INVESTIGATING THE PERFORMANCE OF AUTOMATIC COUNTING SENSORS FOR PEDESTRIAN TRAFFIC DATA COLLECTION

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ABSTRACT

There has been an increasing need to obtain high-quality pedestrian counts for many transportation studies. Traditional data collections cannot satisfy the extensive data collection requirements such as long term and high accuracy. Advancements of sensor technologies in recent years have been promoting the development of automatic devices to automate pedestrian counting process. A number of pedestrian counters are now commercially available but their accuracy under urban environmental settings is still not well-known. Thus, this study aims to shed light on the understanding of the field performances of two infrared pedestrian counters by performing rigorous pair-wise comparisons. It finds that both sensors were systematically undercounted the actual pedestrian traffic and one sensor outperformed the other one in most cases. The magnitude of errors varied from sites to sites and the reasons are different. It also finds the potential of deploying infrared counters for intersection use.

Keywords: Pedestrian counters, infrared counters, pedestrian traffic, data collection

INTRODUCTION

Pedestrian counts are essential for decision making in pedestrian facility planning, signal timing, and pedestrian safety modelling. However, it remains difficult to obtain high-quality pedestrian counts *(1)*. Pedestrian and bicycle traffic are still not as extensively monitored as motor vehicle traffic. Data related to pedestrians are lacking in most areas. Even where data exist, they are not always useful *(2)*. Many pedestrian data sources still rely on conventional methods such as manual counting and video recording *(3, 4)*. These methods are labour intensive and expensive, and they do not always guarantee economic, sufficient, and accurate pedestrian data.

Automatic pedestrian counting technology is expected to be a viable alternative to manual counting. To explore cost-effective and reliable methods of pedestrian counting, researchers and practitioners have been investigating automatic pedestrian detecting or counting technologies. In a recent study, Bu et al. *(5)* described the pros and cons of the available pedestrian counting technologies, including infrared beam counters, passive infrared counters, piezoelectric pads, laser scanners, and computer vision.

The advance in new technologies now makes it possible to automatically count pedestrians for long periods of time. However, the feasibility of using these automated pedestrian technologies on a larger scale still needs to be investigated. It is difficult to assess the suitability of different sensor types for different count locations. Some sensors that are claimed to be more accurate are substantially more expensive than comparable products. Ease of deployment, power needs, and other long- and short-term deployment issues all play an important role in the selection of a suitable pedestrian counter.

This study attempts to shed light on understanding the field accuracy of two commercially available automatic pedestrian counters[1]—namely, a passive infrared counter by EcoCounter and a thermal sensor (passive infrared counter with imaging) by TrafSys. Accuracy of the selected counters is evaluated by field tests.

The paper is organized as follows: A review of the studies that evaluated infrared pedestrian counters is presented next. The methodology section presents the description of the selected counters, field tests and data collection, and data analysis method. Finally, the summary of major findings and their implications on pedestrian data collection are presented.

LITERATURE REVIEW

Pedestrian counters are not as widespread and advanced as vehicle sensors, and their performance has not been widely studied. Only a limited number studies evaluated the accuracy of infrared pedestrian sensors deployed in outdoor settings.

[1] *Sensor and counter are used interchangeably throughout the paper.*

Beckwith and Hunter-Zaworski *(6)* tested the accuracy of passive infrared, ultrasonic, and microwave radar It found passive infrared had a 0 percent close range and 1.5 percent long range no-detection rate. Noyce et al. *(7)* conducted a study for the Massachusetts Highway Department to identify and evaluate existing technologies that can detect, count and classify bicycles and pedestrians. An active-infrared imaging sensor was tested. The results showed that approximately 97 percent of the bicyclists and 92 percent of pedestrians were successfully detected, and 77 percent of bicyclists detected were correctly classified. Further development of a new algorithm improved the sensor performance, where approximately 100 percent of bicycles and pedestrian were successfully detected and about 92 percent of bicycles and pedestrians successfully classified *(8)*. The loss in accuracy was suggested to be the impact of extreme cases such as multiple bicycles or pedestrians passing the sensor's detection zone.

The aforementioned studies focused on identifying the performance of pedestrian detection rather than counting. Recent years, several studies attempted to directly investigate the performance of infrared sensors for pedestrian counting. All tested infrared counters were found to suffer from errors when counting real pedestrian traffic. For instance, Missoula Technology and Development Center (MTDC) tested infrared pedestrian counters at five trail settings, and found a 0 to 6 percent error for the active infrared counter and 13 percent to 24 percent error for the passive infrared counter *(9)*. Because the field tests were conducted for monitoring forest service trail, the results cannot reflect the sensors' performance when deployed at urban settings.

