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16. ABSTRACT

Caltrans is looking to improve crosswalk technology in urban areas. Specifically using a crosswalk sensor which can detect pedestrian motion and extend walk time accordingly. Caltrans is interested in three sensors: AGD 326, MS Sedco SmartWalk XM, and iComs TMA-011 LV. The objective of this research is to evaluate each of the three sensors and help Caltrans make decisions in choosing a sensor that satisfies Caltrans' purposes. The systems were evaluated using an apparatus mounted on a truck bed, a phone-controlled camera, a spray-painted grid on the AHMCT test track, a custom LED indicator cable, and a portable charger. This is the final report for the overall task, TMS Innovative Product Proof of Concept (POC) Support, as well as the detailed report for Technical Evaluation of Detectors for Pedestrian Walk Time Extension.

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TMS Innovative Product Proof of Concept (POC) Support, Including Technical Evaluation of Detectors for Pedestrian Walk Time Extension

Anh Duong &
Ty Lasky: Principal Investigator

Report Number: CA23-4049
AHMCT Research Report: UCD-ARR-23-04-05-01
Final Report of Contract: 65A0749 Task 4049

April 5, 2023

California Department of Transportation

Division of Research, Innovation and System Information

Executive Summary

Advanced Highway Maintenance and Construction Technology (AHMCT) researchers evaluated three crosswalk walk sensors to help the California Department of Transportation (Caltrans) make decisions on which sensor(s) will be compatible for Caltrans' purposes. Caltrans is interested in systems that can detect pedestrians in crosswalks and extend walk time as appropriate. The three sensors evaluated are:

- AGD 326
- MS Sedco SmartWalk XM
- iComs TMA-011 LV

The sensors were set up and tested on AHMCT's test track separately. The sensors' settings were adjusted so they could perform according to manufacturer specifications. This report summarizes notable features from each sensor which will assist the Caltrans decision making process.

Problem, Need, and Purpose of Research

Pre-set crosswalk walk time does not always provide pedestrians enough time to walk across the road, especially when it comes to elders and individuals with disabilities. To address this problem, an available technology that aids with adding walk time is considered. The sensor picks up pedestrian motion and signals the controller to add walk time as desired. This evaluation includes three candidate sensors: AGD 326, SmartWalk XM, and iComs TMA-011 LV. If one of the sensors fits Caltrans' needs, the commercial off-the-shelf (COTS) technology is ready to be applied in the field.

Background

AHMCT procured and evaluated the three crosswalk sensors: AGD 326, SmartWalk XM, and iComs TMA-011 LV. The sensors' manuals were followed to ensure that testing was carried out fairly. The sensors were set up on the same apparatus with similar testing procedure. The similarity in testing steps allows reasonable comparison between sensors. The sensors were mounted approximately ten feet high on a truck-mounted apparatus. The sensors were tested separately to ensure their wavelengths did not interfere with one another. The walking process under each sensor was recorded and analyzed to determine whether the sensors behave according to their respective manufacturer claims.

Overview of the Work and Methodology

Each sensor was tested separately. The sensor was mounted on a rigid structure built on a truck bed to achieve a ten-foot mounting height that would not allow it to wobble in the wind. In addition, having the structure on the truck helped with transporting test equipment.

To identify detection range, a spray-painted grid was created on the AHMCT test track. The grid outer dimensions were six by thirty-two meters. The grid accommodated most of the sensors' detection specifications. The grid did not have the capacity to accommodate the full AGD 326 detection width. Therefore, the testing result for the AGD 326's maximum detection width might not be fully evaluated.

A phone-controlled camera was setup to oversee the testing process and the custom light-emitting diode (LED) indicator cable. This cable connected to the sensor's relay, and the LED would light up when the relay was activated. In addition, a pedestrian would walk to cover the whole grid, as well as walking off-grid. When the crosswalk motion sensor picked up a pedestrian, the LED would light up. The process was recorded and re-watched to analyze sensor activity. Each sensor was tested five times to ensure the accuracy of the evaluation.

Major Results and Recommendations

AGD 326

Strengths

- User-friendly browser interface for setup. Detection tracing technology helps user determine whether the desired detection zone has been fully covered.
- Up to four sensors can co-exist at the same location.
- Provides flexibility in detection zone parameters as length and width can be adjusted in one-meter increments.
- The only sensor that has both sound and LED detection indicator. These indicators can be switched off if desired.
- Provides a terminal where command code can be input. However, the functionality of this terminal was not tested.

Weaknesses

- A smart device (phone, tablet, or laptop) must be available when setting up the sensor.
- Has the shortest detection length when a pedestrian is moving away from the sensor.
- Detection is the most discontinuous.

SmartWalk XM

Strengths

- Has the longest detection length when a pedestrian is moving away from the sensor.
- The only sensor that has pedestrian motion sensitivity and fail safe state.
- Has an output ready to be wired into the crosswalk timing control/ warning lights.

Weaknesses

- Weight heaviest among the candidates.
- Does not have sound or LED detection indicator.
- The cover must be unscrewed and opened so the settings can be adjusted internally.
- Does not have detection length or width adjustment option.
- Does not have frequency adjustment.

iComs TMA-011 LV

Strengths

- Weight lightest among the candidates.
- Up to four sensors can co-exist at the same location.

- Provides four detection length settings: 8, 12, 16, and 30 meters.
- Provides all-weather operating conditions with minimal to no maintenance. However, the sensor was not tested in different environment factors.
- Has two bright LEDs that activate when motion is detected.

Weaknesses

- Settings must be adjusted before protective sticker is placed. Once sticker is placed, settings are no longer accessible.
- Has some flexibility in adjusting detection length parameters, but limited to four options.
- Does not have detection width adjustment option.
- Does not have sound detection indicator.

Overall, AHMCT would recommend the AGD 326 sensor to be the best candidate for Caltrans' purposes. The AGD 326 has the most user-friendly interface, which makes the setting adjustment process straightforward. The AGD 326 sensor is the only candidate that allows flexibility in adjusting the detection zone parameters to match the desired crosswalk parameters. The AGD 326 also presents a visual demonstration in its manual where the user can check the integrity of the sensor detection parameters. These unique features are more valuable when compared to the SmartWalk XM and iComs features.

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Acronyms and Abbreviations

Acronym	Definition
AHMCT	Advanced Highway Maintenance and Construction Technology Research Center
Caltrans	California Department of Transportation
COM	Common
COTS	Commercial Off–The-Shelf
DOT	Department of Transportation
DRISI	Caltrans Division of Research, Innovation and System Information
FMCW	Frequency Modulated Continuous Wave
LED	Light-Emitting Diode
NC	Normally Closed
NO	Normally Open
RF	Radio Frequency

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Chapter 1: Introduction

Problem

Caltrans is interested in systems that can detect pedestrians in crosswalks and extend walk time as appropriate. Three sensors were selected to evaluate how well they can fulfill Caltrans' vision: AGD 326, SmartWalk XM, and iComs TMA-011 LV.

Objectives

The sensors were evaluated based on their manufacturer specifications. Each sensor has unique functionalities.

- AGD 326 provides remote setup via smartphone, tablet, or laptop. The sensor displays detection traces to the user using its Wi-Fi browser interface.
- SmartWalk XM minimizes false activations from vehicular traffic. The sensor has an output ready to wire into crosswalk timing controls/warning lights.
- iComs TMA-011 LV operates in all weather conditions with minimal to no maintenance needed. The sensor has bright warning LEDs that activate~~s~~ in the presence of cyclists or pedestrians.

AHMCT evaluated the sensors in similar environmental conditions with the same apparatus setup. The setup maximized the sensor capabilities while allowing fair comparison.

Table 1.1: Timeline of the project

	month	1	2	3	4	5	6
	calendar year	2022					
	Tasks	Jul	Aug	Sep	Oct	Nov	Dec
A	Develop draft features to be evaluated						
B	Finalize features to be evaluated						
C	Evaluate detectors						
D	Develop summary report						

- SmartWalk XM and iComs TMA-011 LV were received in the beginning of August. AGD 326 was received in mid-September.
- A test plan was developed for the three sensors in August and September.
- Testing was executed for the three sensors by the beginning of October. The evaluation drafts of each sensor were sent to Caltrans for review.
- This summary report documents the testing and evaluation.

Background

This research and its results are focused on Caltrans' vision of improving urban communities. The focus is to evaluate the feasibility of applying a crosswalk sensor to existing traffic signal infrastructure so walk time can be extended accordingly. Because each sensor is unique in functionality and specifications, AHMCT tested the three sensors individually in similar testing conditions. AHMCT provides the testing results from each sensor to help Caltrans determine which sensor(s) will be the most compatible with its operational needs. If the results are positive for Caltrans' purposes, Caltrans can decide to install the chosen sensor(s) in a large scale.

Table 1.2 shows the sensor specifications evaluated by AHMCT.

Table 1.2: Sensor specifications evaluated

Feature	AGD 326	SmartWalk XM	iComs TMA-011
Detector range	X	X	X
Range adjustment	X		X
Width adjustment	X		
Minimum detection speed	X		X
Detection LEDs	X		X
Remote setup	X		
Remote setup range	X		
LED for WiFi	X		
Hold time after pedestrian has exited	X		X
Detection mode	X	X	X
Pedestrian motion sensitivity		X	
Extension time range and accuracy		X	
Relay output voltage	X	X	X
Confirm function for final parameter selection	X	X	X

Research Methodology

AHMCT created an apparatus that accommodated the sensors' specifications. The apparatus was built on the bed of a Ford truck to achieve the recommended ten-foot mounting height on a rigid structure. In addition, the apparatus on the truck allowed equipment to be transferred to the test track efficiently. On top of the structure, the crosswalk sensor was mounted to a custom bracket. Next to the crosswalk sensor was a phone-controlled camera that captured the testing process. In between the camera and the sensor, a custom LED cable was made to indicate the crosswalk sensor relay activity while in the view of the camera. The system ultimately included: a crosswalk sensor, a phone controlled camera, and a custom LED cable that connected to the relay of the crosswalk sensor. The system was powered by a portable power bank. Figure 1.1 shows the apparatus used in testing.

Figure 1.1: Testing apparatus

In addition to the apparatus, a grid layout was spray-painted on the test track. The grid is 32 meters or approximately 105 feet in length, 6 meters or approximately 20 feet in width. The parameters of the grid were maximized to accommodate the specifications of the sensors.

Each sensor detection range given by their respective manufacturer is as follows:

- AGD 326 has a maximum detection length of 24 meters or approximately 79 feet, and a maximum detection width of 10 meters or approximately 33 feet. The parameters can be adjusted in 1-meter increments.
- SmartWalk XM has a maximum detection length of 55 feet or approximately 16.8 meters, and a maximum detection width of 15 feet or approximately 4.6 meters. The parameters cannot be adjusted.
- iComs TMA-011 LV has a maximum detection length of 30 meters or approximately 98 feet. The manufacturer does not list the maximum detection width. The detection length can be adjusted to 8, 12, 16, or 30 meters.

The grid width was not wide enough for all sensors. Off-grid testing was included to fully cover maximum detection range. Figure 1.2 shows the grid layout.

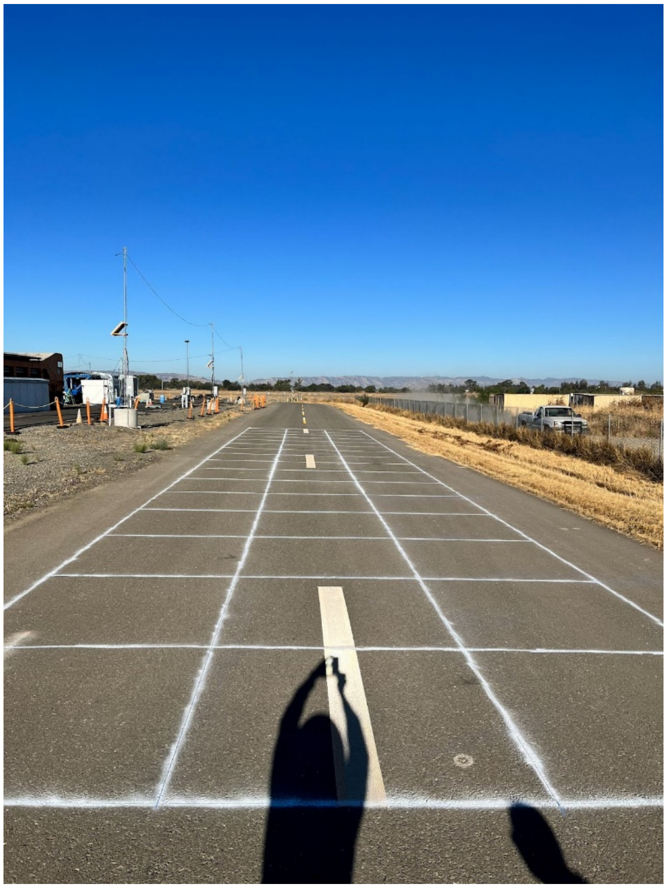

Figure 1.2: Spray-painted grid on AHMCT test track

A phone-controlled camera was setup to capture the custom LED indicator and the grid, depicted in Figure 1.3. The recordings were analyzed to understand each sensor's detection behavior.

Figure 1.3: An excerpt of the test recording

The detection observed from the recordings was marked on the scale digital grid, Figure 1.4. The length of the grid was numbered from 01 to 16. Each square parameter is 2 meters by 2 meters. For instance, the square numbered 01 is 2 meters in length and width. The width of the grid was identified by right R, left L, and center C. The right and left is interchangeable depending on perspectives. If the pedestrian walked from the beginning to the end of the grid, the left and the right parameter in Figure 1.3 would interchange and vice versa. The left and right parameter being interchangeable does not affect the testing results as long as the correct perspective is applied.

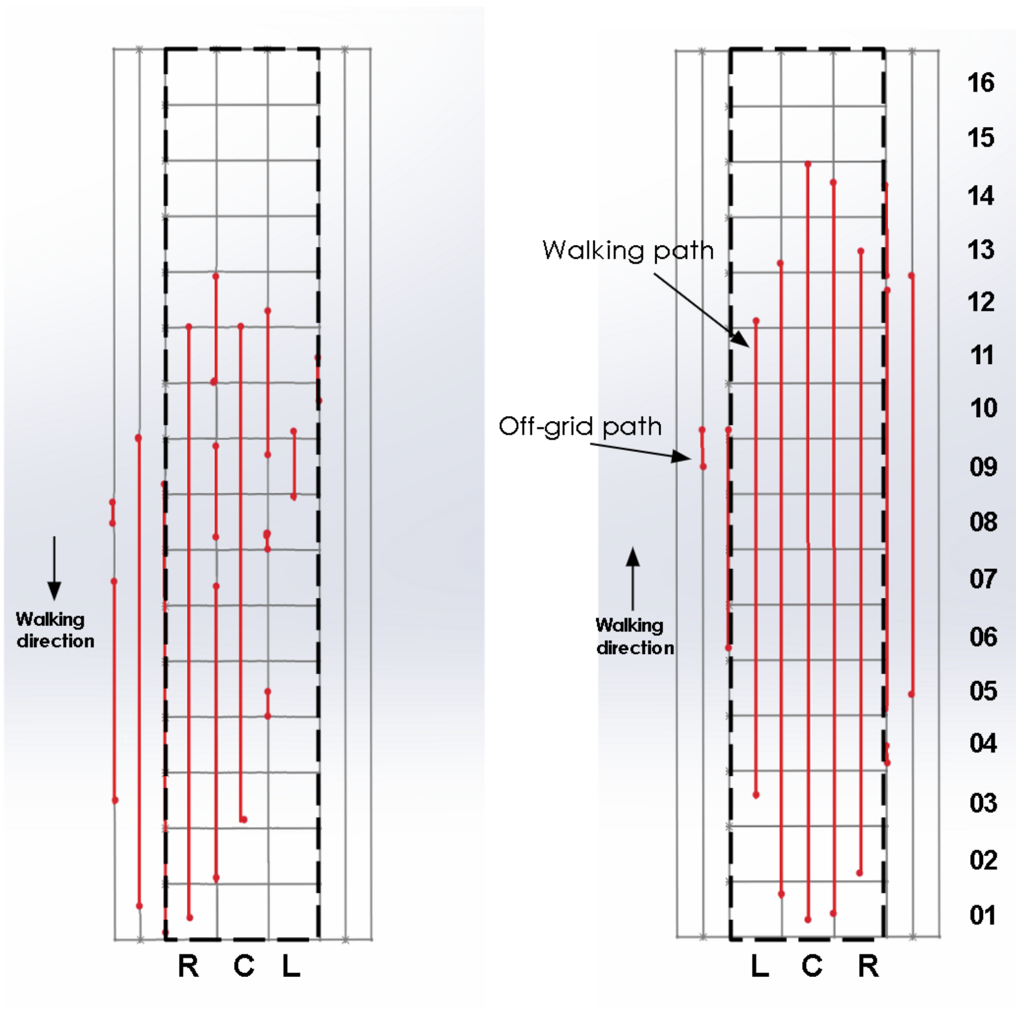

Figure 1.4: A sample marked grid

In Figure 1.4, the black dash outline depicts the spray-painted grid boundaries. As mentioned, the left and right parameter interchanged depending on the walking direction. The off-grid paths taken were 1 meter and 2 meters away from the sides of the grid, respectively.

The walking direction has two categories: walking toward the sensor or walking away from the sensor. Each direction was marked separately. There were five trials for each sensor.

The placement of the sensors allowed their detection range to distribute as evenly as possible on the grid. Figure 1.5 shows each sensor's placement with respect to the grid.

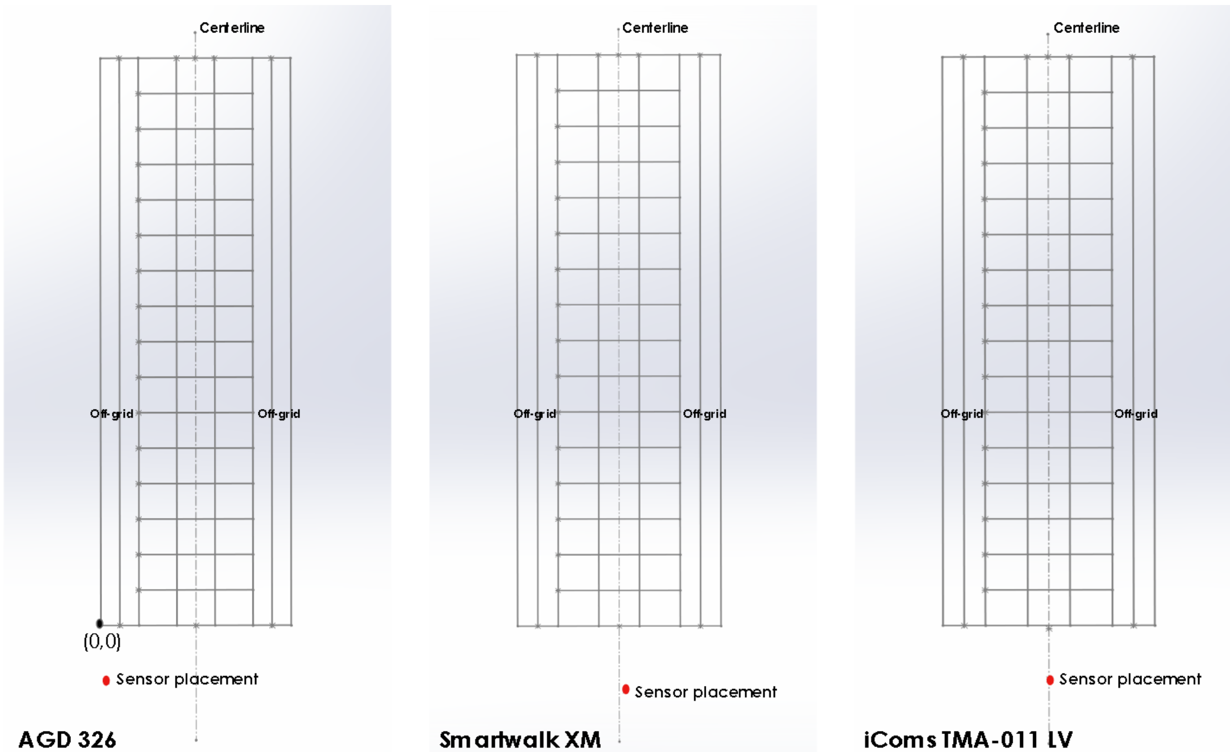

Figure 1.5: Sensor placement

- AGD 326 manufacturer recommended the sensor placement to be either left or right of the crosswalk.
- SmartWalk XM manufacturer recommended the sensor placement to be at the centerline of the crosswalk.
- iComs TMA-011 LV manufacturer did not specify where would be the best placement. The manufacturer recommended adjusting the sensor placement until getting desired results.

iComs TMA-011 LV was placed at the centerline of the grid to keep the horizontal radar operating angle at zero degrees.

