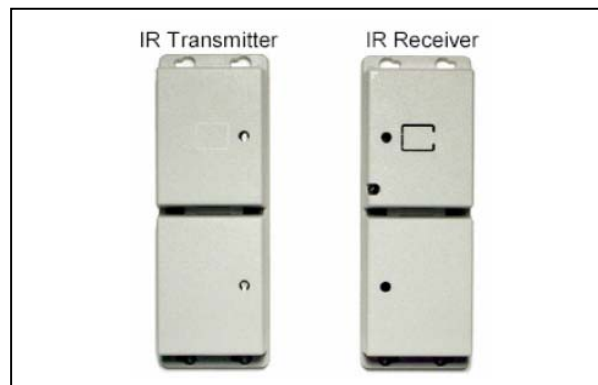
There are three types of infra-red beam counters. Figure 3.1 shows the infra-red beam counter with separated infra-red beam transmitter and receiver. Figure 3.2 shows the infra-red beam counter with transmitter and receiver in the same housing. A separate reflector is used to bounce back the infra-red beam. Figure 3.3 shows the infra-red beam counter with a two beam setup that can provide the pedestrian traveling direction.



**Figure 3.1: Infra-red beam transmitter and receiver**



**Figure 3.2: Infra-red beam transmitter/receiver and reflector**



**Figure 3.3: Infra-red beam counter with directional counting**

The following are some of the major drawbacks of infrared beam counters:

1. Infrared beam counters cannot differentiate between pedestrians and other objects. Vehicles, insects flying close to the transmitter, or even rain drops could block the counting beam and trigger the counter;
2. The transmitter and receiver need to be aligned carefully to ensure the reception of the beam at the receiver end. If either the transmitter or receiver are installed on a flexible structure, strong winds or other disturbances could cause the beam to miss the receiver;
3. When several pedestrians cross the counting beam simultaneously, they are only registered as one count.

## 4. PASSIVE INFRARED COUNTERS

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Passive infrared devices count pedestrians by tracking the heat emitted by moving objects. The earliest infrared counters were based on CCD (charge coupled device) and CMOS (complementary metal oxide semiconductor) technologies. These are very expensive and usually targeted for military use. More recently, pyroelectric sensing technology has been developed as cheap alternative that does not require expensive cooling methods.

Figure 4.1 shows an example of a single sensor pyroelectric people counting device manufactured by Eco-Counter, a company based in France. It operates by detecting the body heat of pedestrians in close proximity (usually within 4 meters).



**Figure 4.1: People counter with single pyroelectric sensor (Eco-Counter)**

Figure 4.2 shows an example of a double sensor pyroelectric counter that is capable of providing directional counts. The device will register a count when it detects an object with a temperature that exceeds a certain threshold. However, neither the single or double sensor device can distinguish whether the heat source is generated by a pedestrians or a vehicle. It also has difficulty distinguishing individual pedestrians walking closely within a group, so may underestimate pedestrian volumes. The Vermont Agency of Transportation is currently testing the pyroelectric sensor developed by Eco-Counter.



**Figure 4.2: People counter with double pyroelectric sensors (Eco-Counter)**

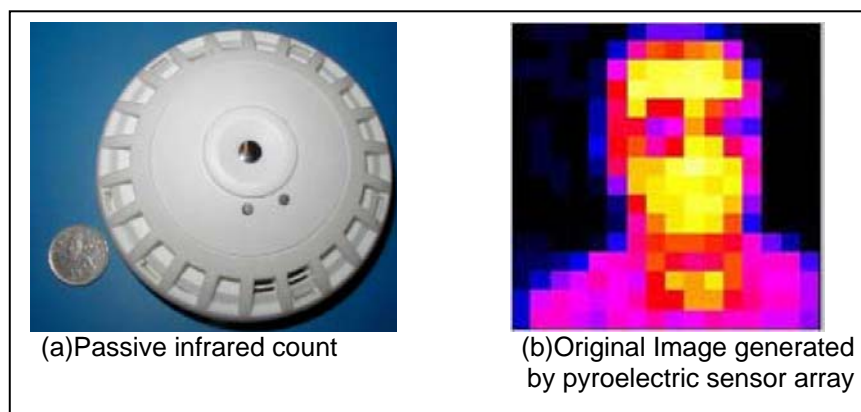
The drawbacks of single (or double) pyroelectric sensor based people counters may be addressed by using a pyroelectric sensor array to generate infrared images.