SRF Consulting Group *(10)* evaluated four automatic pedestrian detection sensors at trail setting for a project sponsored by Minnesota Department of Transportation. A total of 100 baseline observations were collected. Among the tested infrared sensors, ASIM DT272 exhibited 100 percent accuracy whereas the Diamond trail counter missed 7 percent of passes. As the researchers noted, the test results may not be indicative of the actual performance because all passes were consisted of single pedestrian arrivals.

Turner et al. *(11)* tested five different pedestrian sensors of which four are infrared technologies. The ASIM intersection sensor showed an overall errors ranging from 9 to 32 percent. Concurrent tests showed that the TrafX and Diamond sensors had similar performance, with overall error rate of -11 percent and -7 percent at one site, and -26 and -24 percent at another site. But the overall count errors of the Jamar sensor were more than -30 percent at both sites.

Greene-Roesel et al. *(12)* tested performance of a dual-sensor passive infrared pedestrian counter. The results showed that the counter consistently undercounted pedestrians, with an overall error rate between -9 percent and -19 percent. Though the error rate was fairly stable at -13.2 percent on average, it is well above the results of the -2 percent error rate indicated by Bell *(13)* and the -5 percent error rate obtained by Aultman-Hall et al. *(14)* deploying the same type of counter to collect pedestrian volume on a sidewalk in Montpelier, Vermont. The infrared sensor tends to undercount pedestrians because they cannot detect pedestrians walking exactly side-by-side *(15)*.

These studies demonstrated the performance of infrared counting sensors and provide valuable guidelines for future use. Results indicate that different pedestrian facilities and walking patterns of pedestrians yield different sensor performances. Therefore, more investigation is needed to explore the accuracy of pedestrian counting devices in more complex outdoor settings, such as intersections.

METHODOLOGY

Passive infrared sensors

There are three types of infrared sensors: active, passive, and target reflective. Active counter uses body mass to break an invisible beam crossing a path. Passive infrared counter detect heat emitted from pedestrians passing through the sensing area. Target reflective counter counts pedestrians by detecting breaks of invisible beam between transmitter and reflector mounted at opposite sides.

Based on the findings of the literature review and follow-ups with various vendors, two passive infrared counters were selected in this study:

1. Double pyroelectric sensor from EcoCounter (passive infrared technology without vision), and

2. Thermal sensor from TrafSys (passive infrared thermal imaging technology).

Figure 1 shows the selected pedestrian counters. In EcoCounter, there are two lenses sensitive to the infrared radiation emitted by the human body that can detect when a pedestrian passes. The counter uses a four-threshold algorithm to avoid false counts generated by the rain or the plants or trees. . Its double-direction vertical technology supports dual-direction counting in any temperature *(16)*. Its protective box keeps it working properly in all weather conditions. Internal battery life is up to 10 years and the data logger can store data in 15-minute intervals up to one year. It can be easily installed within 10 minutes if a mounting pole is available. This type of non-intrusive sensors is ideal for places where pedestrians pass a constrained path such as sidewalk or trail and other extraneous counts are avoidable. So far, only limited case studies have reported the performance of the counter *(12, 13, 14, 17)*.

The thermal sensor uses infrared thermal imaging to identify directional pedestrian movement by monitoring body heat in the detection area. Its sensor creates a pair of imaginary lines that, when crossed by a pedestrian, will either result as an inbound or outbound count. The location of the lines can be modified so that user can make the detection pattern fit specific environment. The counter is best installed in environments where an overhead mounting height of 11.5 feet can be accommodated *(18)*. Real-time data are available through wireless transmitter. The counter is unaffected by ambient lighting or other environmental conditions. Data can be integrated into 5-minute intervals. External power is required to deploy the sensor. It takes approximately an hour to install and calibrate the thermal sensor. It is designed to collect foot traffic data in indoor settings, such as malls, there are no studies reporting its performance and accuracy in urban outdoor settings.