Because the apparatus was on a truck, it was challenging to park the truck at the desired location. The test track is also not perfectly flat. It was difficult to achieve high accuracy. The test was carried out as close to the planned parameters as possible, and within the accuracy requirements of this evaluation.

Table 1.3: Sensor's exact placement (referencing Figure 1.5)

AGD 326	
Vertical distance from the beginning of the grid to the sensor	124.1 inches
Horizontal distance from coordinate (0,0) to the sensor	11.8 inches
SmartWalk XM	
Vertical distance from the beginning of the grid to the sensor	142.5 inches
Horizontal distance from the centerline to the sensor	11.8 inches
iComs TMA-011 LV	
Vertical distance from the beginning of the grid to the sensor	119.3 inches
Horizontal distance from the centerline to the sensor	1.25 inches

The manufacturers provided a recommended mounting height as noted in Table 1.4.

Table 1.4: Mounting height recommendation

AGD 326	
Maximum mounting height	4 m/ 13.1 ft
Minimum mounting height	2 m/ 6.6 ft
SmartWalk XM	

Maximum mounting height	3.7 m/ 12 ft
Minimum mounting height	3 m/ 10 ft
iComs TMA-011 LV	
Maximum mounting height	4.5 m/ 14.8 ft
Minimum mounting height	3.5 m/ 11.5 ft

All sensors were mounted approximately 10 feet from the ground. The mounting height was the same so a comparison of the sensor performance could be made consistently.

The SmartWalk XM manual specifies a maximum vertical tip angle of 15 degrees, but the AGD 326 and iComs TMA-011 LV manuals do not list maximum vertical tip angles. None of the manuals list maximum horizontal rotation angles. The manufacturers recommended trial and error. The angles should be adjusted until achieving desired results.

The truck was parked on the uneven test track. The truck tip angles added to the sensors' tip angles. The tilt angles of the sensors were also affected, but not as significantly.

The sensor's angles used during testing were collected. Those angles, including the effect from tip angles of the truck, are demonstrated visually in Figures 1.6 – 1.8.

Figure 1.6: AGD 326 angles used in testing. The horizontal rotation angle was zero.

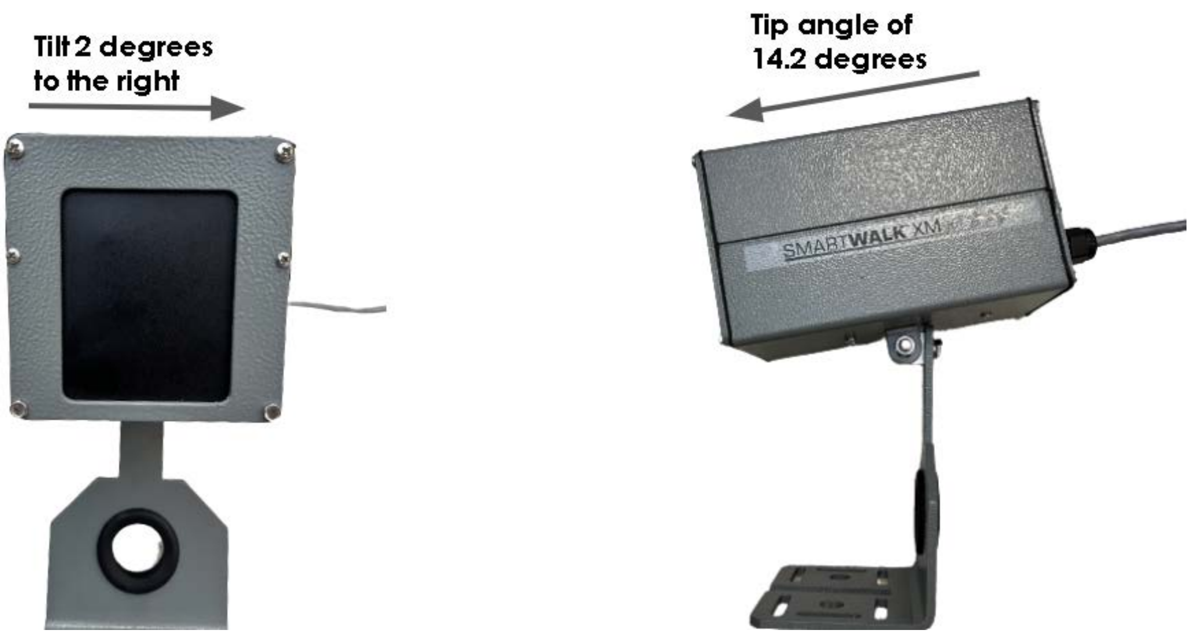

Figure 1.7: SmartWalk XM angles used in testing. The horizontal rotation angle was zero.

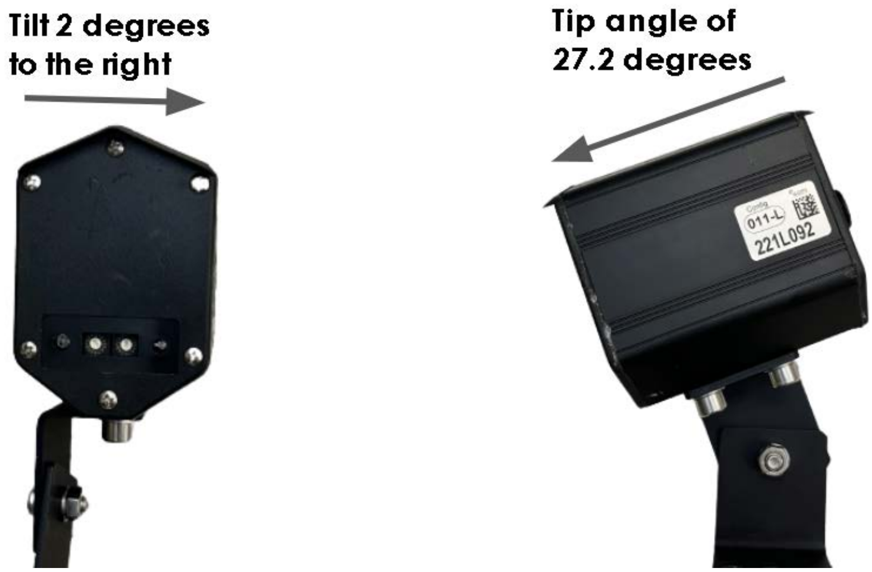

Figure 1.8: iComs TMA-011 LV angles used in testing. The horizontal rotation angle was zero.

Overview of Research Results and Benefits

The key deliverables of this project include:

- Evaluation of detection range performed by each sensor
- Assessment of each sensor's unique features
- Assessment of sensor specifications claimed by manufacturer
- Comparison across all sensors
- Advantages and disadvantages in using the sensor
- Conclusion and recommendation

The benefits of evaluating the sensors include:

- Clarify manufacturers' claims
- Understanding of how certain features work
- Understanding of the sensor capabilities and limitations
- Understanding of the sensor installation process and determination of whether it can be applied on a large scale
- Determination of the sensor's relevance to Caltrans' operational needs

Chapter 2: Evaluation

Detection range performance

Based on the recordings, the detection range was marked five times for each sensor. Then, the five trials were inputted into one graph for comparison. The black outline on the graphs represents the grid boundaries. As mentioned, off-grid paths were conducted to ensure the detection range was fully covered. The red crosshatch area represents the “always-detected” zone, which is defined as the area where detection was picked up by all five trials.

In the case of the AGD 326 sensor, the detection was not continuous. In addition, the hold time of the AGD 326 is 800 milliseconds. Due to these characteristics, there are discontinuations within walking paths. The discontinuation is reflected in the detection zone plots. The averages of data points were taken to determine the always-detected zone of the AGD 326.

AGD 326

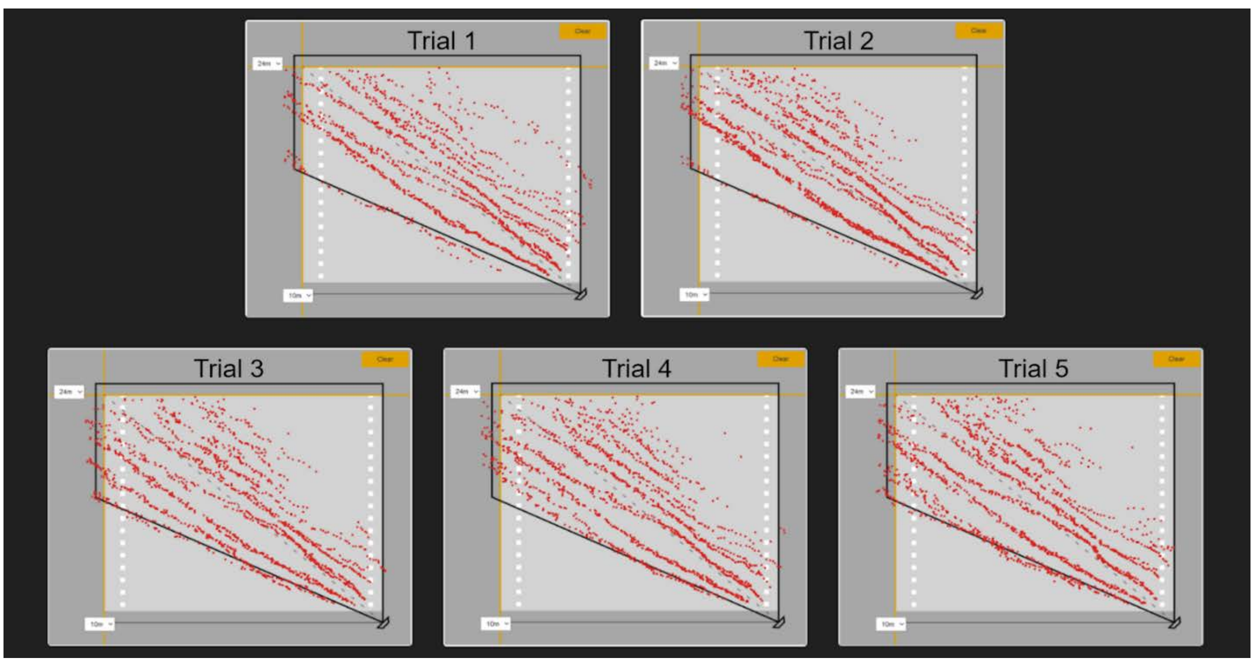

Figure 2.1: Tracing of the five trials via AGD 326 interface browser

Figure 2.2: AGD 326 detection zone when moving away from the sensor (dimensions in feet)

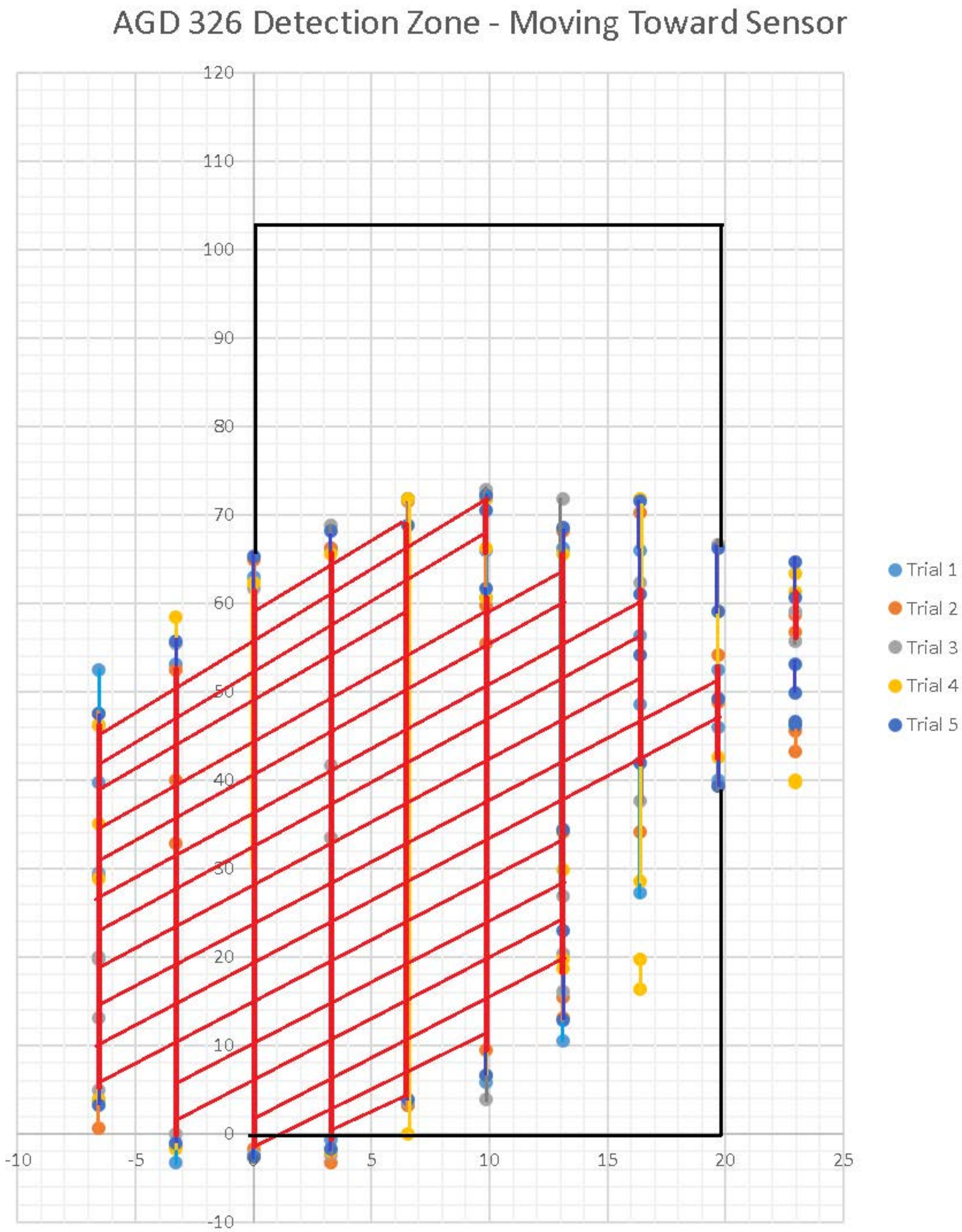

Figure 2.3: AGD 326 detection zone when moving toward the sensor (dimensions in feet)

Figure 2.1 shows the five trials traced by the AGD 326 browser. Compared to Figures 2.2 and 2.3 obtained from the recordings, both data sets display discontinuity. Table 2.1 demonstrates the detection range concluded from the five trials.

The always-detected zone is defined as an area where detection was picked up across all five trials. The always-detected zone is the red crosshatch area shown in Figures 2.2 and 2.3.

Table 2.1: AGD 326 detection range in the always-detected zone comparing to manufacturer claims

Tested detection range	Expected detection range	Difference between tested and expected range
Maximum length (moving away)		
20.9 m/ 68.6 ft	24.0 m/ 78.7 ft	3.1 m/ 10.2 ft less
Maximum length (moving toward)		
20.2 m/ 66.3 ft	24.0 m/ 78.7 ft	3.8 m/ 12.5 ft less
Maximum width (moving away)*		
7.0 m/ 23.0 ft	10.0 m/ 32.8 ft	3.0 m/ 9.8 ft less
Maximum width (moving toward)*		
8.0 m/ 26.3 ft	10.0 m/ 32.8 ft	2.0 m/ 6.5 ft less

*Important note: AHMCT test track was not wide enough to accommodate 10 meters. The maximum width may exceed what was collected from testing.

From Table 2.1, the sensor performed differently with respect to the different directions. The maximum detection length when the pedestrian walked away from the sensor is slightly larger than when the pedestrian walked toward the sensor. The maximum detection width when the pedestrian walked away from the sensor is slightly smaller than when the pedestrian walked toward sensor. The maximum detection length and width collected from testing were less than manufacturer claims.

SmartWalk XM

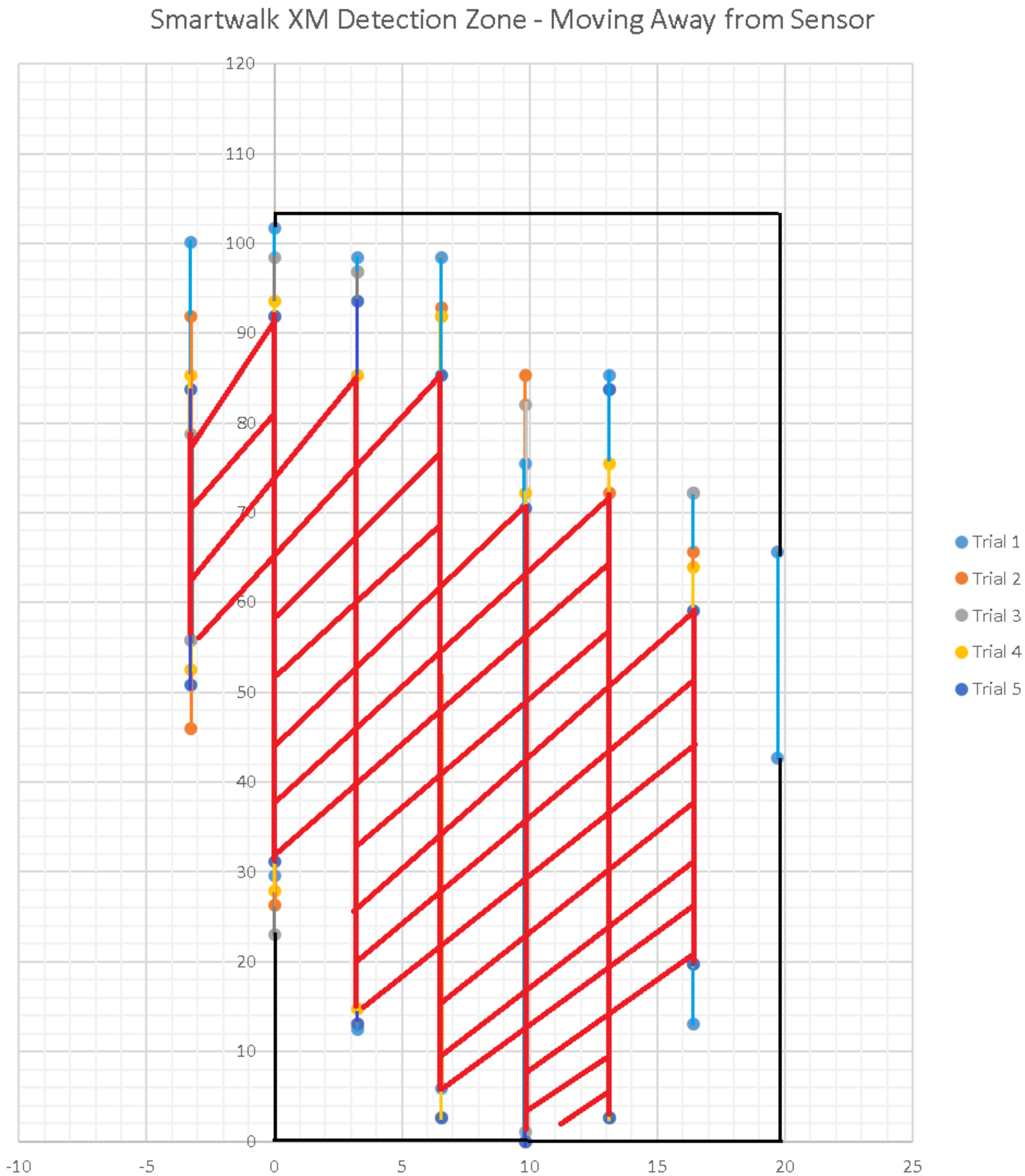

Figure 2.4: SmartWalk XM detection zone when moving away from the sensor (dimensions in feet)