Figure 4.3a shows a top mounted people counter with 16 by 16 pyroelectric sensor array manufactured by IRISYS.

The low resolution (16 by 16) thermal images produced by pyroelectric sensors (Figure 4.3b) can be improved to 128 by 128 by using interpolation algorithms. Afterwards, standard video imaging processing techniques can be applied to extract pedestrian counts.

Although the coverage area for single IRISYS passive infrared people counter is small (3.5m-by-3.5m), IRISYS provides an option to connect up to 30 counters using a CAN (Controller Area Network) bus device.

Kerridge et al. (2004) conducted experiments with the IRISYS people counter in an indoor corridor. They monitored the counter's ability to track pedestrian movements. The results showed some loss of tracking ability at higher pedestrian densities, when it became more difficult for the detector to distinguish adjacent pedestrians.



**Figure 4.3: Passive infrared counter with pyroelectric sensor array  
(IRISYS people counter)**

## 5. PIEZOELECTRIC PAD

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Piezoelectricity, or “pressure” electricity, is the property of certain materials that produce a change in electrical properties with mechanical pressure. For application to pedestrian detection, piezo-cables with piezoelectric material are usually fabricated into a “mat” (Figure 5.1). When a person steps onto the mat, an electrical signal is generated and triggers a count.



**Figure 5.1: Piezoelectric pad counter (Eco-Counter)**

A piezoelectric pad counter is a simple reliable sensor for pedestrian counting. Several piezoelectric pads can be buried together for large coverage area. Timer systems have also been developed to ensure that only one person is counted even if they make two steps on the pad.

The piezoelectric pad counter does not require complex signal processing. However, it does require physical contact between a pedestrian and the sensor mat. Therefore, the piezoelectric pad counter is ideal when direct physical contact between pedestrian and sensor is assured, such as at a location where pedestrians are channeled into a crossing.

## 6. LASER SCANNER

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A laser scanner is a high-resolution laser range finder (Fuerstenberg and Lages, 2003; Fuerstenberg and Scholz, 2005; Streller and Dietmayer, 2004; Zhao and Shibasaki, 2005). The laser scanner emits infrared laser pulses and detects the reflected pulses. The measurement principle is based on the time-of-flight method, where the distance to the target is directly proportional to the time interval between transmission and the reception of a pulse.

Scanning of the measurement beam is achieved by a rotating prism and covers a viewing angle of up to 360 degrees. The original data from a laser scanner is much like vision image data in the horizontal scanning plane with accurate distance (centimeter level) and azimuth angle information (from 0.25 degree to 1 degree depending on scanning frequency).

A procedure similar to image processing is applied to analyze the laser “image.” First, clustered data points are grouped into different objects by segmentation. Then the objects are classified into different categories according to their characteristics. For example, pedestrians can be classified by the characteristics of their moving legs (Fuerstenberg and Dietmayer, 2004).

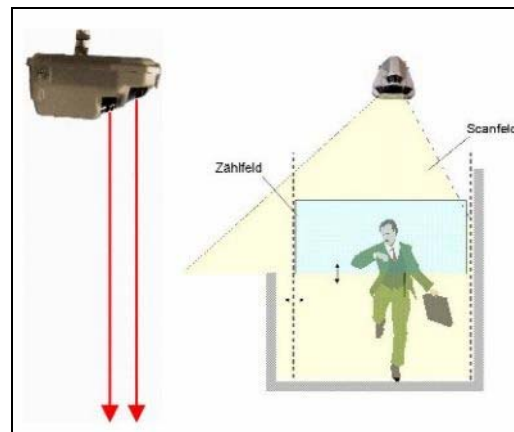
There are two classes of laser scanner: horizontal scanning and vertical scanning. Figure 6.1 shows a multifunctional traffic sensor with a horizontal scanning Sick laser scanner (Lottraffic from LogObject AG). It is capable of detecting and counting pedestrian within a 15m radius.



**Figure 6.1: Horizontal scanning configuration (Lottraffic with Sick laser scanner)**



Figure 6.2 shows a vertical laser scanner with two vertical scanning laser beams (PeCo people counter from LASE GmbH). It is capable of covering a passage width of up to 26m and providing directional counts and classification of pedestrians according to their height.