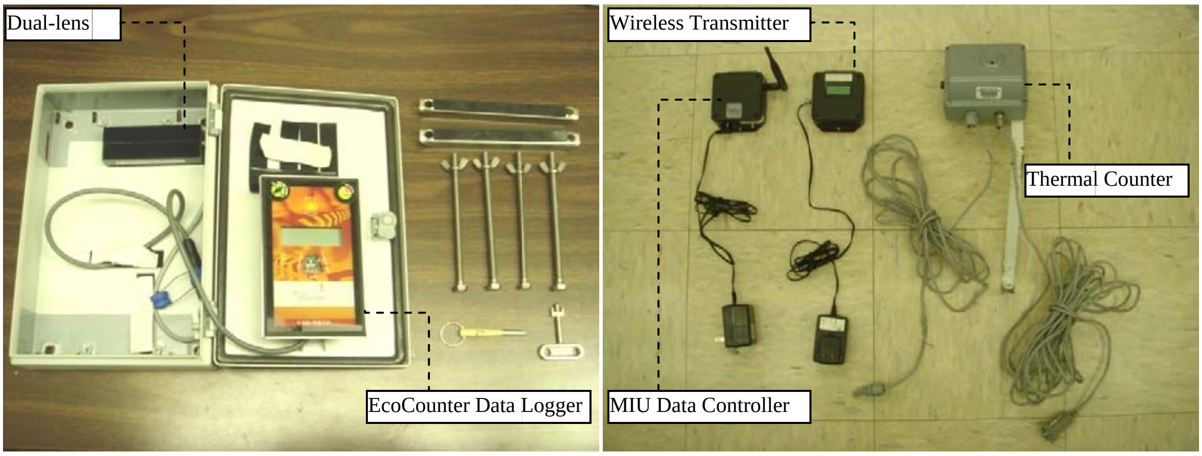

Figure 1. Demonstration of selected counters

Field tests and data collection

To evaluate the performance of automatic pedestrian counters in outdoor settings, field tests were conducted at seven sites in New Jersey. Selection of the test sites was based on the following criteria: (1) pedestrian volume, (2) availability of mounting facility and space to install counters, and (3) location accessibility. Figure 2 shows the selected sites. Table 1 summarizes the information about the field tests.