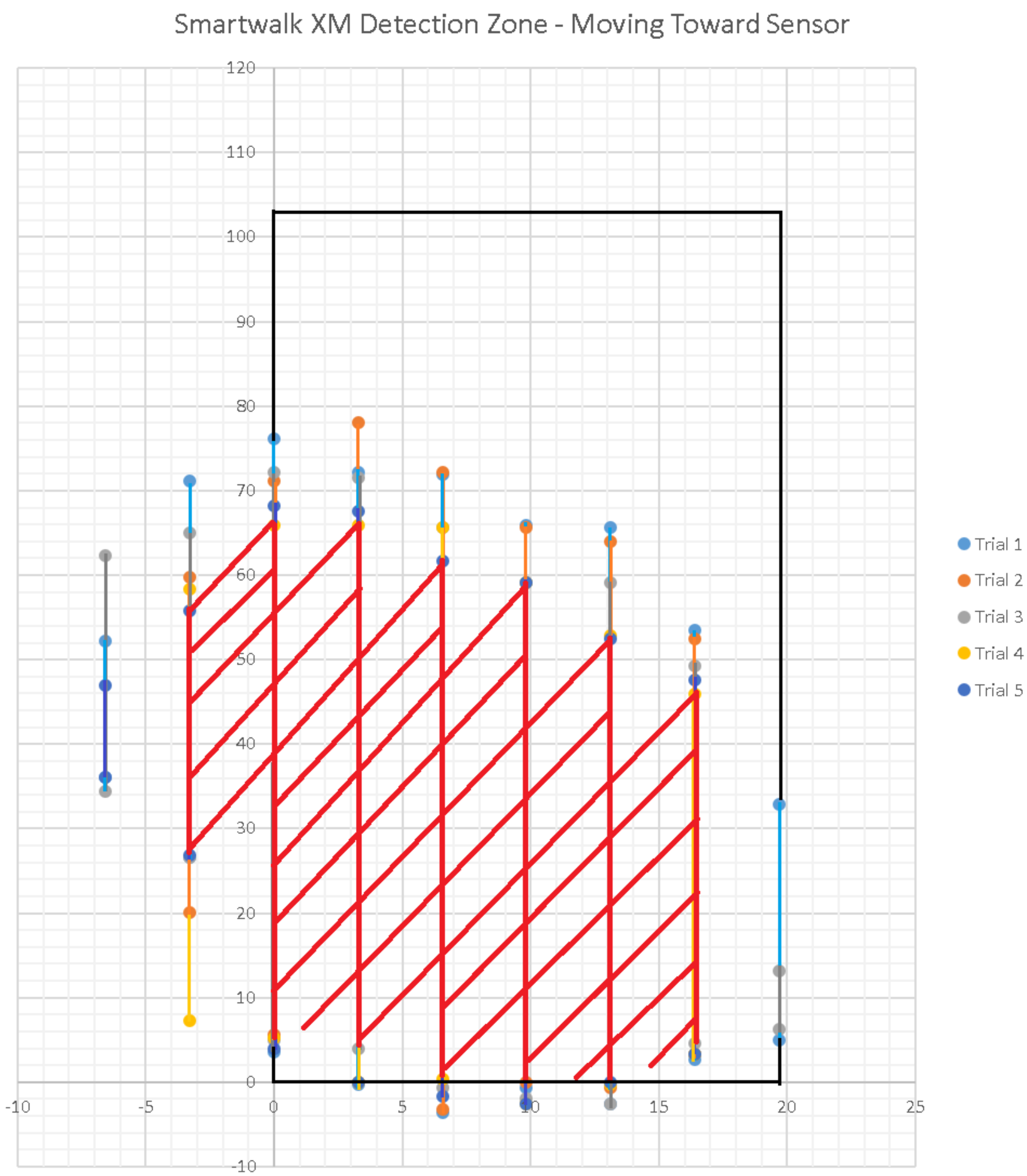

Figure 2.5: SmartWalk XM detection zone when moving toward the sensor (dimensions in feet)

The always-detected zone is defined as an area where detection was picked up across all five trials. The always-detected zone is the red crosshatch area shown in Figures 2.4 and 2.5.

Table 2.2: SmartWalk XM detection range in the always-detected zone comparing to manufacturer claims

Tested detection range	Expected detection range	Difference between tested and expected range
Maximum length (moving away)		
24.2 m/ 79.4 ft	16.8 m/ 55 ft	7.4 m/ 24.4 ft more
Maximum length (moving toward)		
19.0 m/ 62.3 ft	16.8 m/ 55 ft	2.2 m/ 7.3 ft more
Maximum width (moving away)		
6.0 m/ 19.6 ft	4.6 m/ 15 ft	1.4 m/ 4.6 ft more
Maximum width (moving toward)		
6.0 m/ 19.6 ft	4.6 m/ 15 ft	1.4 m/ 4.6 ft more

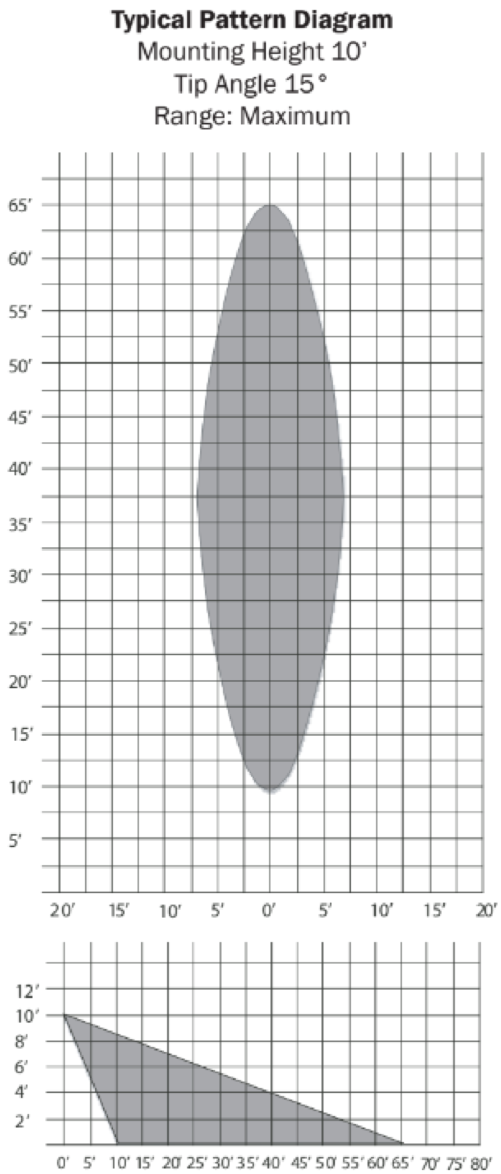

Figure 2.6: Detection zone on the top view and side view provided by the manufacturer

Comparing Table 2.2 and Figure 2.6, the sensor performed better than manufacturer claims overall. Based on testing alone, the sensor performed better in length when the pedestrian was walking away from the sensor.

iComs TMA-011 LV

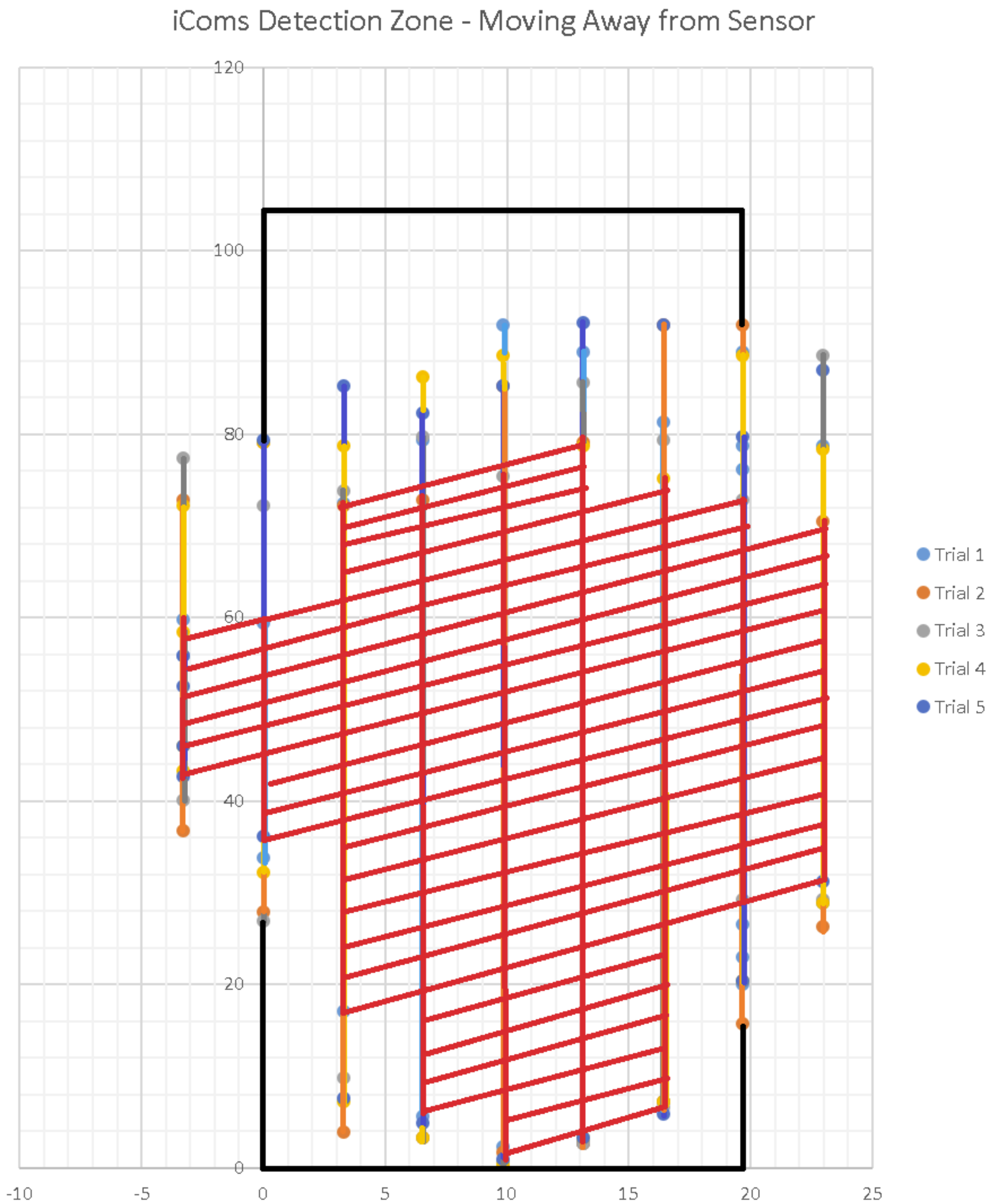

Figure 2.7: iComs TMA-011 LV detection zone when moving away from the sensor (dimensions in feet)

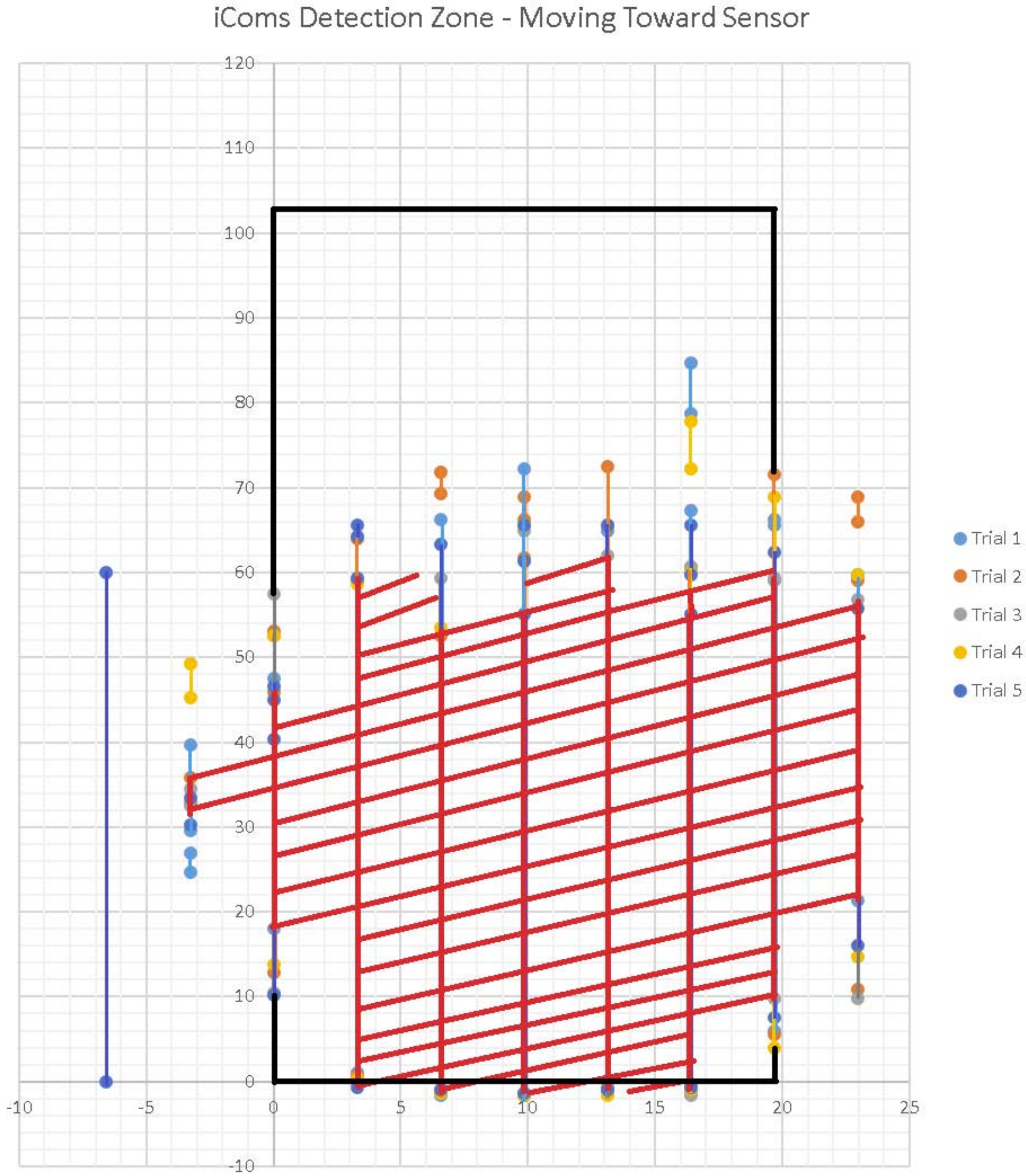

Figure 2.8: iComs TMA-011 LV detection zone when moving toward the sensor (dimensions in feet)

In Figure 2.8, there was a long off-grid detection in blue during Trial 5. The sensor did not pickup detection for the other four trials. The sensor was also detecting when the pedestrian had already exited the crosswalk for approximately 3 seconds which was more than manufacturer claim of 800 milliseconds hold time. The long off-grid detection in blue was unexpected because the off-grid detections next to it were brief. Therefore, the long off-grid detection in blue was not considered in the iComs evaluation.

The always-detected zone is defined as an area where detection was picked up across all five trials. The always-detected zone is the red crosshatch area shown in Figures 2.7 and 2.8.

Table 2.3: iComs TMA-011 LV detection range in the always-detected zone comparing to manufacturer claims

Tested detection range	Expected detection range	Difference between tested and expected range
Maximum length (moving away)		
23.0 m/ 75.5 ft	30.0 m/ 98.4 ft	7.0 m/ 22.9 ft less
Maximum length (moving toward)		
19.1 m/ 62.7 ft	30.0 m/ 98.4 ft	10.9 m/ 35.7 ft less
Maximum width (moving away)		
8.0 m/ 26.3 ft	N/A	N/A
Maximum width (moving toward)		
8.0 m/ 26.3 ft	N/A	N/A

According to Table 2.3, the sensor performed better in length when the pedestrian walking away from the sensor. The manufacturer did not provide the sensor maximum detection width. In Figure 2.7, the sensor achieved close to the expected range at 28.1 m/ 92.2 ft in length in trial five. Overall, the sensor did not achieve the manufacturer claims.

Detection range adjustments

Table 2.4: Detection range adjustment comparison

AGD 326	SmartWalk XM	iComs TMA-011 LV
Detection length adjustment (in meters and feet)		
1 to 24 meters, in 1 meter increments	Not adjustable	8, 12, 16, 30 meters
3.3 to 78.7 feet, in 3.3 feet increments	Not adjustable	26.2, 39.4, 52.5, 98.4 feet

AGD 326	SmartWalk XM	iComs TMA-011 LV
Detection width adjustment (in meters and feet)		
2 to 10 meters, in 1 meter increments	Not adjustable	Not adjustable
6.6 to 32.7 feet, in 3.3 feet increments	Not adjustable	Not adjustable
Detection direction		
Bi-directional	Uni- or bi-directional	Uni- or bi-directional
Parameters used in testing		
24 meters, 10 meters, bi-directional	Bi-directional	30 meters, bi-directional

Unique features and settings

AGD 326

The AGD 326 has remote Wi-Fi set up that takes approximately 10 minutes. To set up the sensor Wi-Fi features, the steps are as follows:

1. Power up the sensor, wait for the LED on the bottom to flash five times.
2. The unit should have a serial number format as 326:XXXXXX-XXXX (the 'X' denotes the S/N). The Wi-Fi will display the unit serial number. Connect to the Wi-Fi, and input the default password as AGD326:XXXXXX-XXXX (the 'X' denotes the S/N)
3. After the Wi-Fi is connected, enter the address http://192.168.4.1 to access the sensor browser
4. The sensor browser gives the user the ability to change settings and keep track of the detected target within/nearby the outline zone, as well as adjust other features, depicted in Figures 2.9 - 2.11.

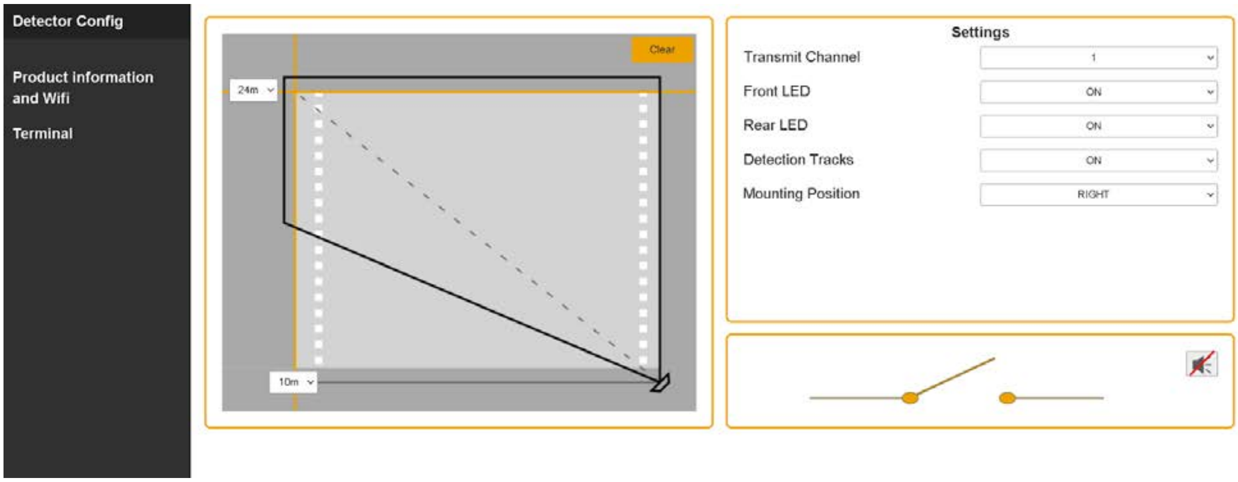

Figure 2.9: User interface of AGD 326 under “Detector Config” in the browser

In Figure 2.9 browser, the setting options are:

- Transmit channel, up to four channels
- Front LED can be turned on, off or timeout
- Rear LED can be turned on, off or timeout
- Detection tracks can be turned on, or auto clear after 5, 10, or 20seconds
- Mounting position can be right or left

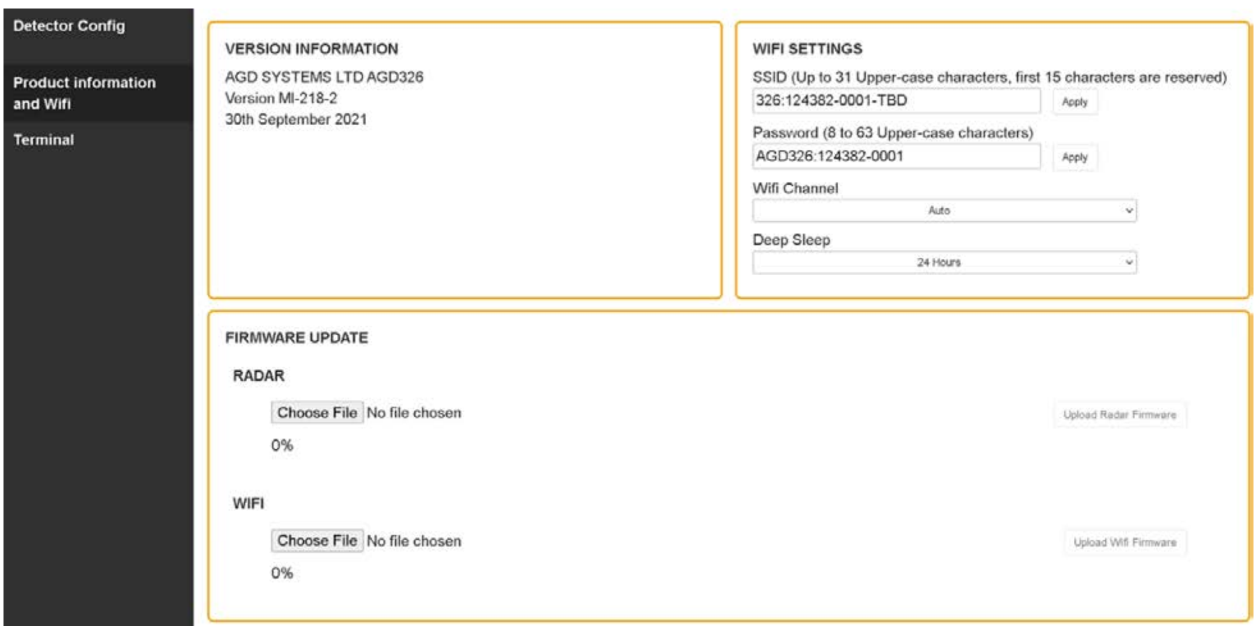

Figure 2.10: User interface of AGD 326 under “Product information and Wifi” in the browser

Figure 2.11: User interface of AGD 326 under "Terminal" in the browser

SmartWalk XM

The SmartWalk XM has detection options that the other two sensors do not have: pedestrian motion sensitivity and a fail-safe state. According to the SmartWalk XM data sheet, fail safe ON means the relay is energized, and fail safe OFF means the relay is de-energized.