**Figure 6.2: Vertical scanning configuration (PeCo from LASE GmbH)**

Excellent range accuracy and fine angular resolution make laser scanners suitable for applications in which a high-resolution image of the surroundings is required. However, since they are optical sensors, weather conditions like fog or snow will limit their detection range. The signal processing is a little more complex for laser scanner compared with ultrasonic or microwave radar, therefore a dedicated CPU (central processing unit) may be needed.

## 7. COMPUTER VISION

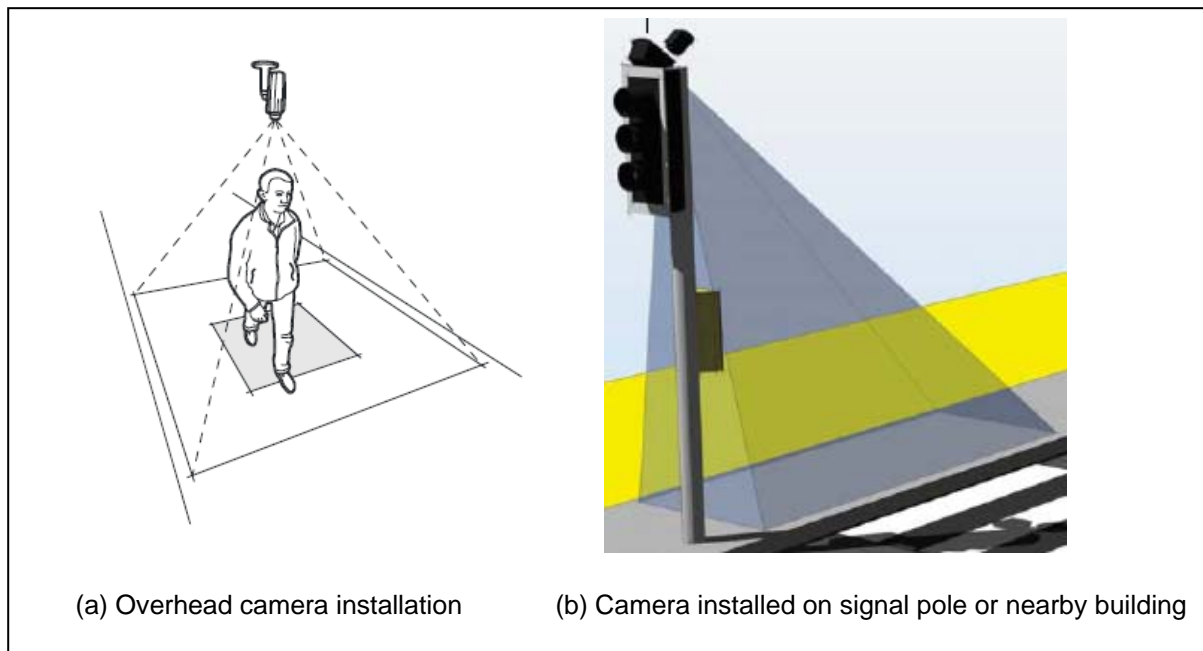
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Computer vision utilizes intelligent processing of digital images of pedestrians captured with a video camera to count pedestrians. The processor subtracts the static background from the image and then tracks the remaining objects to determine whether they are pedestrians (CLP, 2005).

Although a video camera can obtain much richer information about the surrounding environment compared with other types of sensors, the image sequences can not be used for anything directly without further interpretation. Extracting useful information from available image sequences is not a trivial task for several reasons (Zhao, 2001; Rabaud and Belongie, 2006):

- ✓ Pedestrian detection and counting involves a complex uncontrolled outdoor environment. Lighting conditions may change due to weather, sunrise or sunset. The cluttered urban environment also makes it difficult to distinguish pedestrian from nearby objects such as buildings, vehicles, poles and trees.
- ✓ A wide range of variations exist in pedestrian appearance because of clothing, pose, occlusion, shadow, motion, size and skin color.
- ✓ Accurate pedestrian counting of high-density pedestrian crowds is extremely difficult due to the potential that pedestrians may occlude one another's images, and because of the need to distinguish among many independently moving bodies.

To count pedestrians using video imaging, the video camera is usually installed at a fixed location. To minimize occlusions among passing pedestrians and simplify the corresponding video processing algorithm, the camera can be mounted directly above the interested area as shown in Figure 7.1a. However, it is not always possible to find a suitable overhead installation position. In this case, video cameras can also be installed on nearby building or signal pole (Figure 7.1b), but there is a risk of occlusion due to the angle of view. To monitor a wide open area, multiple cameras may be needed for overhead installation.