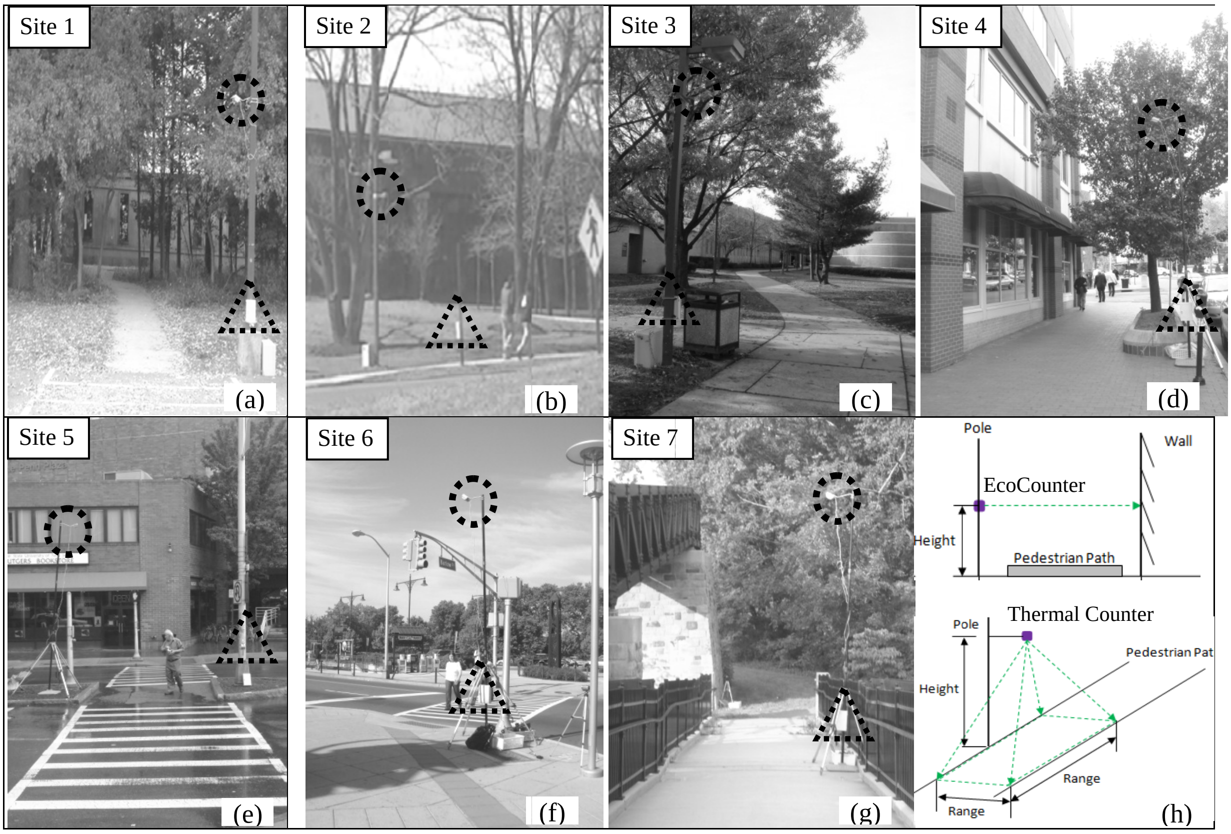

Figure 2. Field data collection at different sites

Table 1. Summary of data collection

Site	City	Facility Type	Test Date	Test Period	Volume(ped)	Flow(ped/hour)
1	Piscataway	Trail	10/08/2009	09:00pm-11:00pm	270	19
2	Piscataway	Trail	04/10/2009	10:30am-10:30pm	3103	259
3	Piscataway	Trail	10/26/2009	09:00am-11:00pm	8294	592
4	New Brunswick	Sidewalk	10/12/2009	09:00am-06:00pm	2011	223
5	New Brunswick	Crosswalk	08/13/2009	01:00pm-07:00pm	1273	212
6	Trenton	Crosswalk	05/22/2009	09:00am-05:00pm	1359	170
7	Trenton	Ped. bridge	08/19/2009	12:00pm-06:00pm	21	4

Both counters were installed either on existing poles or customized mounting facilities nearby the sensing areas based on vendors' recommendations. Field test at each site was conducted 6 to 14 hours. Baseline data were collected using a camcorder. Positions of the camcorder were carefully selected so that the presences of camera do not affect pedestrians walking behaviours and clear videos can be collected. Once simultaneously recorded from the field tests, the videotapes were carefully reviewed and pedestrian counts were extracted as the baseline data in the Rutgers Intelligent Transportation Systems (RITS) laboratory. Both baseline data and sensors' outputs were integrated into 15-minute intervals for further analysis.

Data Analysis

The main objective of this study is to investigate the accuracy of the two selected infrared sensors under different field conditions. According to definitions of the quality of traffic data by FHWA *(19)*, accuracy is defined as *"the measure or degree of agreement between a data value or set of values and a source assumed to be correct".* The accuracy of a pedestrian counter is thus evaluated by the difference between the ground truth counts and the counter readings. To describe the accuracy of the pedestrian counters quantitatively, the following error indicators are defined.

$$Relative\ Error\ per\ Period(\%) = \frac{Y_t - X_t}{X_t} \quad (1)$$

$$Mean\ Absolute\ Percent\ Error\ (MAPE)(\%) = \frac{1}{n}\sum_{t=1}^{n}\left|\frac{Y_t - X_t}{X_t}\right| \quad (2)$$

$$Overall\ Error(\%) = \frac{\sum_{t=1}^{n} Y_t - \sum_{t=1}^{n} X_t}{\sum_{t=1}^{n} X_t} \quad (3)$$

where X_t is the ground truth count at period t, Y_t is the APC count at period t, n is the total number of all observed periods.

These different error formulations are all valid measures of accuracy but may yield slightly different results. The errors are expressed as percentages. The relative error per period provides an in-depth investigation of different sensors' performances for the test duration. For each test, the errors are calculated for different data integration intervals—for instance, 5 minutes, 15 minutes, 30 minutes, and 1 hour. The average value of relative errors for all periods was not used as an indicator because the positive and negative errors cancel out in this indicator. Instead, the mean absolute percent error (MAPE) statistic is used. MAPE is a commonly used measure that corrects the "cancelling out" effects and also takes into account the different scales at which this measure can be computed. The overall error can be used to compare the aggregate accuracy of the measurements over the test duration. It shows the performance in a larger scope.

Sensor outputs and baseline counts can be regarded as a paired measurement (Xa, Xb). Wilcoxon signed-ranks test was applied to test the sensor performances *(20)*. Infrared counters have been reported to systematically undercount the true volumes *(21, 22)*. To clarify whether the infrared really undercount the truth at all test sites, the null hypothesis is defined as, H0: Difference=0, namely sensor counts are equal to the ground truth counts (H1: Difference is not equal to 0).