The fail-safe switch being on or off does not affect the detection performance of the SmartWalk XM sensor. When the fail safe is ON, the relay is always energized, even when the SmartWalk XM does not detect any pedestrians. When the fail safe is OFF, the relay will only be energized (the relay closes its contact) when a pedestrian is detected. The fail safe switch (on or off) dictates what happens to the state (high voltage or low voltage) of the orange and white wires if the sensor relay fails. The fail safe can be configured via wiring or dipswitch as follows:

- Fail safe ON wiring diagram, or dipswitch #4 is ON
    - Red wire: voltage in is 12V to 24V AC/DC+
    - Black wire: voltage in is 12V to 24V AC/DC-
    - White wire: relay normally open (NO)
    - Green wire: relay common (COM)
    - Orange wire: relay normally closed (NC)
- Fail safe OFF wiring diagram, or dipswitch #4 is OFF
    - Red wire: voltage in is 12V to 24V AC/DC+
    - Black wire: voltage in is 12V to 24V AC/DC-
    - White wire: relay NC

- Green wire: relay COM
- Orange wire: relay NO

When AHMCT received the SmartWalk XM sensor, the fail safe switch #4 was OFF. AHMCT decided to keep the setting as is for dipswitch #4 and wired the sensor according to the fail-safe OFF instructions. The SmartWalk XM data sheet stated that the default setting for the relay is fail safe ON (dipswitch #4 ON).

Table 2.5 shows the pedestrian detection logic (high-low state of white and orange wires) for the fail-safe switch being on or off when the relay fails. When the fail-safe switch is OFF and the relay fails, the logic will indicate no pedestrians being detected at any time. When the fail-safe switch is ON and the relay fails, the logic will indicate pedestrians being detected all the time. To adjust the settings, the user has to unscrew the lid of the unit (Figure 2.13).

Table 2.5: Logic of the fail safe state

Fail safe switch on	Wire color	No pedestrian detection	Pedestrian detection
Relay normal	White	Low	High
Relay normal	Orange	High	Low
Relay failed	White	High	High
Relay failed	Orange	Low	Low
Fail safe switch off	Wire color	No pedestrian detection	Pedestrian detection
Relay normal	White	High	Low
Relay normal	Orange	Low	High
Relay failed	White	High	High
Relay failed	Orange	Low	Low

FAIL SAFE OFF #4 OFF
PIN 1........ 12V to 24V AC/DC+
PIN 2........ 12V to 24V AC/DC-
PIN 3........ N/A
PIN 4........ Relay Normally Closed (N.C.)
PIN 5........ Relay Common (COM)
PIN 6........ Relay Normally Open (N.O.)

Dip Switch Settings

SW	SWITCH DESCRIPTION	SWITCH 'OFF'	SWITCH 'ON'
1*	Detection Direction	Unidirectional Motion detection	Bi-directional Motion detection
2	Pedestrian Motion Sensitivity	Pedestrian Motion More Sensitive	Pedestrian Motion Less Sensitive
3	Not Used	Not Available	Not Available
4	Fail Safe State	Fail Safe Disabled	Fail Safe Enabled
5	Not Used	----------	Must Leave in 'ON' Position
6*	Approach/Depart	Approach	Depart

SW 6 is override when SW 1 is ON

Figure 2.12: SmartWalk XM detection options, green rectangles depict settings used in testing

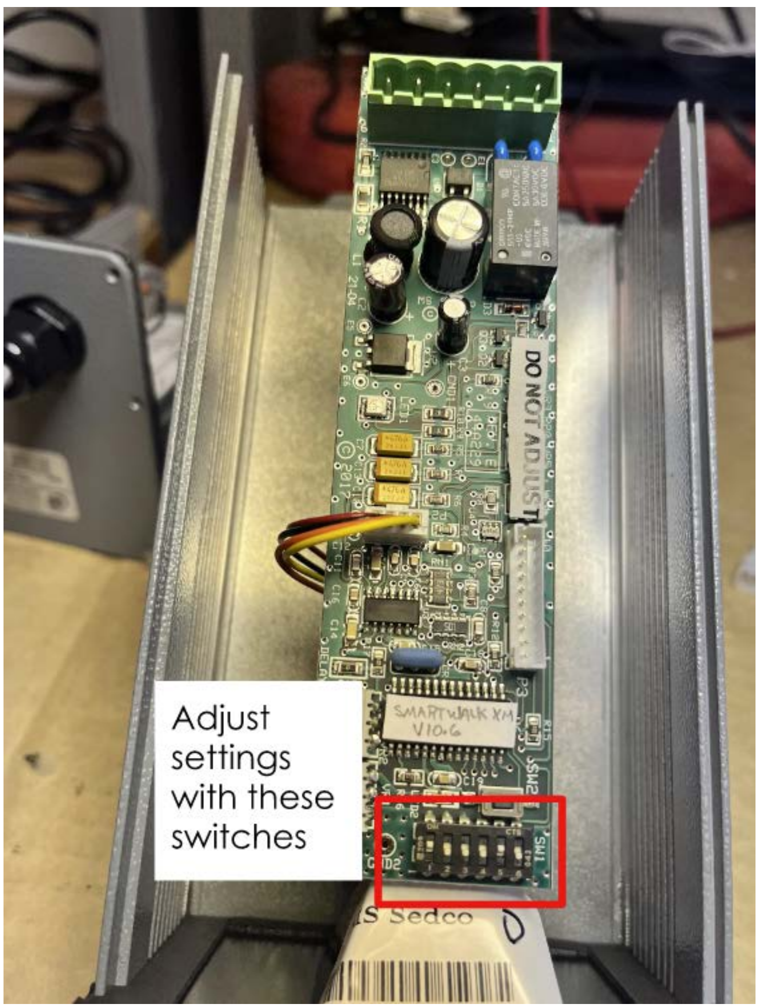

Figure 2.13: Internal components of SmartWalk XM

iComs TMA-011 LV

The iComs manufacturer claims the unit operates in all-weather conditions with little to no maintenance required. To satisfy the claim, a protected sticker has to be placed on the unit after the settings are adjusted. AHMCT did not evaluate environmental performance for the systems.

Figure 2.14: Protected sticker placed over the dial settings

The dials can be turned clockwise or counter-clockwise to adjust the settings. Tables 2.6 and 2.7 demonstrate setting options. iComs has four radio frequency (RF) channels which allows up to four sensors operating in the same location.

Table 2.6: Dial settings on the left when looking at iComs front view (next to the red LED)

Parameter	Value																Units
Detection distance	8				12				16				30				m
Encoder position	*0*	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F	

Factory setting = 0

Table 2.7: Dial settings on the right when looking at iComs front view (next to the green LED)

Parameter	Value			
Uni/bi-directional	Bi-directional		Uni-directional	
Direction	BI	BI	IN	OUT

RF channel	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Encoder position	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F

Factory setting = 0

Other features

Detection indication

Table 2.8: Detection indicator comparison

Sensor type	LED(s) indicator	Sound indicator
AGD 326	1 LED	Toggle beep via browser interface
SmartWalk XM	N/A	N/A
iComs TMA-011 LV	2 LEDs	N/A

The SmartWalk XM and iComs TMA-011 LV do not have a sound indicator when a detection is made. AGD 326 has a toggle beep sound indicator via its browser interface, Figure 2.15. If the browser is not opened, the sound will not beep. The toggle beep can be turned off in the browser.

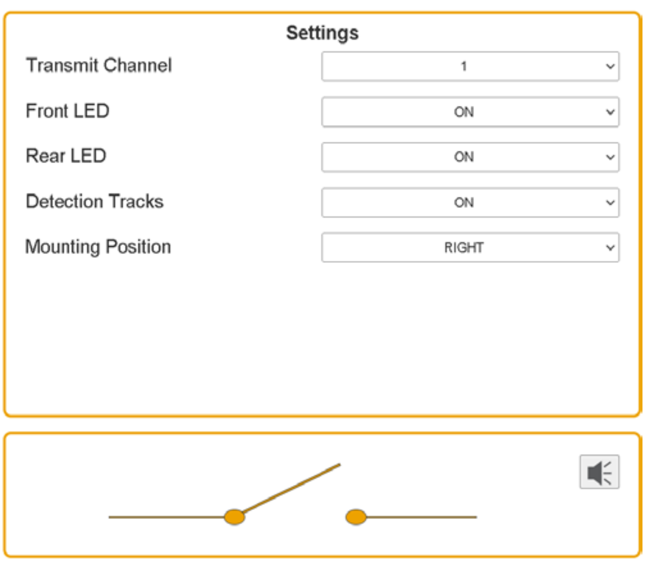

Figure 2.15: Sound indicator on the AGD 326 browser

The AGD 326 has one LED indicator when a detection is made (Figure 2.16). The SmartWalk XM does not have an LED indicator. The iComs TMA-011 LV has two LED indicators when a detection is made (Figure 2.17).

Figure 2.16: LED indicator on the AGD 326 unit, front view

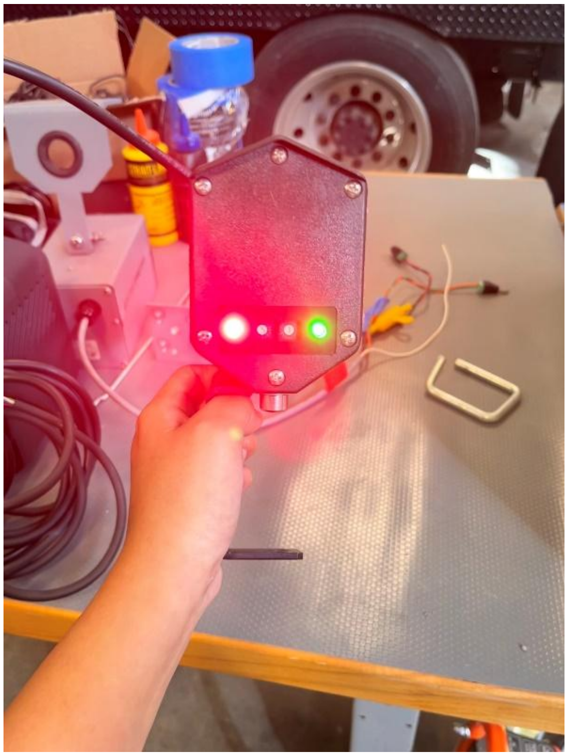

Figure 2.17: LEDs indicator on the iComs unit (without protected sticker), front view

Detection speed range and hold time

Table 2.9: Detection speed range comparison

AGD 326	SmartWalk XM	iComs TMA-011 LV
Minimum detection speed provided by the manufacturer		
1.5 km/h or 0.41 m/s	N/A	0.5 km/h or 0.14 m/s
Maximum detection speed provided by the manufacturer		
N/A	N/A	100 km/h or 27.78 m/s
Minimum detection speed collected from testing		
0.5 m/s	0.5 m/s	0.25 m/s
Hold time after the pedestrian has exited the crosswalk provided by the manufacturer		
800 milliseconds	0.1 to 5 seconds	750 milliseconds

The manufacturer provided detection speed range and hold time for each sensor. Testing was carried out to check manufacturer claims and results were as follows:

- AGD 326
  - When the walking speed was below 0.5 m/s (1.64 ft/s), the sensor did not detect consistently.
  - When the walking speed was below 0.24 m/s (0.79 ft/s), the sensor did not detect at all.
  - The sensor hold time was less than one second. If there was no significant movement, the sensor would stop detecting. The short hold time affected the discontinuation in data as shown in detection range section.
- SmartWalk XM
  - When the walking speed was below 0.5 m/s (1.64 ft/s), the sensor did not detect consistently.
  - When the walking speed was below 0.18 m/s (0.59 ft/s), the sensor did not detect at all.
  - The provided sensor hold time range is 0.1 to 5 seconds. During testing, the sensor hold time was approximately 1 second after the pedestrian had exited the crosswalk.
- iComs TMA-011 LV
  - When walking speed was below 0.25 m/s (0.82 ft/s), the sensor did not detect consistently.
  - The provided minimum speed threshold is 0.14 m/s (0.46 ft/s). During testing, the pedestrian tried to walk as slow as possible but did not reach the minimum speed threshold.
  - The sensor hold time was less than one second. But, iComs detection was more continuous when compared to AGD 326.

Physical comparison

Table 2.10: Physical comparison for the three sensors

Sensors	AGD 326	SmartWalk XM	iComs TMA-011 LV
Dimensions	4.3"W x 6.9"H x 2.8"L	4"W x 4"H x 7"L	2.7"W x 3.9"H x 4.7"L
Weight	1.4 lb	4 lb	0.77 lb

Sensors	AGD 326	SmartWalk XM	iComs TMA-011 LV
Material	Black polycarbonate	Powder coated aluminum	N/A
Coating	IP56	N/A	IP65
Detection method*	FMCW radar	Microprocessor analyzed Doppler microwave	Microwave radar
Frequency	Four selectable from 2412-2472 MHz, 70 MHz band width	24.125 GHz ± 60 MHz, K-band	24.165-24.235 GHz
Power requirements	12/24V AC/DC, 42V AC or 230V AC	12-24V AC or DC±10%	10-30V AC, 50-60 Hz, 12-60V DC
Power consumption	12V DC - 84mA (peak 195mA) 24V DC - 43mA (peak 95mA) 24V AC - 66mA (peak 115mA) 42V AC - 50mA (peak 90mA) 230V AC - 10.1mA (peak 20mA)	2 W maximum	<1.2 W at 12V DC
Relay output	Single opto	Form C, rated at 1 amp at 24V DC	1 relay contact
Output power	N/A	5mW typical, 2mW minimum	N/A
Relay contact ratings	N/A	0.5A:50V AC 1A:24V DC	N/A
Temperature range	-15°C to 60°C	-34°C to 74°C	-40°C to 60°C

* Further explanation below

The AGD 326 manufacturer provided differences between Doppler vs Frequency modulated continuous wave (FMCW) radar. SmartWalk XM and iComs TMA-011 LV are microwave based compared to AGD 326 which is FMCW radar based.

- Doppler
    - Rely on the target altering the original waveform
    - Detection point varies according to target size

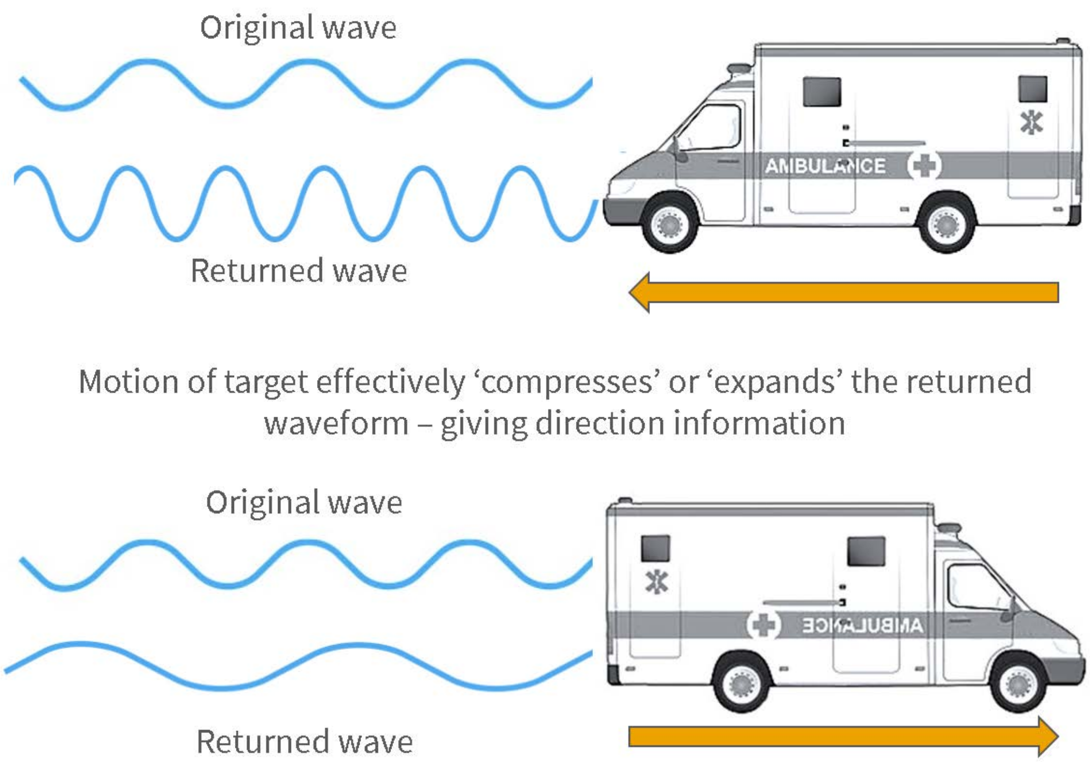

Figure 2.18: Doppler effect (courtesy of AGD 326 product training presentation)

- FMCW
    - Able to determine range and directional information from targets
    - Waveform frequency is subject to a linear increase, allows a reference point for range calculations

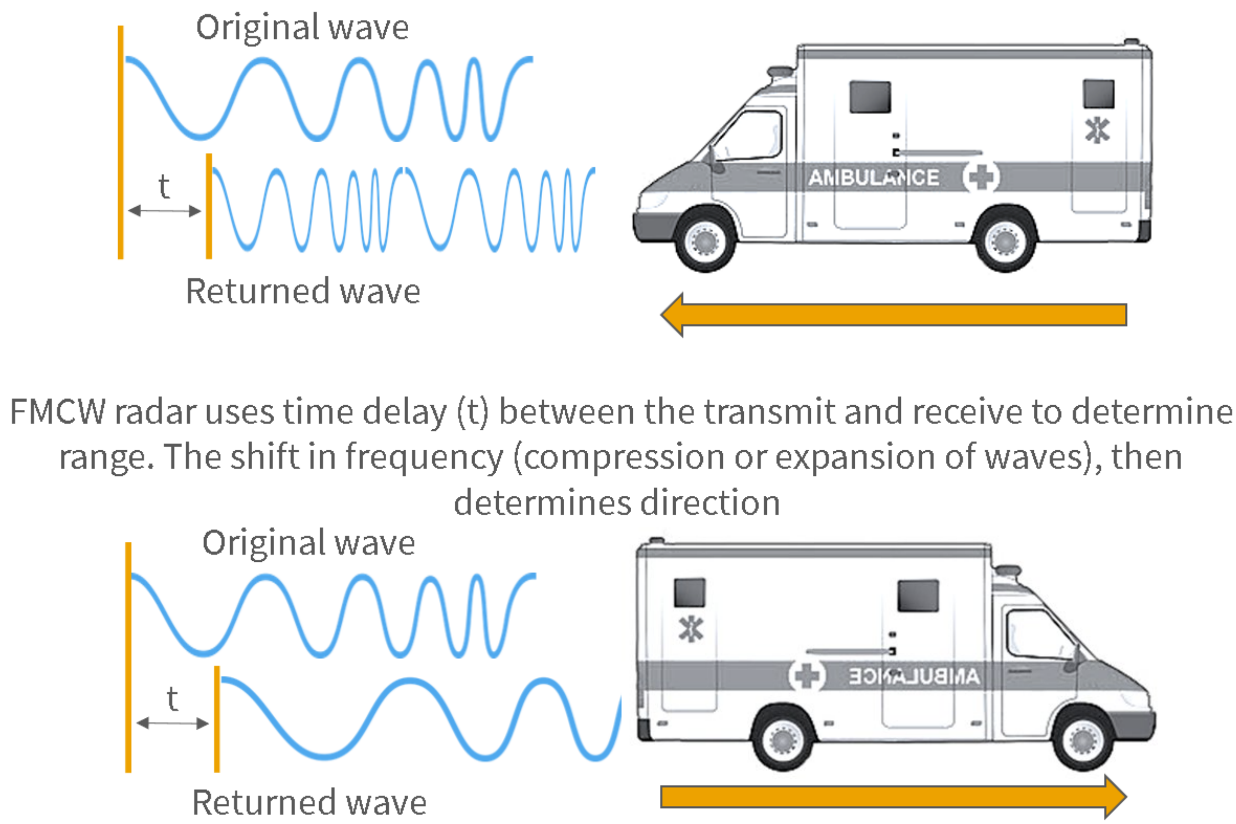

Figure 2.19: FMCW radar (courtesy of AGD 326 product training presentation)

Although the AGD 326 uses different radar technology, all three sensors determine detection when their returned waves have discrepancy compared to their original waves. As a result, all sensors picked up non-pedestrian motions during testing, Figure 2.20. This characteristic can affect how effective the sensor is at adding additional walk time. For instance, if a vehicle enters the detection zone as it makes a right turn, the sensor might pick up vehicular motion and add unnecessary walk time.