**Figure 7.1: Camera Installations**

To cope with inherently dynamic phenomena (people enter the scene, move across the field of view of the camera, and finally cross the counting line), the people tracking and counting problem has been decomposed into the following three steps (Rossi and Bozzoli, 1994; Kim et al., 2003):

1. Determine whether any potentially interesting objects have entered into the scene (alerting phase);
2. Track their motion until the counting line is reached (tracking phase);
3. Establish how many people correspond to tracked objects (interpretation phase).

### **7.1. Alerting Phase**

The alerting phase includes foreground objects extraction and pedestrian detection. Since the camera is usually installed on a fixed position, a background image is generated for calibration purposes at the beginning of installation. These images are updated using a very slow recursive function to accommodate background changes such as lighting conditions (Masound and Papanikolopoulos, 2001). Foreground objects including pedestrians and vehicles can be extracted by subtraction from the

background. Terada et al. (1999) used distance information acquired from stereo cameras to further improve the performance of foreground object extraction.

Various algorithms have been proposed to detect pedestrians in image sequences acquired from video cameras based on their unique features. Recent research shows two main trends. Motion-based approaches take into account temporal information and try to detect the periodic features of human gait in the movement of candidate patterns. Shape-based approaches rely on shape features to recognize pedestrians.

#### *7.1.1. Motion-based detection approaches*

Motion-based approaches use rhythmic features or motion patterns unique to human beings. Yasutomi and Mori (1994) used the Maximum Entropy Method to observe the periodic changes of image intensity caused by walking. Cutler and Davis (2000) used Fourier Transformation with Hanning window to find periodicity in the acquired image sequences.

The United Kingdom's Defense Evaluation and Research Agency counted pedestrian motions in order to estimate their exposure to risk in traffic (Allsopp and Smith, 1997). The report on this work dates from 1997, when it was necessary to use custom computer hardware. The results showed video imaging was capable of 85% accuracy when sampling 35 pedestrians in 30 minutes. There were concerns about occlusion problems at high pedestrian densities.

There are several limitations to motion-based approaches. First, motion-based schemes cannot detect stationary pedestrians or pedestrians engaged in unusual movements like jumping. Second, the pedestrian's feet or legs must be visible in order to extract rhythmic features or motion patterns. Third, the recognition procedure requires a sequence of images, which delays the identification until several frames later and increases processing time.

#### *7.1.2. Shape-based detection approaches*

Shape-based methods allow recognition of both moving and stationary pedestrians. Papageorgiou and Poggio (1999) represented human shape characteristics using

Harr wavelets. A support vector machine trained with characteristics extracted from example human images is used as a classifier.

In order to detect a partially occluded pedestrian, the same system is modified to first detect components of the human body (e.g. head, torso or limbs) and then the detected body parts are assembled together (Mohan et al., 2001). The proposed system has to search the whole image at multi-scale for pedestrian characteristics. This search process increases the computation cost substantially.

Although the shape-based method is more general, the major drawbacks associated with the shape method are:

1. High false positive rate due to variation of human shape and changing lighting conditions.
2. Heavy computation burden when performing feature matching.

Different approaches can be tried in order to resolve these drawbacks. The single-frame shape match can be combined with motion analysis to reduce false positive rates (Shashua et al., 2004). A specialized system-on-a-chip hardware solution can be used to increase processing speed (Elouardi et al., 2004; Mobileye, 2007). Knowledge about certain sites and situations (e.g. traffic signal, pedestrian crossing, etc.) can be used as *a priori* information to optimize the vision-processing algorithm (Lombardi and Zavidovique, 2004).

The main difficulty associated with shape based approaches is the problem of accommodating the wide range of variations in pedestrian appearances due to pose, various articulations of body parts, lighting, clothing, occlusion, etc. The key issues are to: (i) find a concise yet sufficient human shape feature representation that could achieve high inter-class variability with low intra-class variability; and (ii) maintain a balance between accuracy of detection and processing time.

## 7.2. Tracking Phase

The purpose of tracking is to establish connections of objects among frames and determine if the pedestrian has reached the counting line. Most tracking algorithms employ different variations of the Kalman Filtering approach (Heikkila and Silven,

2004). In the study of (Masound and Papanikolopoulos, 2001), the ground-plane constraint was imposed on the pedestrian motion model. This constraint assumes that all pedestrian motion is constrained to the ground plane.