RESULTS AND DISCUSSION

The comparisons between the two counters were presented on Table 2. Both counters appeared to systematically undercount pedestrians, presenting an overall error rate of between -1.1 percent and -27.3 percent for EcoCounter, between -0.7 percent and -18.3 percent, for the thermal counter. Except for site 5, thermal counter is more accurate than EcoCounter as its overall errors were all less than those of EcoCounter. The -14.3 percent of overall error rate for EcoCounter obtained at sidewalk (site 4) is comparable with -9 percent to -19 percent obtained at sidewalks in California *(12)* but greater than -2 percent to -5 percent obtained in Vermont *(13, 14)*. For the higher volume trails (site 2 and 3), the error rates are larger than -20 percent. Other than the extreme high volume trail (site 3), thermal counter performed relative well at facilities such as trails, sidewalk and bridge, with less than -10 percent error.

Interesting results were observed at the two intersections (site 5 and 6). EcoCounter had larger error rate of -27.3 percent at site 6 while had a relative error rate of -5.3 percent at site 5. Similarly, thermal counter had larger error rate of -14.6 percent at site 5 but had only -2.2 percent error at site 6. A possible explanation for the higher error rate at intersections is that some pedestrians waiting for signals either blocked EcoCounter (at site 6) or lingered in the detection zone of thermal counter (site 5). But in-depth investigation is needed to identify specific reasons. Despite the fact that not all the overall error rates at intersections are relative small, each counter' lower error rate obtained at one of the intersections implies some potential of their application at intersections even though both sensors are not designed for intersection use.

MAPEs and overall errors are not always consistent with each other. Smaller overall errors associated with larger MAPEs for instance, the thermal counter at site 1 and 3, reflect the "cancelling out" effect when calculating the overall errors.

Results of Wilcoxon matched-pairs signed-ranks test were summarized in Table 3. The results show that there is a significant difference between EcoCounter outputs and the ground truth at all the high volume sites (site 2, 3, 4, 5, and 6) given the significant level of 0.05. Similarly, the thermal counter also undercounted at site 2, 3, 4, and 5. Both sensors performed well at the low volume site 1 and site 7. The insignificant difference between thermal counts and the truth indicated that the thermal performed better at the one of the intersection, site 6.

Table 2. Counter errors at different sites

Site	Period (hour)	Baseline (ped)	Sensor Counts (ped)		Overall Error (%)		MAPE (%)	
			EcoCounter	Thermal	EcoCounter	Thermal	EcoCounter	Thermal
1	14	270	281	268	-1.1	-0.7	38.2	67.3
2	12	3103	2468	2947	-20.5	-5.0	19.7	13.1
3	14	8294	6236	6774	-24.8	-18.3	20.8	22.3
4	9	2011	1723	1848	-14.3	-8.1	14.0	12.1
5	6	1273	1206	1087	-5.3	-14.6	7.6	17.0
6	8	1359	988	1329	-27.3	-2.2	27.2	12.7
7	6	21	17	19	-19.0	-9.5	3.8	1.9

Table 3. Statistical analysis the sensor outputs

Site	Sample Size	Wilcoxon Paired Signed-Rank Test		p-value	
		H0	H1	EcoCounter	Thermal
1	56	Difference =0	Difference <0	0.321	0.452
2	48	Difference =0	Difference <0	6.753×10^{-10}	0.049
3	56	Difference =0	Difference <0	1.11×10^{-16}	1.821×10^{-4}
4	36	Difference =0	Difference <0	5.297×10^{-9}	0.006
5	24	Difference =0	Difference <0	7.367×10^{-4}	1.55×10^{-5}
6	32	Difference =0	Difference <0	2.328×10^{-9}	0.184
7	24	Difference =0	Difference <0	0.25	0.25

Figure 3 shows the scatter plot between pedestrian flows and relative errors of each 15-minute interval. The results are consistent with previous study *(12)* that pedestrian flow did not show a strong effect on the infrared counters' accuracy. There is weak linear relationship between pedestrian flows and relative errors of both counters as the maximum R-squares obtained at the seven sites were all less than 0.47. Figure 3 also shows that both sensors sometimes overcounted and thermal counter had more overcounting cases. By reviewing videos, the EcoCounter appears to overcount when some pedestrians lingered around the counter or walked slowly. And the undercounting occurred when more pedestrians walked side-by-side or simultaneously arrived. This Therefore, the pedestrian walking patterns rather than the level of volume are more related to EcoCounter's performance. The reasons for the overcounting and undercounting cases of thermal counter are not clear. The field tests showed that the thermal sensor is miscounts when pedestrians walk closely. Irregular counting errors also suggest that both counters cannot be simply calibrated by using single correction factor when deploying at different sites.