Figure 2.20: Sensors picked up non-pedestrian motions

Chapter 3: Conclusions and Recommendations

AGD 326

The AGD 326 maximum detection parameters during testing were less than the manufacturer's claims*. Table E.1 provides comparison between manufacturer claims and testing results.

Table 3.1: AGD 326 detection range testing results compared to manufacturer claims

Tested detection range	Expected detection range	Difference between tested and expected range
Maximum length achieved during all five trials (moving away)		
20.9 m/ 68.6 ft	24.0 m/ 78.7 ft	3.1 m/ 10.2 ft less
Maximum length achieved during all five trials (moving toward)		
20.2 m/ 66.3 ft	24.0 m/ 78.7 ft	3.8 m/ 12.5 ft less
Maximum width achieved during all five trials (moving away)*		
7.0 m/ 23.0 ft	10.0 m/ 32.8 ft	3.0 m/ 9.8 ft less
Maximum width achieved during all five trials (moving toward)*		
8.0 m/ 26.3 ft	10.0 m/ 32.8 ft	2.0 m/ 6.5 ft less
Maximum length achieved during one of the trials		
23.9 m/ 78.4 ft	24.0 m/ 78.7 ft	0.1 m/ 0.3 ft less
Maximum width achieved during one of the trials*		
8.0 m/ 26.3 ft	10.0 m/ 32.8 ft	2.0 m/ 6.5 ft less

*** The AHMCT tested track was not wide enough to accommodate ten meters in width**

As mentioned, maximum width evaluation for the AGD 326 might not be accurate due to limited space on the AHMCT test track.

The AGD 326 was the only sensor with a Wi-Fi browser interface. This browser interface is responsible for adjusting sensor setup as the AGD 326 does not have a physical interface to change setup directly on the unit. The browser interface provides a terminal where code can be input, but this terminal function was not evaluated.

SmartWalk XM

The SmartWalk XM maximum detection parameters during testing exceeded the manufacturer's claims. Table E.2 provides comparison between manufacturer claims and testing results.

Table 3.2: SmartWalk XM detection range testing results compared to manufacturer claims

Tested detection range	Expected detection range	Difference between tested and expected range
Maximum length achieved during all five trials (moving away)		
24.2 m/ 79.4 ft	16.8 m/ 55 ft	7.4 m/ 24.4 ft more
Maximum length achieved during all five trials (moving toward)		
19.0 m/ 62.3 ft	16.8 m/ 55 ft	2.2 m/ 7.3 ft more
Maximum width achieved during all five trials (moving away)*		
6.0 m/ 19.6 ft	4.6 m/ 15 ft	1.4 m/ 4.6 ft more
Maximum width achieved during all five trials (moving toward)*		
6.0 m/ 19.6 ft	4.6 m/ 15 ft	1.4 m/ 4.6 ft more
Maximum length achieved during one of the trials		
31 m/ 101.7 ft	16.8 m/ 55 ft	14.2 m/ 46.7 ft more
Maximum width achieved during one of the trials*		
6.0 m/ 19.6 ft	4.6 m/ 15 ft	1.4 m/ 4.6 ft more

The SmartWalk XM was the only sensor to have detection modes such as pedestrian motion sensitivity and a fail-safe state. However, to adjust its settings, the SmartWalk XM cover has to be unscrewed and removed so the settings can be adjusted internally.

iComs TMA-011 LV

The iComs TMA-011 LV maximum detection parameters during testing were less than the manufacturer's claims. Table E.3 provides comparison between manufacturer claims and testing results.

Table 3.3: iComs TMA-011 LV detection range testing results compared to manufacturer claims

Tested detection range	Expected detection range	Difference between tested and expected range
Maximum length achieved during all five trials (moving away)		
23.0 m/ 75.5 ft	30.0 m/ 98.4 ft	7.0 m/ 22.9 ft less
Maximum length achieved during all five trials (moving toward)		
19.1 m/ 62.7 ft	30.0 m/ 98.4 ft	10.9 m/ 35.7 ft less
Maximum width achieved during all five trials (moving away)*		
8.0 m/ 26.3 ft	N/A	N/A
Maximum width achieved during all five trials (moving toward)*		
8.0 m/ 26.3 ft	N/A	N/A
Maximum length achieved during one of the trials		
28.1 m/ 92.2 ft	30.0 m/ 98.4 ft	1.9 m/ 6.2 ft less
Maximum width achieved during one of the trials*		
8.0 m/ 26.3 ft	N/A	N/A

The iComs TMA-011 LV was the only sensor that can operate in all weather conditions with minimal maintenance needed, according to manufacturer claims. To satisfy these claims, a protected sticker (provided along with the sensor) must be placed on the unit after the desired settings are set. AHMCT did not test or evaluate environmental performance of the sensors in this study.

Table 3.4: Comparison across three sensors

Sensors	AGD 326	SmartWalk XM	iComs TMA-011 LV
Detection length adjustment	1 to 24 meter, in 1 meter increments 3.3 to 78.7 feet, in 3.3 feet increments	Not adjustable	8, 12, 16, 30 meter 26.2, 39.4, 52.5, 98.4 feet
Detection width adjustment	2 to 10 meter, in 1 meter increments 6.6 to 32.7 feet, in 3.3 feet increments	Not adjustable	Not adjustable
Detection direction adjustment	Bi-directional	Uni- or bi-directional	Uni- or bi-directional
Detection LED indicator	1 LED	0 LEDs	2 LEDs
Detection sound indicator	Yes, via browser interface	No	No
Minimum detection speed provided by manufacturer	1.5 km/h or 0.41 m/s	N/A	0.5 km/h or 0.14 m/s
Minimum detection speed during testing	0.5 m/s	0.5 m/s	0.25 m/s
Maximum detection speed provided	N/A	N/A	100 km/h or 27.78 m/s

Sensors	AGD 326	SmartWalk XM	iComs TMA-011 LV
by manufacturer			
Maximum detection speed during testing	Was not tested	Was not tested	Was not tested
Hold time after pedestrian had exited the crosswalk provided by manufacturer	800 milliseconds	0.1 to 5 seconds	750 milliseconds
Hold time after pedestrian had exited the crosswalk during testing	Less than one second	Approximately one second	Less than one second
Dimensions	4.3"W x 6.9"H x 2.8"L	4"W x 4"H x 7"L	2.7"W x 3.9"H x 4.7"L
Weight	1.4 lb	4 lb	0.77 lb
Material	Black polycarbonate	Powder coated aluminum	N/A
Coating	IP56	N/A	IP65
Detection method	FMCW radar	Microprocessor analyzed Doppler microwave	Microwave radar
Frequency	Four selectable from 2412-2472 MHz, 70 MHz band width	24.125 GHz ± 60 MHz, K-band	24.165-24.235 GHz
Power requirements	12/24V AC/DC, 42V AC, or 230V AC	12-24V AC or DC±10%	10-30V AC, 50-60 Hz, 12-60V DC

Sensors	AGD 326	SmartWalk XM	iComs TMA-011 LV
Power consumption	12V DC - 84mA (peak 195mA) 24V DC - 43mA (peak 95mA) 24V AC - 66mA (peak 115mA) 42V AC - 50mA (peak 90mA) 230V AC - 10.1mA (peak 20mA)	2 W maximum	<1.2 W at 12V DC
Relay output	Single opto	Form C, rated at 1 amp at 24V DC	1 relay contact
Output power	N/A	5mW typical, 2mW minimum	N/A
Relay contact ratings	N/A	0.5A:50V AC 1A:24V DC	N/A
Temperature range	-15°C to 60°C	-34°C to 74°C	-40°C to 60°C

Overall, AHMCT would recommend the AGD 326 sensor. First, the AGD 326 enables detection length and width to be adjusted in one-meter increments. This characteristic allows the user the most flexibility to match the dimensions of the detection zone to those of the crosswalk. Second, the AGD 326 provides a Wi-Fi browser, providing a user-friendly interface for sensor settings that is more straightforward compared to the dials of the iComs TMA-011 LV and the switches of the SmartWalk XM. In other words, a new user would not need to make as much effort to understand how the AGD 326 settings work compared to the iComs and SmartWalk XM settings. Third, the AGD 326 sensor gives the user the option to input command code from its terminal, although this functionality was not evaluated. In general, the AGD 326 sensor has unique features that are more valuable than the SmartWalk XM and iComs TMA-011 LV.

A weakness that all sensors have in common is the inability to distinguish between non-pedestrian and pedestrian motion. Sensors can pick up potential vehicular motion and add unnecessary walk time, which decreases the effectiveness of the system.

Appendix A:
AGD 326 evaluation draft

Specifications provided by the manufacturer

AGD 326 is one of three sensors to be evaluated. Its notable features include: providing easy remote setup via smartphone, tablet, or laptop, tracing and marking detection via Wi-Fi, and co-location of up to four detectors. Tables A.1 and A.2 provide AGD 326 manufacturer specifications.

Table A.1: Sensors physical comparison

Physical attributes			
Sensors	**AGD 326**	**SmartWalk XM**	**iComs TMA-011 LV**
Dimensions	4.3"W x 6.9"H x 2.8"L 109x175x71 mm	4"W x 4"H x 7"L 101x101x178 mm	2.7"W x 3.9"H x 4.7"L 68x99x119 mm
Weight	1.4 lb 0.650 kg	4 lb 1.814 kg	0.77 lb 0.350 kg
Material	Black polycarbonate	Powder-coated aluminum	N/A
Coating	IP56	N/A	IP65

Table A.2: AGD 326 manufacturer specifications

Method	FMCW Radar
Frequency	Four selectable via Wi-Fi 2412-2472 MHz (70 MHz band width)
Range	Maximum 24 meter in length Maximum 10 meter in width
Speed threshold	1.5 kph or 0.4 m/s
Mounting height	2 meter minimum, 4 meter maximum
Power	12 VDC
Operation temp	-15°C to 60°C
Weight	1.4 lb/0.650 kg
Hold time	800 milliseconds

To set up the sensor Wi-Fi features, the steps are as follows:

1. Power up the sensor, wait for the LED on the bottom to flash 5 times.
2. The unit should have a serial number format as 326:XXXXXX-XXXX (the 'X' denotes the S/N). The Wi-Fi will display the unit serial number. Connect to the Wi-Fi, and input the default password as AGD326:XXXXXX-XXXX (the 'X' denotes the S/N)
3. After the Wi-Fi is connected, enter the address http://192.168.4.1 to access the sensor browser

4. The sensor browser gives the user the ability to change settings and keep track of the detected target within/nearby the outline zone, as well as adjust other features, as depicted in Figures A.1-A.3.

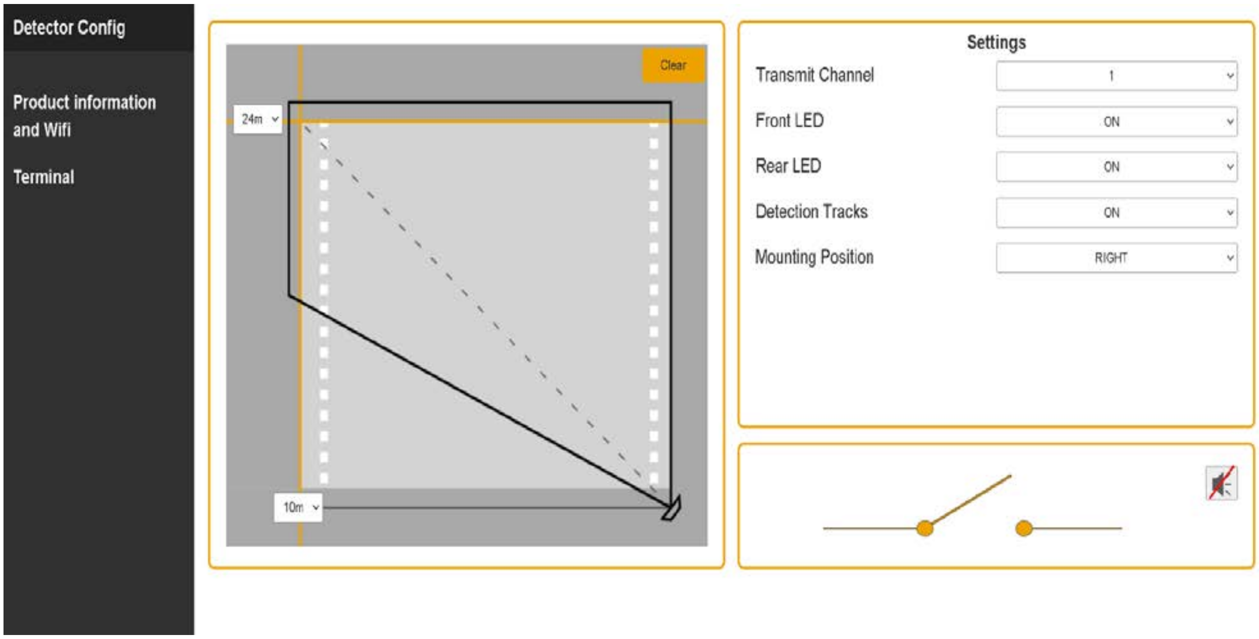

Figure A.1: User interface of AGD 326 under "Detector Config" in the browser

In Figure A.1 browser, the setting options are:

- Transmit channel, up to 4 channels
- Front LED can be turned on, off or set to timeout
- Rear LED can be turned on, off or set to timeout
- Detection tracks can be turned on, or auto-clear after 5, 10, or 20 seconds
- Mounting position can be right or left
- The length setup is from 2 to 24 meters in increments of 1 meter
- The width setup is from 2 to 10 meter in the increments of 1 meter

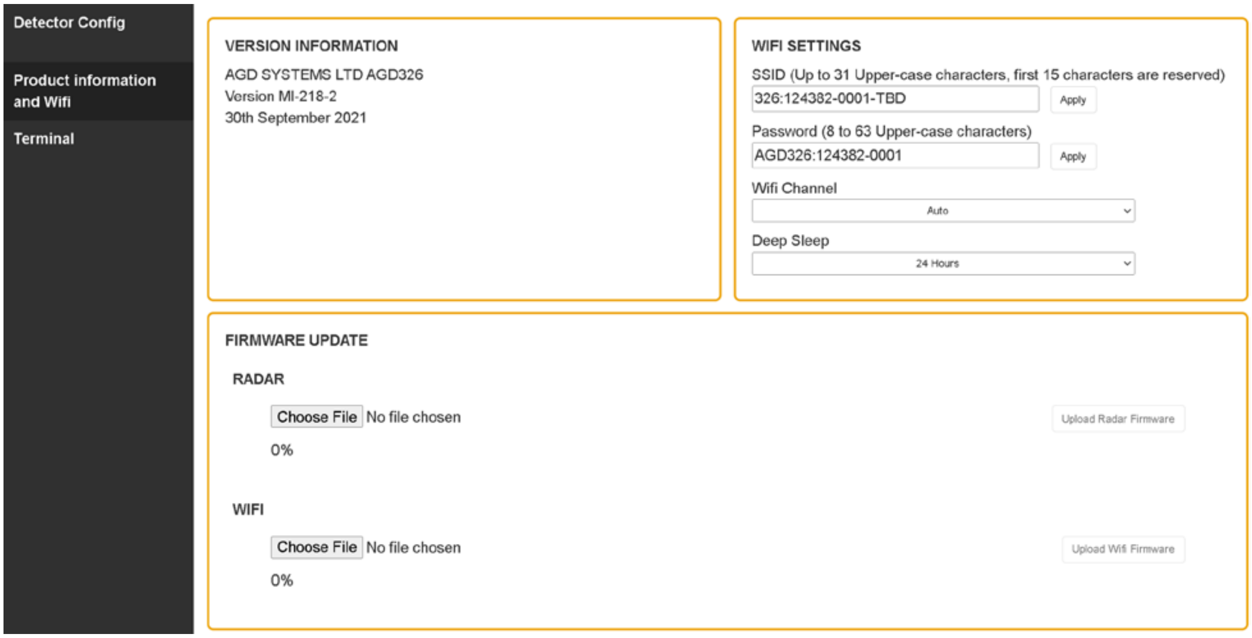

Figure A.2: User interface of AGD 326 under "Product information and Wifi" in the browser

Figure A.3: User interface of AGD 326 under "Terminal" in the browser

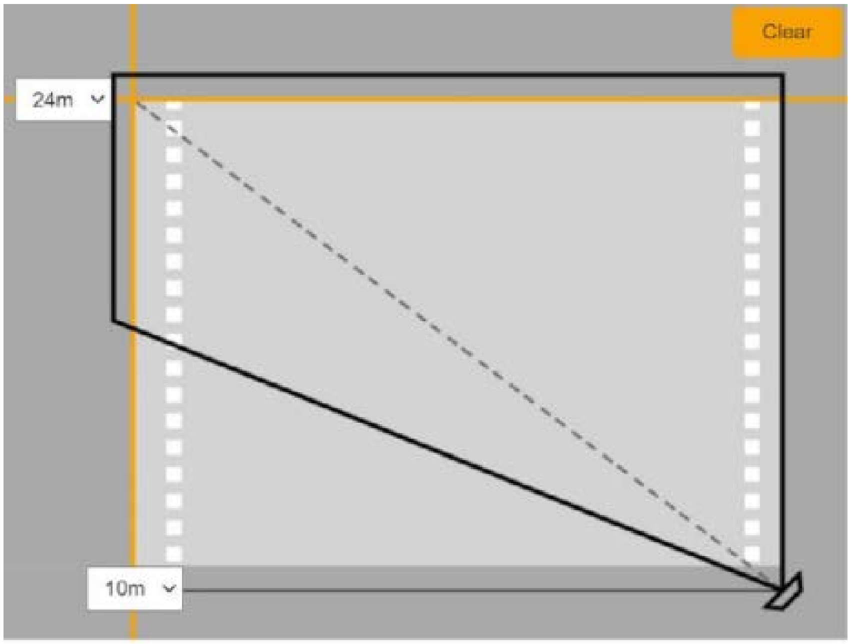

Figure A.4: Detection range viewing from the top

The detection range is indicated by the black outline. To ensure that the sensor is covering 24 meters in length and 10 meters in width, the manufacturer recommends that the sensor is aligned with the end corner of the crosswalk, as shown in Figure A.5.