### **7.3. Interpretation phase**

The interpretation phase of vision based pedestrian counting involves determining the actual pedestrian count based on the pedestrian objects detected and tracked in the previous phases. For the motion based pedestrian detection technique, different pedestrian objects generated from the detection step may belong to the same person (Antonini and Thiran, 2006). Therefore an overestimation may occur. Clustering techniques can be applied to the detected target trajectories in order to reduce the bias between the number of tracks and real number of pedestrians (Antonini and Thiran, 2006).

Some of the tracked objects may consist of several pedestrians (Heikkila and Silven, 2004). A computer-generated shape of a pedestrian group with two or three persons can be introduced so that such groups can be counted properly. If high-density crowds are present (e.g. during a political demonstration), the occlusion of pedestrians makes it very difficult to distinguish among each individual pedestrian. Face recognition and head detection can be used to improve counting accuracy in these situations (Casas and Folch, 2005; Liu et al., 2005).

One study developed a specialized tracker (a highly parallel version of Kanade-Lucas-Tomasi Feature Tracker) to process the video into a set of feature trajectories. The identified trajectories were then clustered into pedestrian objects (Rabaud and Belongie, 2006). In Kong et al. (2005) the number of pedestrians is first assumed to be proportional to the pixels of pedestrian objects. To further address the occlusion problem, a nonlinear relationship between pedestrian count and the pixels of pedestrian object is established and a neural network is trained to represent such nonlinear relations.

Researchers at the National Institute of Transportation Safety Research in France (INRETS) were able to accurately count the number of passengers passing through specific locations in transit stations using a “linear camera” optical method (Khoudour et al., 1998). They used an infrared camera and an active illumination source on the

ceiling, looking down at reflective lines on the ground, and then counted the number of pedestrians passing by, including estimates of their speed. The study resulted in an accuracy of 99% in counting pedestrians passing through a 3 m wide passageway, but noted some loss of accuracy at higher densities when pedestrians were so close that their image “blobs” merged together.

## 8. COMPARISON BETWEEN AUTOMATED METHODS

There are a variety of technologies capable of counting pedestrians. Each technology has strengths and weaknesses that make it particularly suited to different purposes, budgets, and counting environments. Table 8.1 provides a summary and comparison of the devices discussed in this document.

**Table 8.1: Summary of automated pedestrian counting devices**

<b>Counter</b>	<b>Pros</b>	<b>Cons</b>	<b>Manufacturer and Cost</b>
<b>Infra-red beam counter</b>	Cheap and widely available commercially; Low power consumption; Easy installation; Highly portable.	Infrared beam counter cannot differentiate pedestrian and other objects;  Transmitter and receiver need to be aligned carefully to ensure the reception of beam at the receiver end;  Both transmitter and receiver should not be installed on a flexible structure;  When several pedestrians cross the counting beam simultaneously, they are only registered as one count.	Jamar Technologies Inc \$790
<b>Passive infra-red counter</b>	Cheap and widely available commercially; Low power consumption; Not affected by wet or foggy weather; Counter with multiple sensor arrays could achieve performance comparable with computer vision.	Single or double sensor counter cannot distinguish between individuals and groups; Temperature can affect counter performance; Limited coverage area.	Irisys \$1400 for counter with multiple sensor array  EcoCounter \$2000 for counter, \$600 for software
<b>Piezo-electric pad</b>	Low maintenance cost; Low power consumption;	Need physical contact between pedestrian and pad;	Eco-Counter Cost estimate not available



<b>Counter</b>	<b>Pros</b>	<b>Cons</b>	<b>Manufacturer and Cost</b>
	Capable of counting pedestrians on sidewalks.	Sub-surface installation is expensive; Limited coverage area; Some of products cannot differentiate between single pedestrian and group of pedestrians.	
<b>Laser scanner</b>	Accurate range measurement; Can differentiate pedestrian according to their height; Easy setup; Large coverage area.	Expensive; Performance could be affected by different weather conditions.	LASE GmbH Around \$9000 for counter only
<b>Computer vision</b>	Large coverage area; Has the potential to count accurately in various conditions such as crowded pedestrians, different lighting conditions; Can be manually reviewed to collect pedestrian characteristics; Easy installation and setup; The video can be recorded for manual review.	Most commercially available products are intended for indoor setting; The difficulty of counting pedestrians in crowded settings has not yet been resolved; The performance can be affected by different environmental conditions if not designed properly.	Video Turnstile Start from \$1230

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