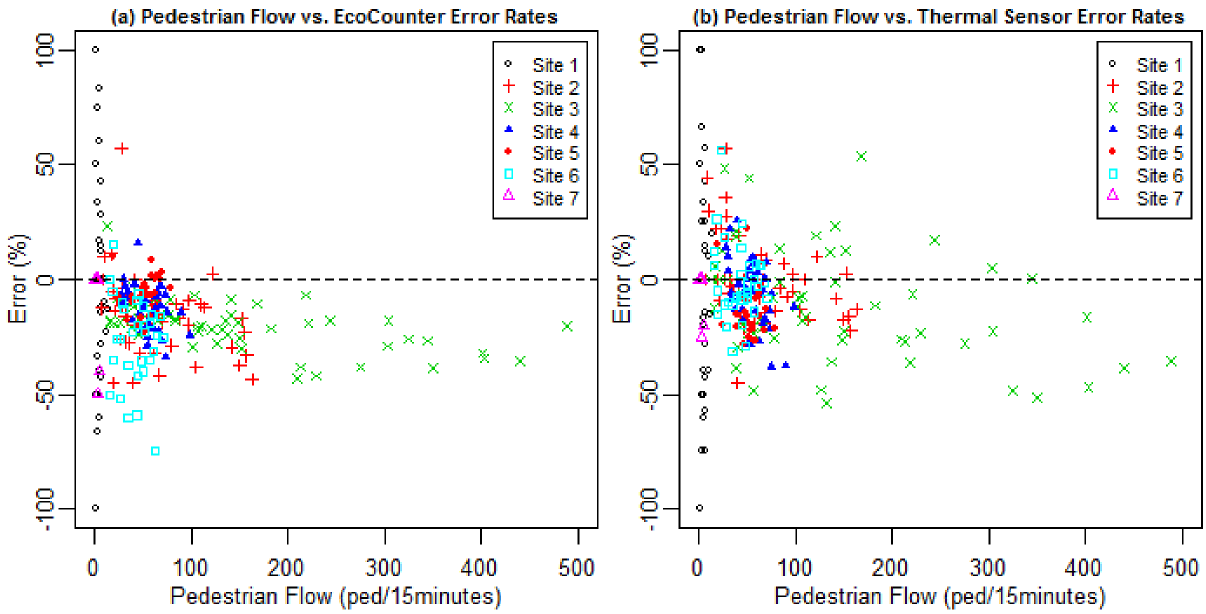

Figure 3. Relationship between pedestrian flow and counter errors

CONCLUSIONS

Emerging sensor technologies have been accelerating the innovation of pedestrian data collection. The main goal of this study was to perform pair-wise comparison of the accuracy of two different pedestrian counters at different locations and times. The pair-wise experiments allow us to eliminate the bias due to discrepancies of locations, times, and pedestrian traffic conditions if counters were tested separately and enables us to focus solely on the performance of each sensor.

Both counters can work properly under different weather conditions. Seven field tests suggest that the thermal counter outperformed the dual passive infrared in many cases. Both counters were found to systematically undercount the actual traffic whereas the causes tend to be different. Inconstant error rates indicate that it is difficult to argue a single number regarding accuracy of each counter because the accuracy depends upon various known and unknown factors. For instance, the dual passive infrared counter significant suffered from inaccuracy if simultaneous arriving or side-by-side walking frequently occurred. But the reasons for inaccurate counting of thermal counter are more complicate and deserve in-depth investigation. Continued work to reveal the field performance these technologies is still needed. In order to obtain reliable results, more detail factors need to be considered when selecting and implementing an appropriate automatic pedestrian counter at a given location.

Though both counters were not designed for intersection use, lower error rates obtained in some sites implied potentials of such infrared counters to be used at intersections. If properly installed, their performance can be as good as trail or sidewalk deployment.

Baseline data collection is a time intensive task. To extract 1-hour data from video, approximately 5 hours of manual counting effort is needed for the high volume sites. This also highlights the importance to automate pedestrian counting process so that much of labour and cost will be saved.

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