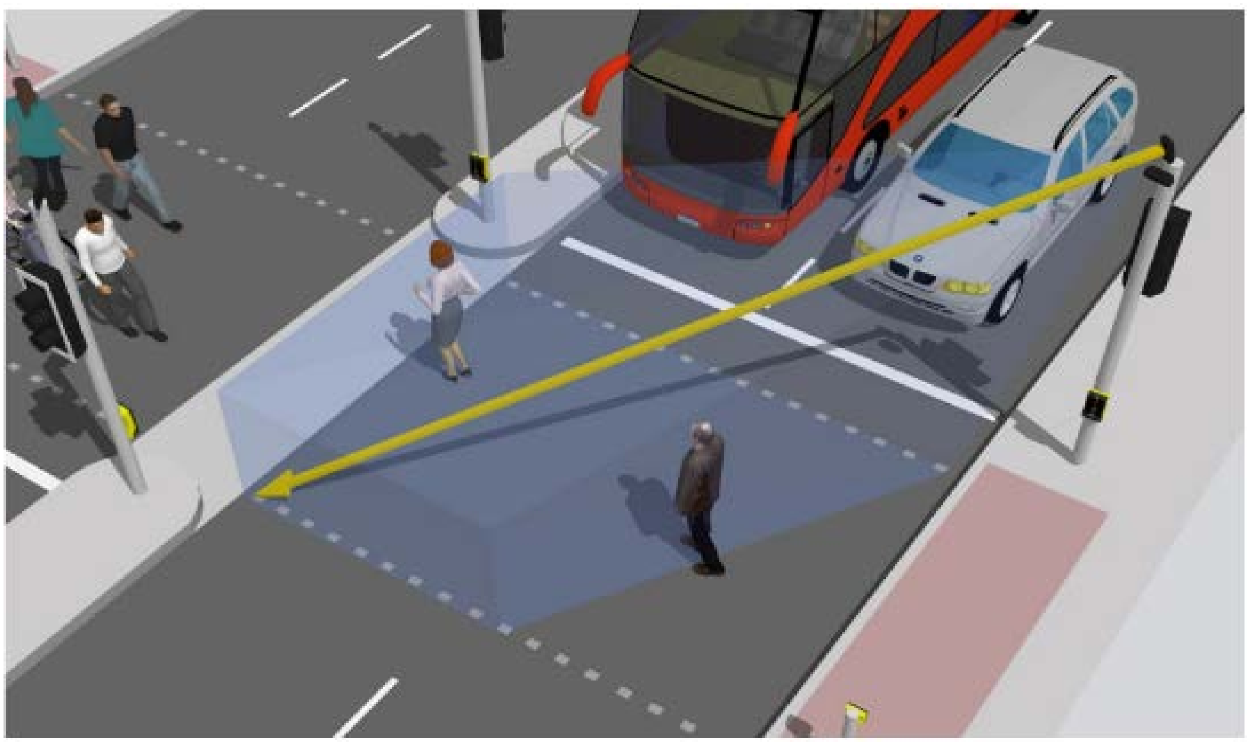

Figure A.5: Visualization of AGD 326 alignment

To test radar alignment, a walk test should be conducted. First, walk diagonally from the sensor to the corner of the crosswalk, as in Figure A.6. Then, walk in the middle and on the sides of the crosswalk, as in Figure A.7. This walk test will ensure that the range is fully covered.

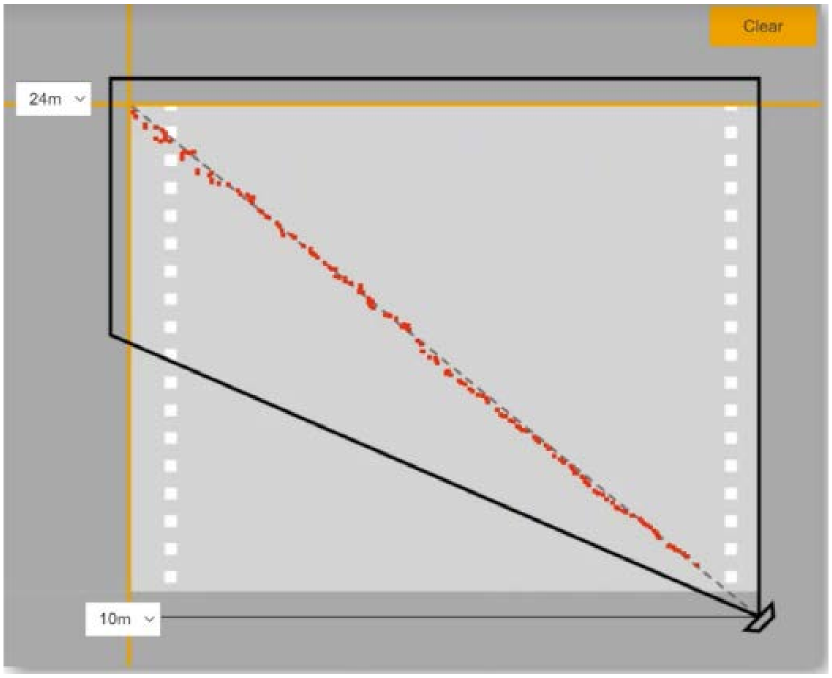

Figure A.6: Diagonal walk test

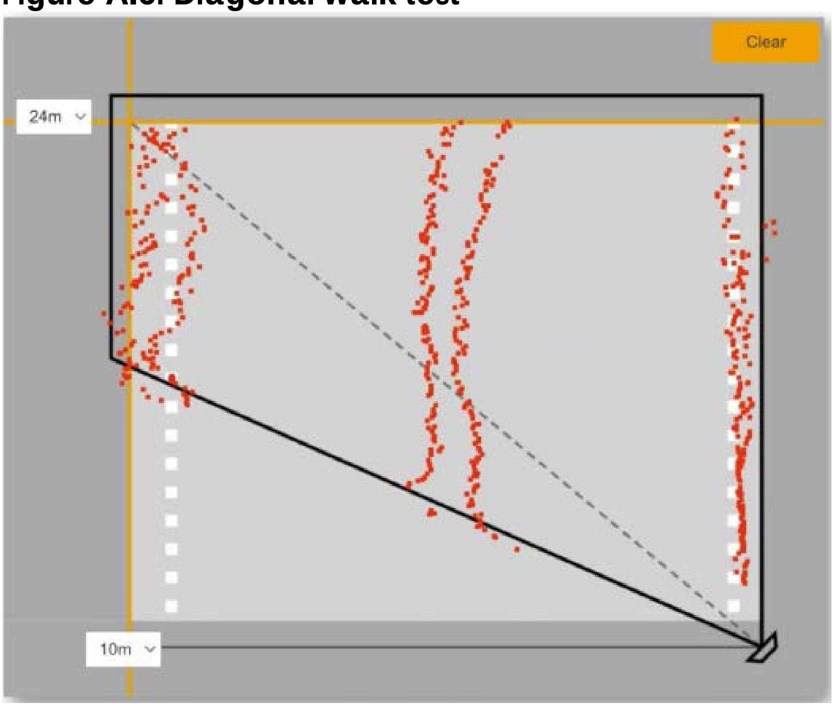

Figure A.7: Sides and middle walk test

Testing procedure

The testing plan for AGD 326 sensor is similar to SmartWalk XM, except the placement of AGD 326 is different. For AGD 326 detection range to be fully evaluated, the placement of AGD 326 should be where the manufacturer recommends.

Planning

An approach is developed to evaluate the crosswalk sensor. The sensor will be mounted on a fixed, rigid apparatus to ensure there is no instability from environmental factors. For testing, the apparatus was set up on a truck for convenient mounting and transporting. It is challenging to park the truck so that the sensor will align as intended.

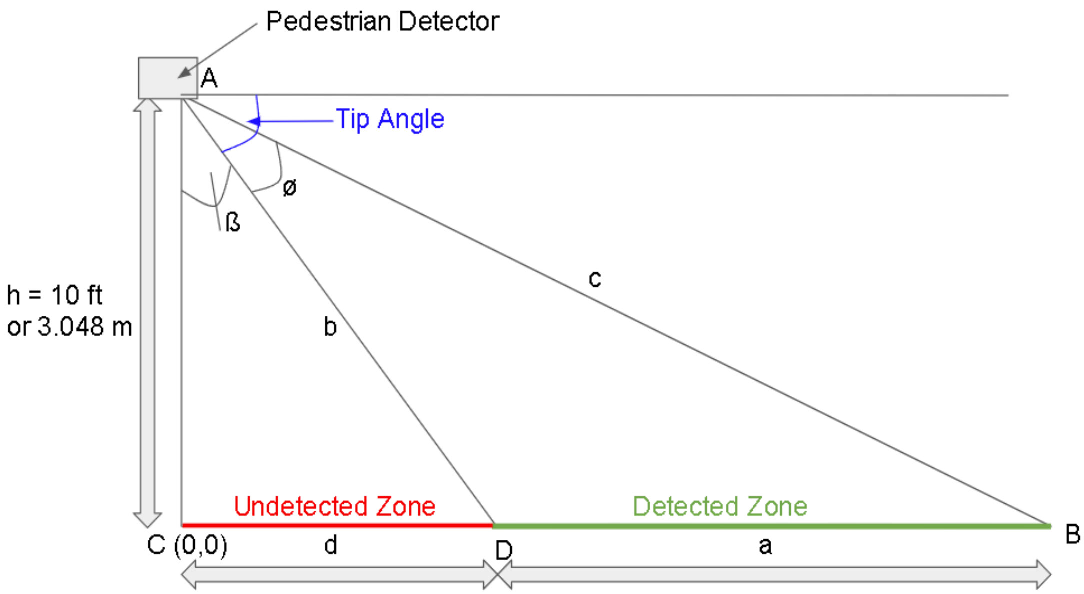

Figure A.8: Front view of the setup

β - Undetected angle

φ - Sensor's spread angle

Tip angle - Sensor's angle with respect to the horizontal plane, φ/2

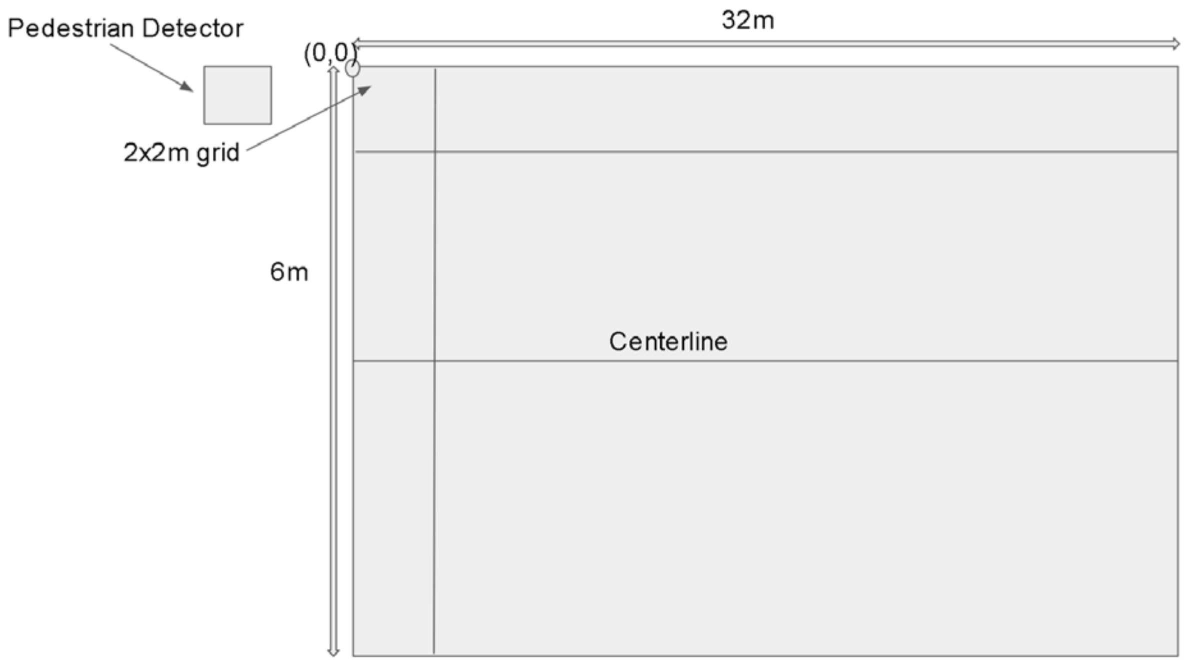

Figure A.9: Top view of the setup

The AGD 326 has an LED indicator and a sound indicator when a detection is made. Those features are shown in Figures A.10 and A.11.

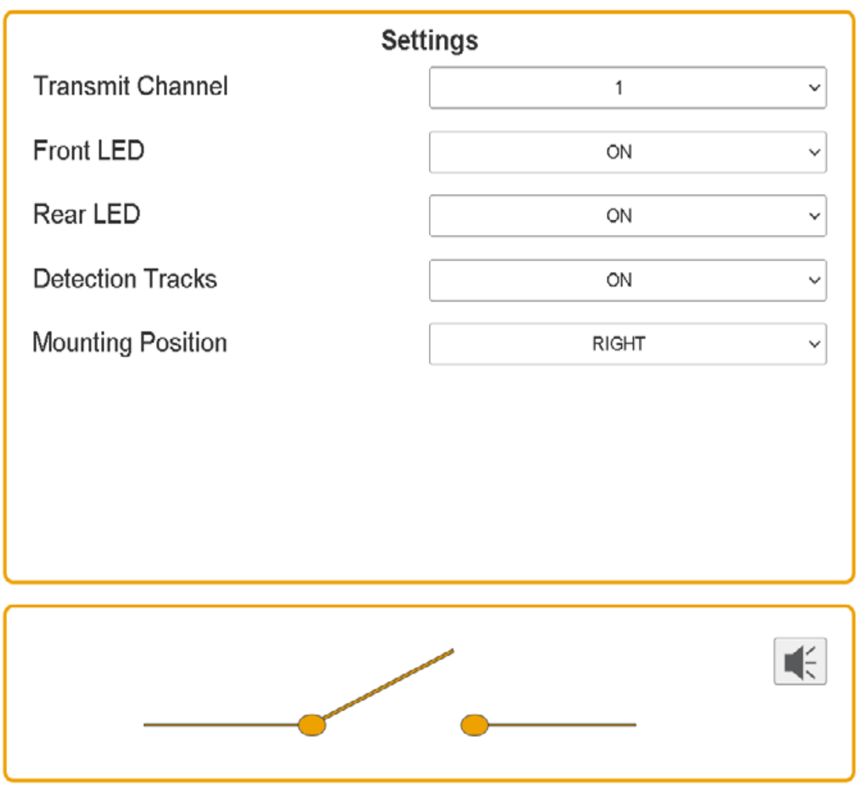

Figure A.10: Sound indicator "toggle beep"

Figure A.11: LED indicator display

For testing, a customized cable with an LED indicator was made. A camera was set up so that it captured the testing being conducted in the field as well as the customized LED indicator.

Figure A.12 shows how the sensor and the customized LED indicator were powered.

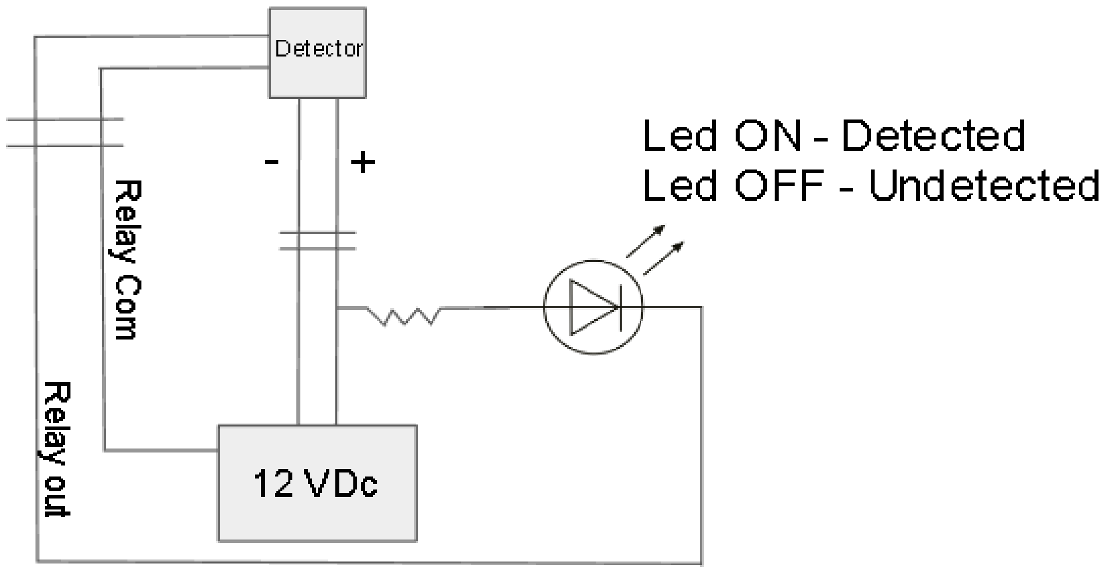

Figure A.12: Circuit diagram for crosswalk sensor(s)

Procedure

Setup the apparatus

Figure A.13 shows the components of the setup.

Figure A.13: Apparatus setup

On the left of the AGD 326 sensor, a phone control camera is setup to capture the walking process on the grid as well as the lightbulb indicator. The system is powered by the portable charger. A laptop was set up to utilize the AGD 326 browser.

Set up the grid

Figure A.14 depicts the spray-painted grid on the left and demonstrates the grid labeling system on the right. There are 16 rows and 3 columns (R is right, L is left, and C is center). Each square is 2x2 meters.

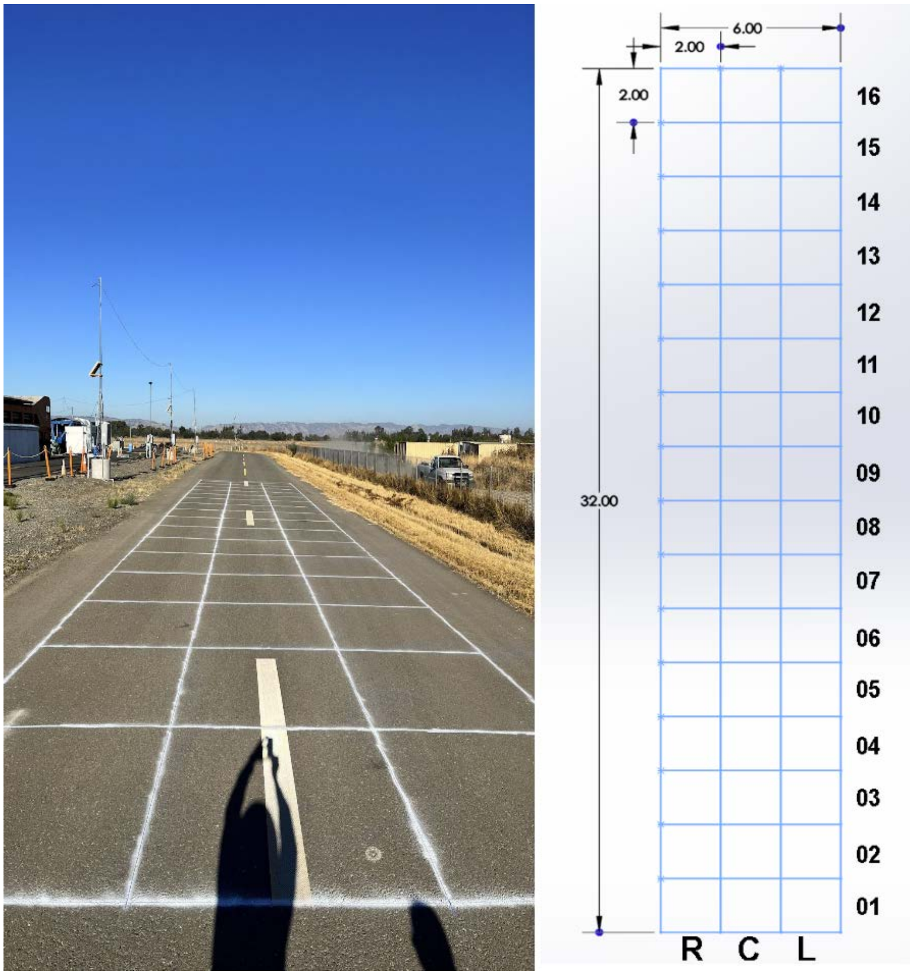

Figure A.14: Spray-painted grid and its labeling system

Drive the truck to the grid

Although the desired position for the sensor is at the centerline of the grid, it is challenging to park the truck at that exact location. The truck was parked as close to the planned location as possible.

The distance that enabled the camera to capture the whole grid and AGD 326 detection range is estimated to be 124.1 inches or 10.432 feet.

The distance from the sensor to the (0,0) coordinate of the grid is estimated to be 11.8 inches or approximately 1 feet. It is difficult to achieve high accuracy because the test track is not perfectly flat. With these parameters, the sensor placement will be located as shown in Figure A.15.

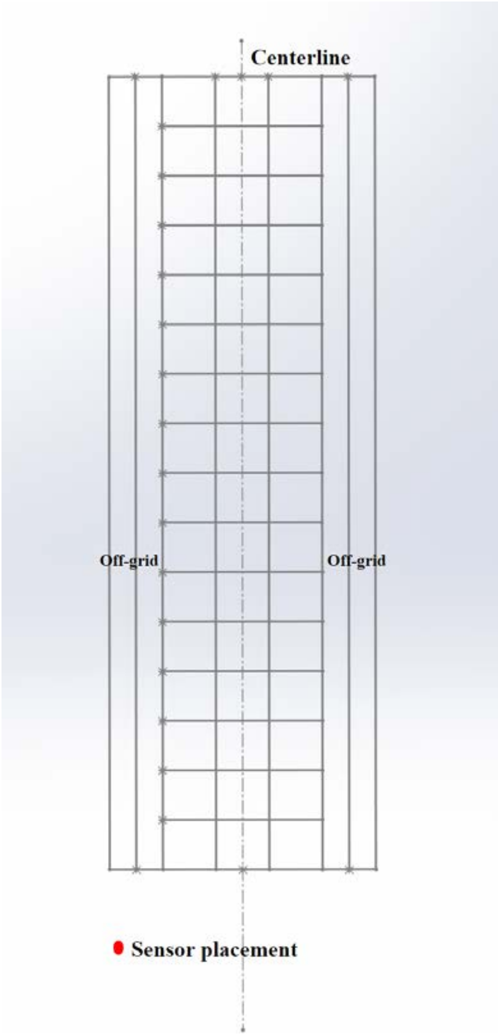

Figure A.15: Sensor placement during the testing

Achieving exactness for the sensor parameters is also challenging. The truck is parked on an uneven surface, which might cause the sensor to have a larger tip angle than anticipated. The tip angle of the sensor is 27.1 degrees, the tilt angle of the truck is 2.1 degrees, which totals the angle to be 29.2 degrees. The sensor tilts to the right at 0.1 degrees.

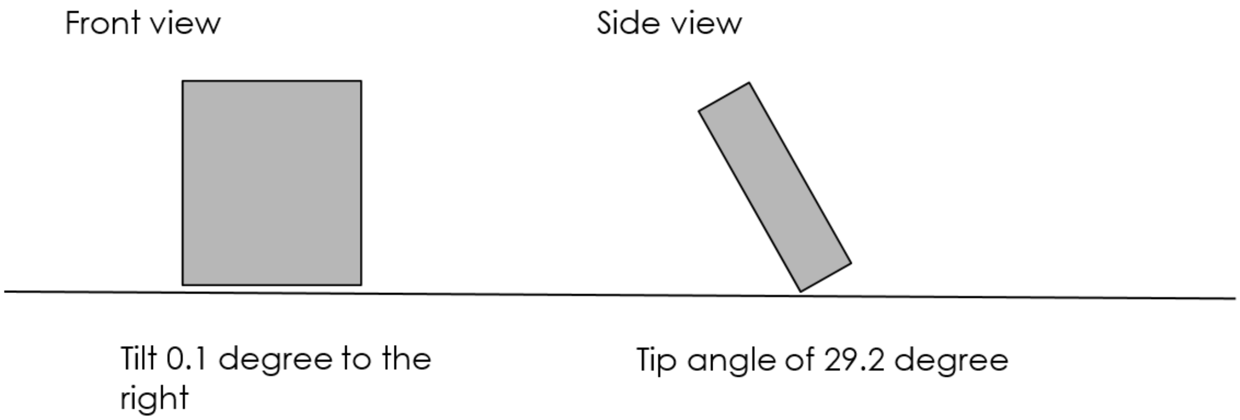

Figure A.16: Visualization of the angles mentioned above

Record the testing process

Mark the starting point and ending point of detection based on the recordings. Figures A.17 and A.18 demonstrate the process.

Figure A.17: An excerpt of the test recording

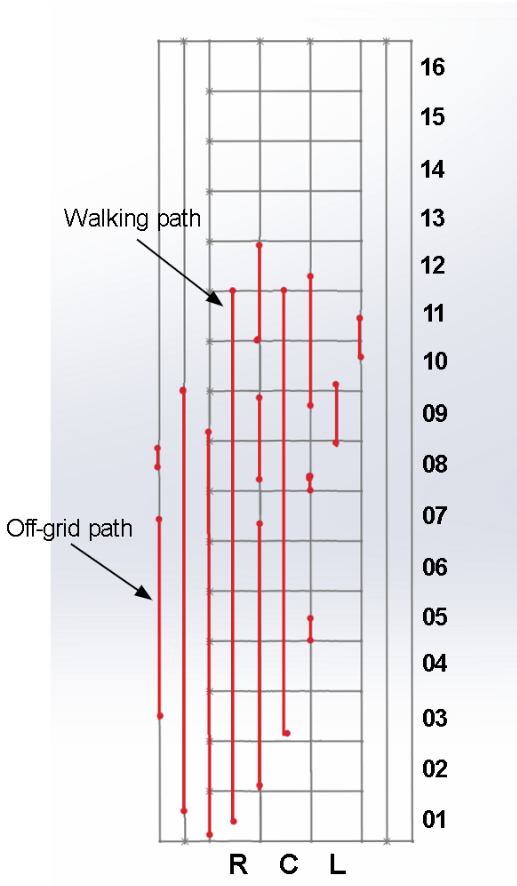

Figure A.18: Sample detected zones marked on the grid

Based on the recordings, the grid is marked as shown in Figure A.18. The walking path is straight from the starting point to the ending point. In addition, off-grid testing was conducted to ensure the detection range is fully covered. There were five trials to ensure the accuracy of the results.

Since AGD 326 has detection tracing feature, this feature was utilized along with the recordings.

Results of evaluated features

Remote setup features

AGD 326 Wi-Fi setup and hold time features

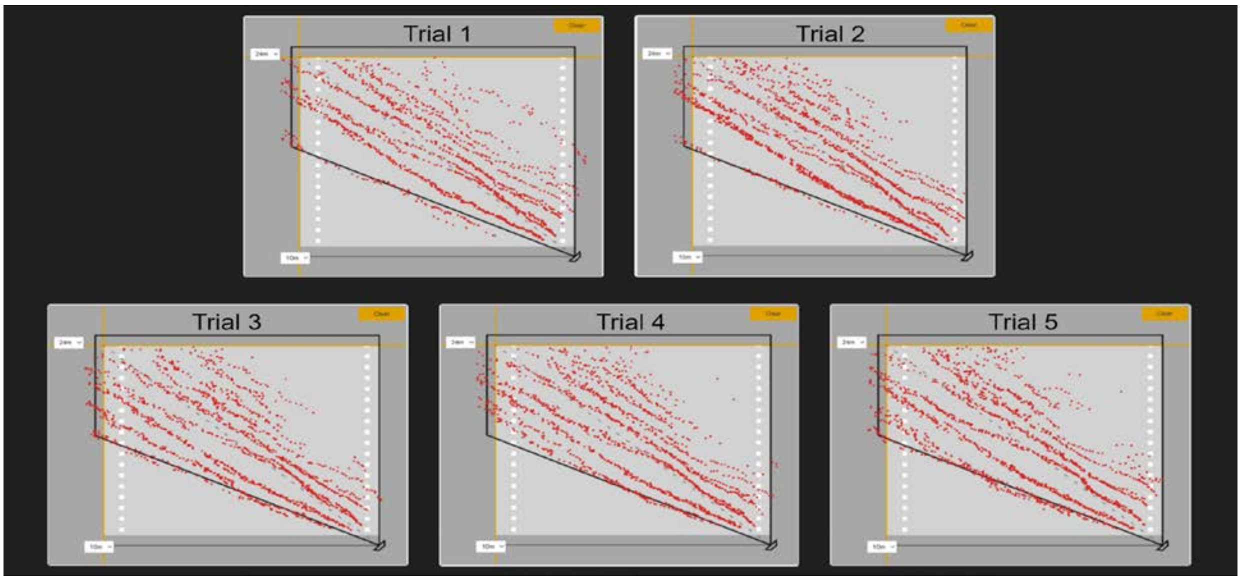

Figure A.19: Tracing of the five trials

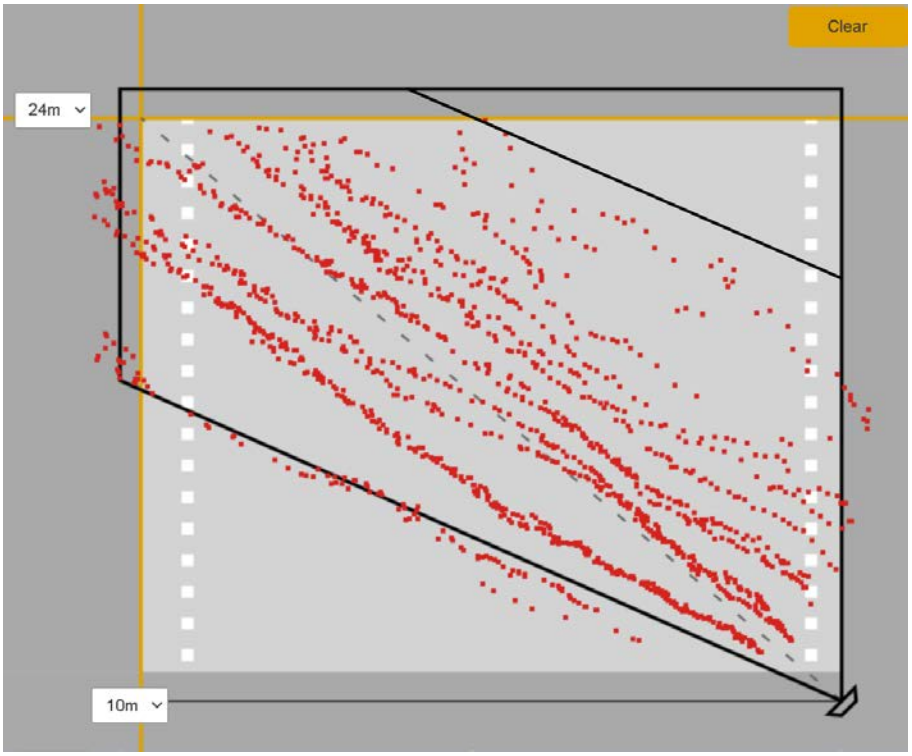

Figure A.20: Black outline represents test track maximum space

Figure A.19 demonstrates the detection tracing in bidirectional direction (moving away and toward the sensor). There is a limitation for the test track. The test track is not wide enough to fully cover 10 meter, Figure A.20.

Based on Figure A.19, the detection tracing is not continuous. The hold time of AGD 326 is 800 milliseconds, which is relatively small. Because of these characteristics, there are walking paths for which detection is discontinuous if the motion is not picked up consistently. In short, the pedestrian can be in the always-detected zone, but that individual detection may not be continuous. Also detection can be cut short when the pedestrian's motion is not significant enough for the relay to pick up. The data collected in Figures A.21 and A.22 reflects the detection discontinuity.

Detection Range

Moving away from sensor

Figure A.21: Detection zone when moving away from the sensor (dimension in feet)

In Figure A.21, each trial data point was input onto the graph. The black outline is the grid. As mentioned, there is off-grid testing to ensure the detection range is fully covered. Data points outside of the black outline are off-grid.

The cross-hatching shows the always-detected zone. As mentioned, there are discontinuous detections within the always-detected zone. To determine the always-detected zone, averages of the data points were taken and plotted in Figure A.21.

The maximum width achieved in the always-detected zone is 7 meters, which is 3 meters less than the given manufacturer specification. The maximum width achieved is 22.96 feet. However, as mentioned, the testing track is not wide enough to evaluate 10 meters.

The maximum length achieved in the always-detected zone is 20.9 meters, which is 3.1 meters less than the given manufacturer specification. The maximum length achieved is 68.57 feet.

Moving toward the sensor

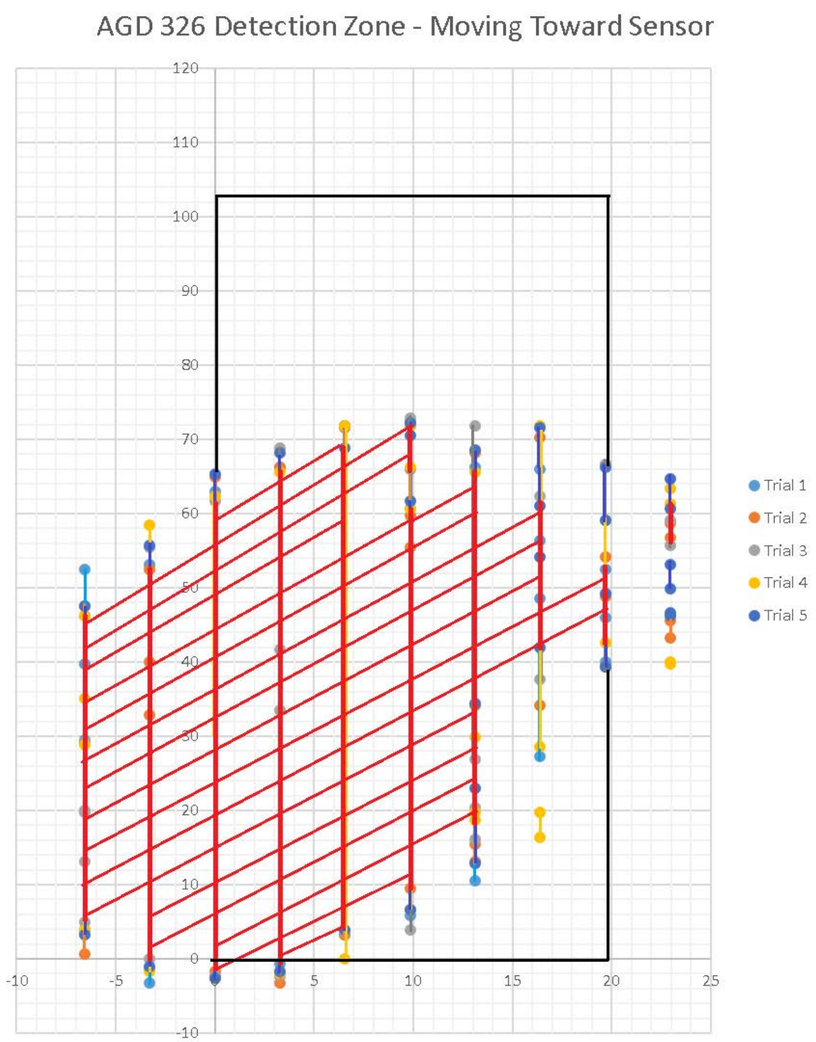

Figure A.22: Detection zone when moving toward the sensor (dimension in feet)

The cross-hatching shows the always-detected zone. The process of obtaining Figure A.22 is the same as for Figure A.21, each trial data point was input onto the graph. As mentioned, there are discontinuous paths within the always-detected zone. To determine the always-detected zone, averages of the data points were taken and plotted in Figure A.22.

The maximum width achieved in the always-detected zone is 8 meters, which is 2 meters less than the given specification. The maximum width achieved is 26.25 feet. However, as noted, the testing track is not wide enough to evaluate 10 meters.

The maximum length achieved in the always-detected zone is 20.2 meters which is 3.8 meters less than the given specification. The maximum length achieved is 66.27 feet.

Minimum Detection Speed

The AGD 326 specification sheets states the sensor has 1.5 kph or 0.4 m/s minimum speed threshold.

Testing was conducted to determine how well the sensor detects in low-speed settings. When the walking speed is below 0.5 m/s (1.64 ft/s), the sensor does not detect consistently. When the walking speed is below 0.24 m/s (0.79 ft/s), the sensor does not detect at all.

In addition, AGD 326 picked up a non-pedestrian motion, Figure A.23. Because AGD 326 is a radar-based motion sensor, its relay picks up changes in the radio wave. Thus AGD 326 does not have the ability to distinguish between pedestrian and vehicle motion. AGD 326 can pick up a vehicle motion and add unnecessary walk time.

Figure A.23: AGD 326 sensor picked up the forklift motion

Detection LEDs

AGD 326 has a detection LED on its body and has a sound indication in its browser interface to indicate relay activation. These features can be turned on or off in the AGD 326 browser interface.

Detection Mode

AGD 326 detection mode is default to the manufacturer. It is not recommended to open its internal components.

Extension Time Range and Accuracy

AGD 326 has 800 milliseconds hold time after the pedestrian has exited the crosswalk.

As mentioned, AGD 326 does not have the ability to distinguish between a pedestrian and vehicle motion. This characteristic can be a disadvantage since a vehicle can get into the sensor detection range and add unnecessary walk time.

Appendix B:
SmartWalk XM evaluation draft

Specifications provided by the manufacturer

SmartWalk XM is one of three crosswalk sensors to be evaluated. Its notable features include: minimizing false activations from vehicular traffic and having an output ready to wire into crosswalk timing control/warning lights. Tables B.1 and B.2 provide SmartWalk XM manufacturer specifications.

Table B.1: Sensors physical comparison

Physical attributes			
Sensors	AGD 326	SmartWalk XM	iComs TMA-011 LV
Dimensions	4.3"W x 6.9"H x 2.8"L 109x175x71 mm	4"W x 4"H x 7"L 101x101x178 mm	2.7"W x 3.9"H x 4.7"L 68x99x119 mm
Weight	1.4 lb 0.650 kg	4 lb 1.814 kg	0.77 lb 0.350 kg
Material	Black polycarbonate	Powder coated aluminum	N/A
Coating	IP56	N/A	IP65

Table B.2: SmartWalk XM manufacturer specifications

Method	Doppler microwave
Frequency	24.125 GHz (K-band) +/- 60 MHz
Range	See Figure 1
Speed threshold	N/A
Mounting height	10-12 feet
Power	12 VDC
Operation temp	-34 to 74° C
Weight	4 lb/1.8 kg
Extension time	0.1 to 5 sec

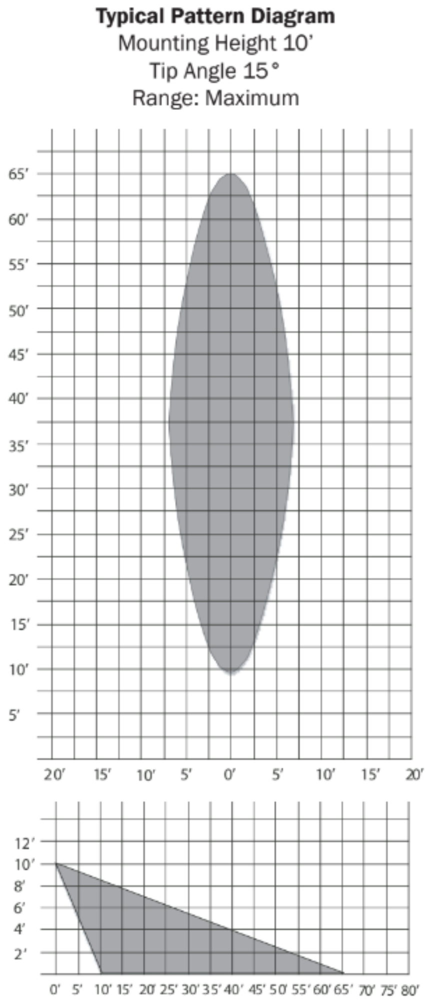

Figure B.1: Detection range viewing from the top and the side

Using Figure B.1, the sensor spread angle is calculated to be 36 degrees. The undetected zone is estimated to be 10 feet from the sensor. With this information, the detection range is predicted to be 55 feet maximum in length, and 15 feet maximum in width with the setup of 15 degree tip angle and 10 feet mounting height.

Testing procedure

Planning

An approach is developed to evaluate the crosswalk. The sensor will be mounted on a fixed, rigid apparatus to ensure there is no instability from environmental factors. For testing, the apparatus was set up on a truck for convenient mounting and transporting. It is challenging to park the truck so that the sensor will align exactly at the centerline.

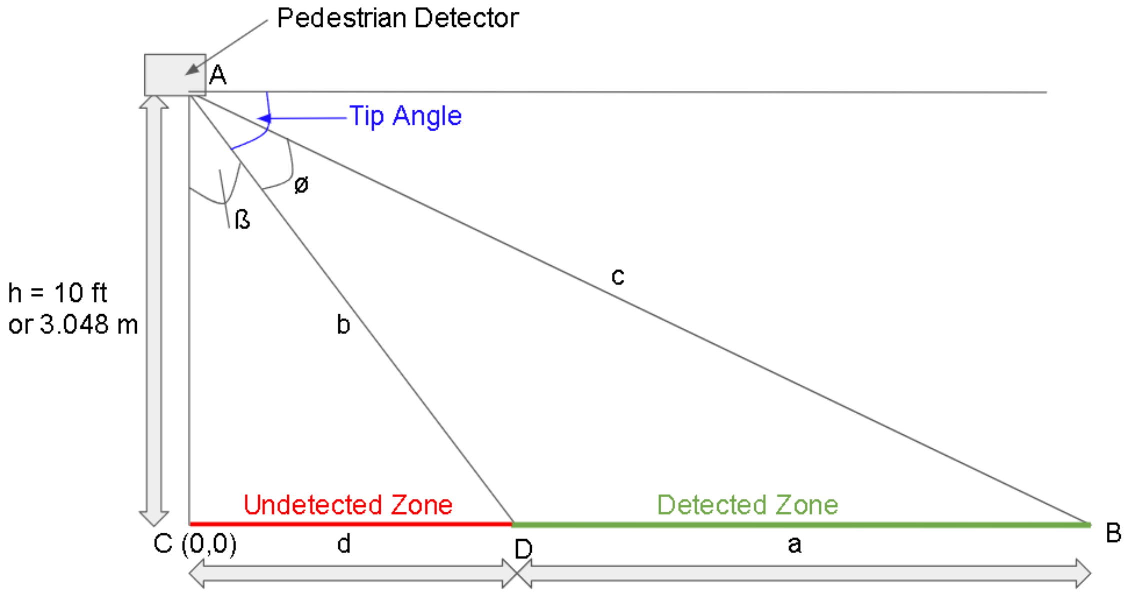

Figure B.2: Front view of the setup

β - Undetected angle

φ - Sensor's spread angle

Tip angle - Sensor's angle with respect to the horizontal plane, φ/2

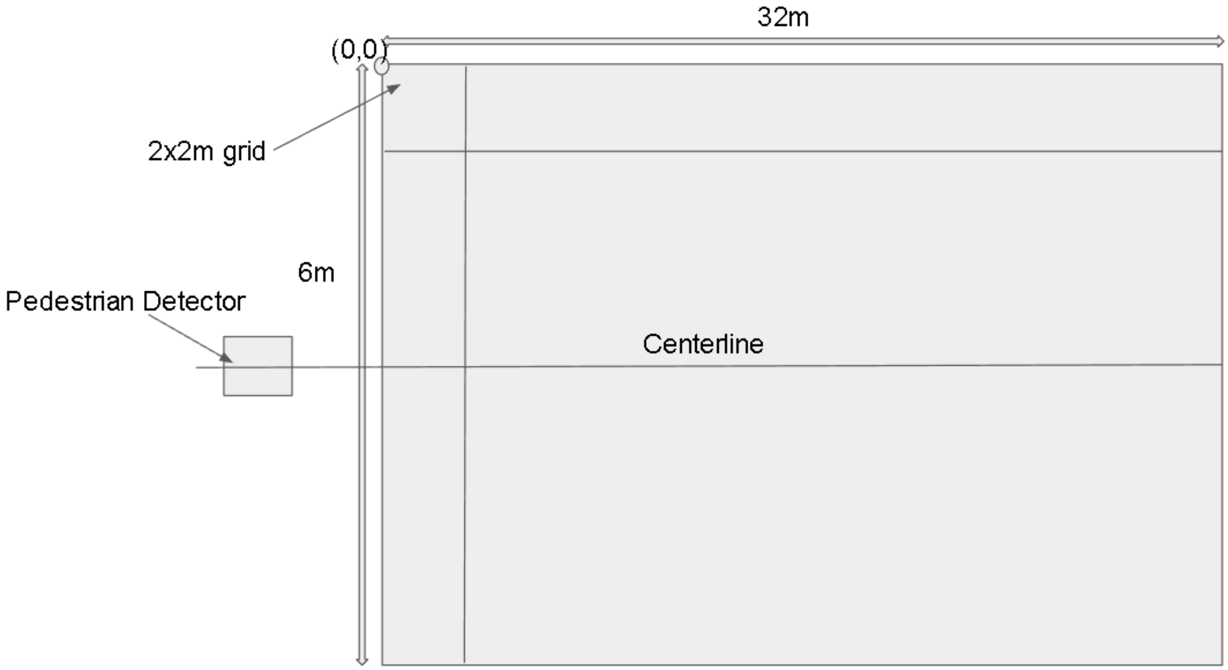

Figure B.3: Top view of the setup

SmartWalk does not have an LED indicator. As a result, it is difficult to determine detected zones. A customized cable was made to add an LED indication. For instance, when a pedestrian is detected, the LED lights up and vice versa. Figure B.4 shows the circuit diagram for the sensor.

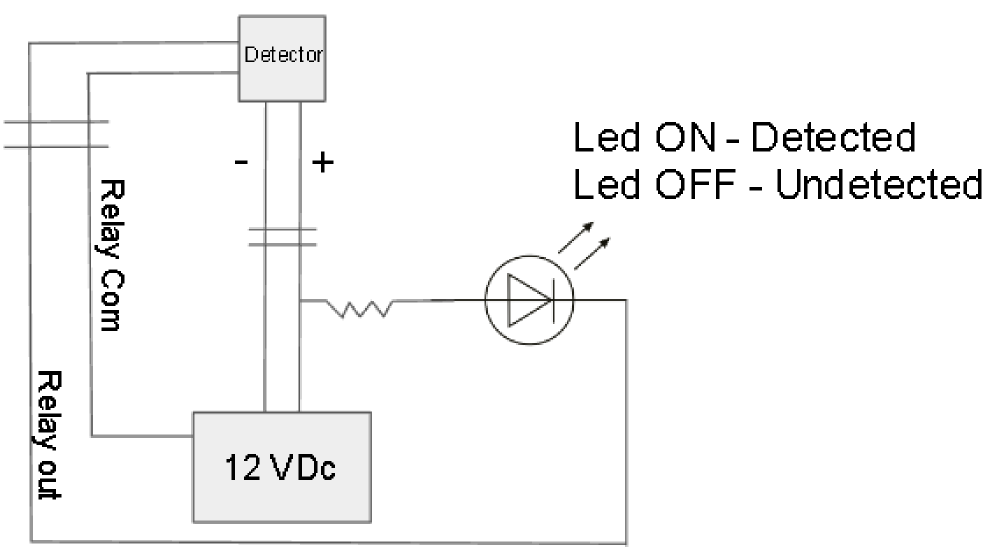

Figure B.4: Circuit diagram for crosswalk sensor(s)

Procedure

Set up the apparatus

Figure B.5 shows the components of the setup.

Figure B.5: Apparatus setup

On the left of the SmartWalk XM sensor, a phone control camera is set up to capture the walking process on the grid as well as the lightbulb indicator. The system is powered by the portable charger.

Set up the grid

Figure B.6 depicts the spray-painted grid on the left and demonstrates the grid labeling system on the right. There are 16 rows and 3 columns (R is right, L is left, and C is center). Each square is 2x2 meters.

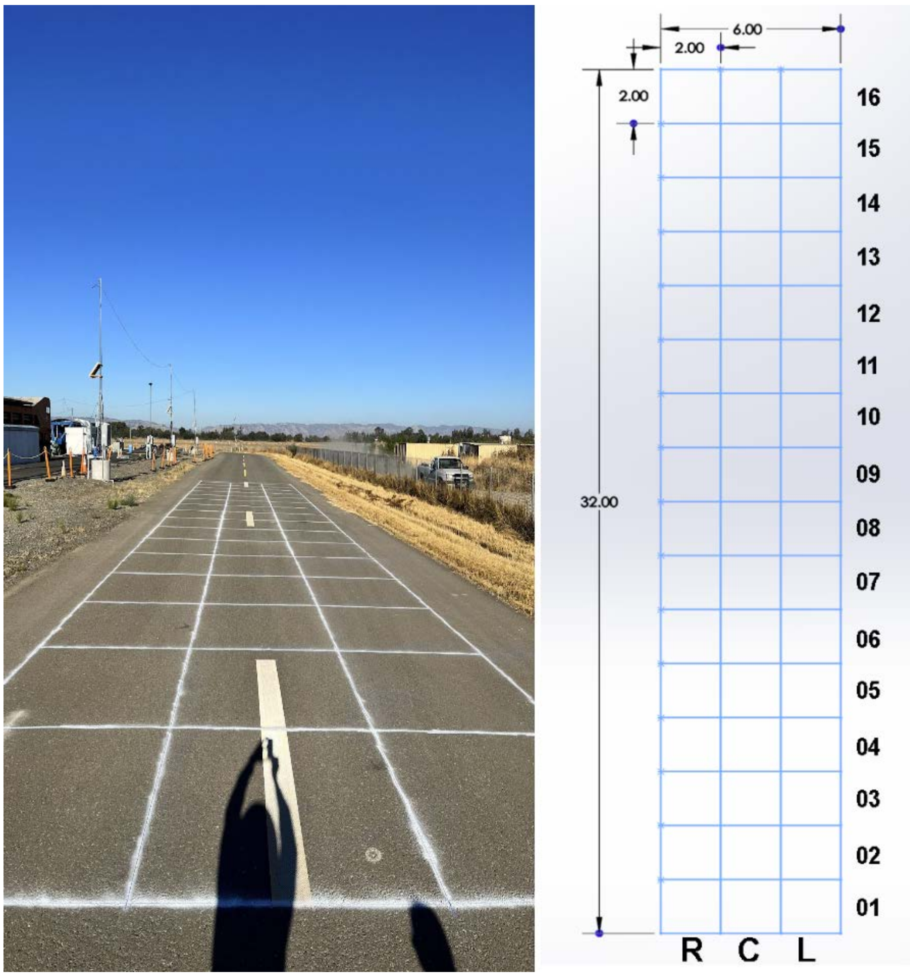

Figure B.6: Spray-painted grid and its labeling system

Drive the truck to the grid

Although the desired position for the sensor is at the centerline of the grid, it is challenging to park the truck at that exact location. The truck was parked as close to the planned location as possible.

Based on Figure B.1, the undetected zone is 10 feet from the sensor to the grid. However, the camera angles would be limited if the truck was parked only 10 feet away. The closest distance to 10 feet that enabled the camera to capture the whole grid is estimated to be 142.5 inches or 11.875 feet.

The distance from the sensor to the centerline of the grid is estimated to be 11.8 inches or approximately 1 feet. It is difficult to achieve high accuracy because the test track is not perfectly flat. With these parameters, the sensor placement will be located as shown in Figure B.7.

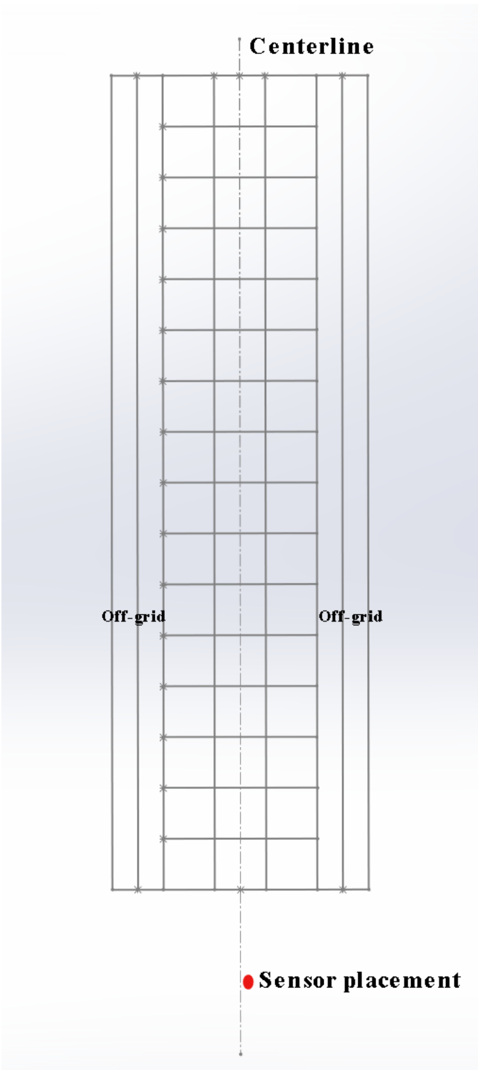

Figure B.7: Sensor placement during the testing

Achieving exactness for the sensor parameters is also challenging. The truck is parked on an uneven surface, which might cause the sensor to have a larger tip angle than the anticipated 15 degrees. To prevent this issue, the tip angle of the sensor is slightly reduced. The tip angle of the sensor is 12.7 degrees, the tilt angle of the truck is 1.5 degrees, which totals the angle to be 14.2 degrees. In addition, the sensor tilts to the right at 2 degrees to compensate for the test track being uneven.

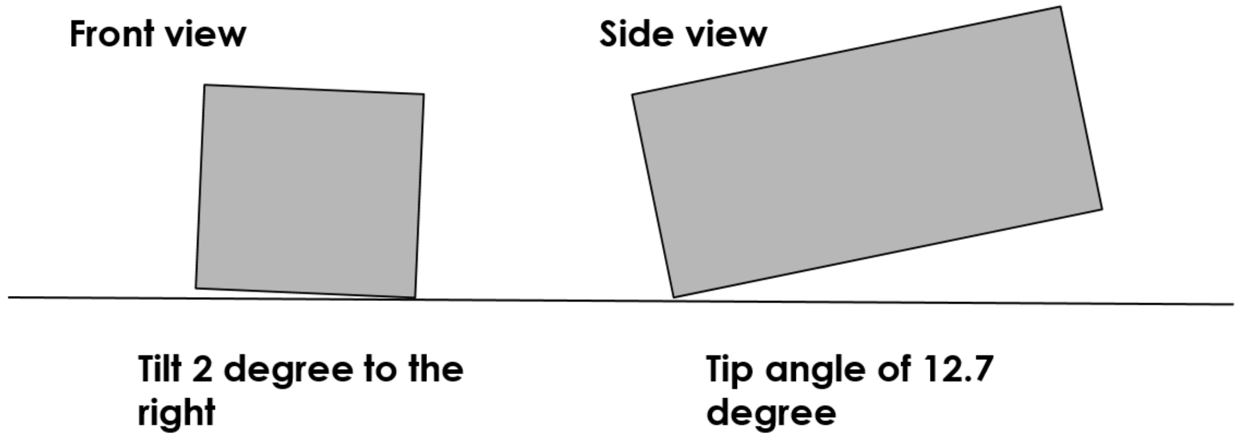

Figure B.8: Visualization of the angles mentioned above

Record the testing process

Mark the starting point and ending point of detection based on the recordings. Figures B.9 and B.10 demonstrate the process.

Figure B.9: An excerpt of the test recording

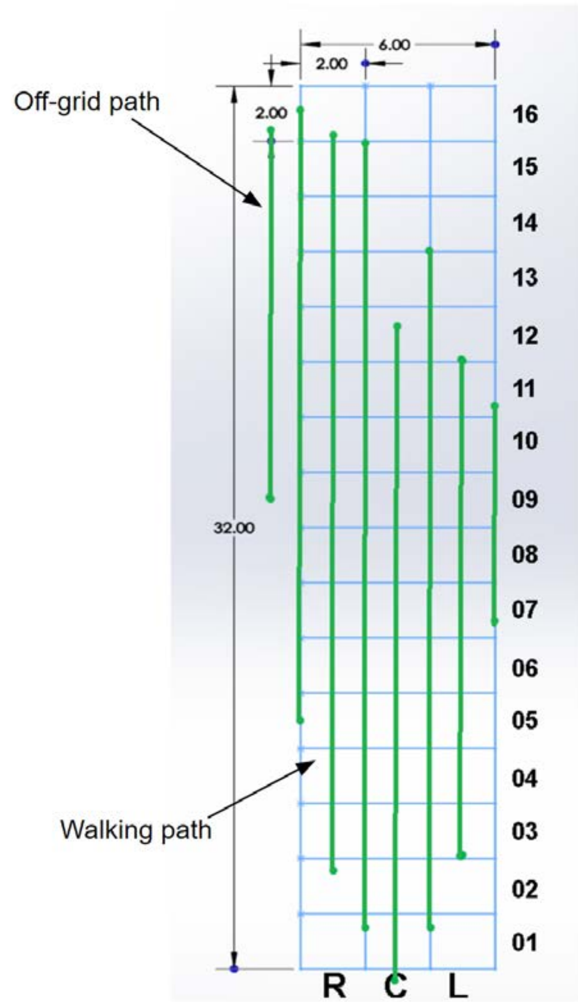

Figure B.10: Detected zones marked on the grid (dimensions in meters)

Based on the recordings, the grid is marked as shown in Figure B.10. The walking path is straight from the starting point to the ending point. In addition, off-grid testing was conducted to ensure the detection range is fully covered. There were five trials to ensure the accuracy of the results.

Results of evaluated features

Detection Range

After conducting five trials, the results are shown below.

Moving away from sensor

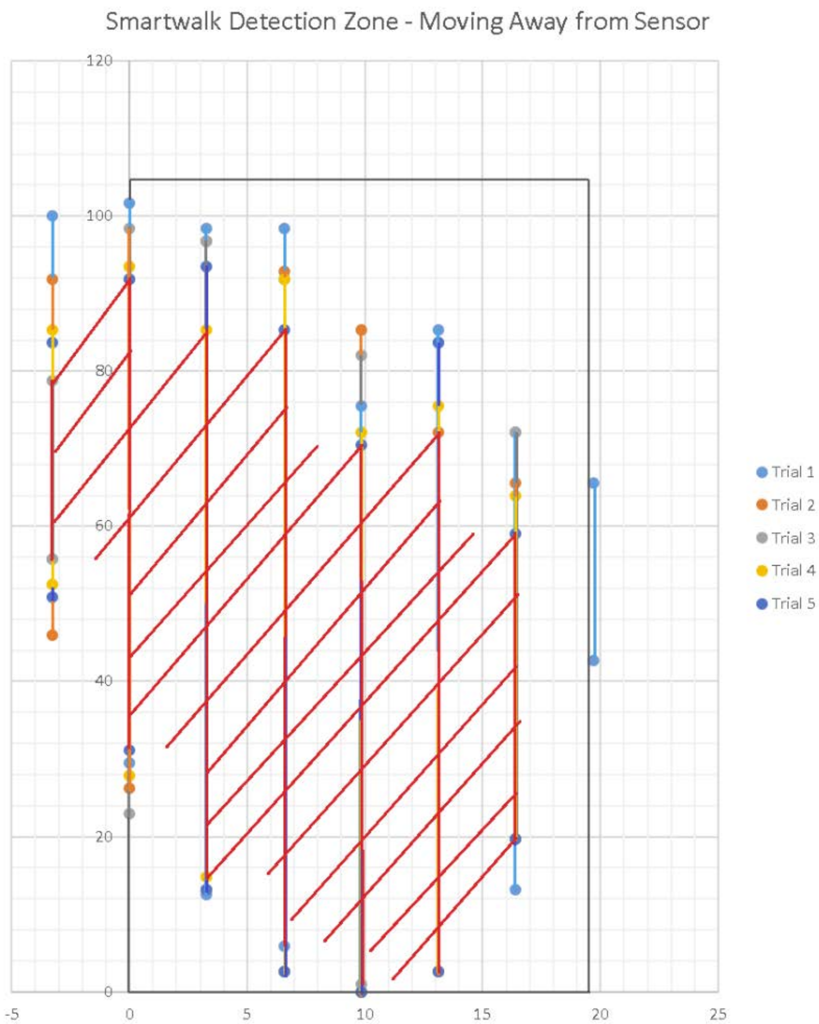

Figure B.11: Detection zone when moving away from the sensor (dimension in feet)

In Figure B.11, each trial data point was input onto the graph. The black outline is the grid. As mentioned, there is off-grid testing to ensure the detection range is fully covered. Data points outside of the black outline are off-grid. The cross-hatching shows the always-detected zone. The red crosshatch zone is the always-detected zone as this zone was picked up by the sensor during all five trials.

The maximum width achieved in the always-detected zone is 19.6 feet, which is 4.6 feet more than the given manufacturer specification.

The maximum length achieved in the always-detected zone is 79.4 feet, which is 24.4 feet more than the given manufacturer specification.

Moving toward the sensor

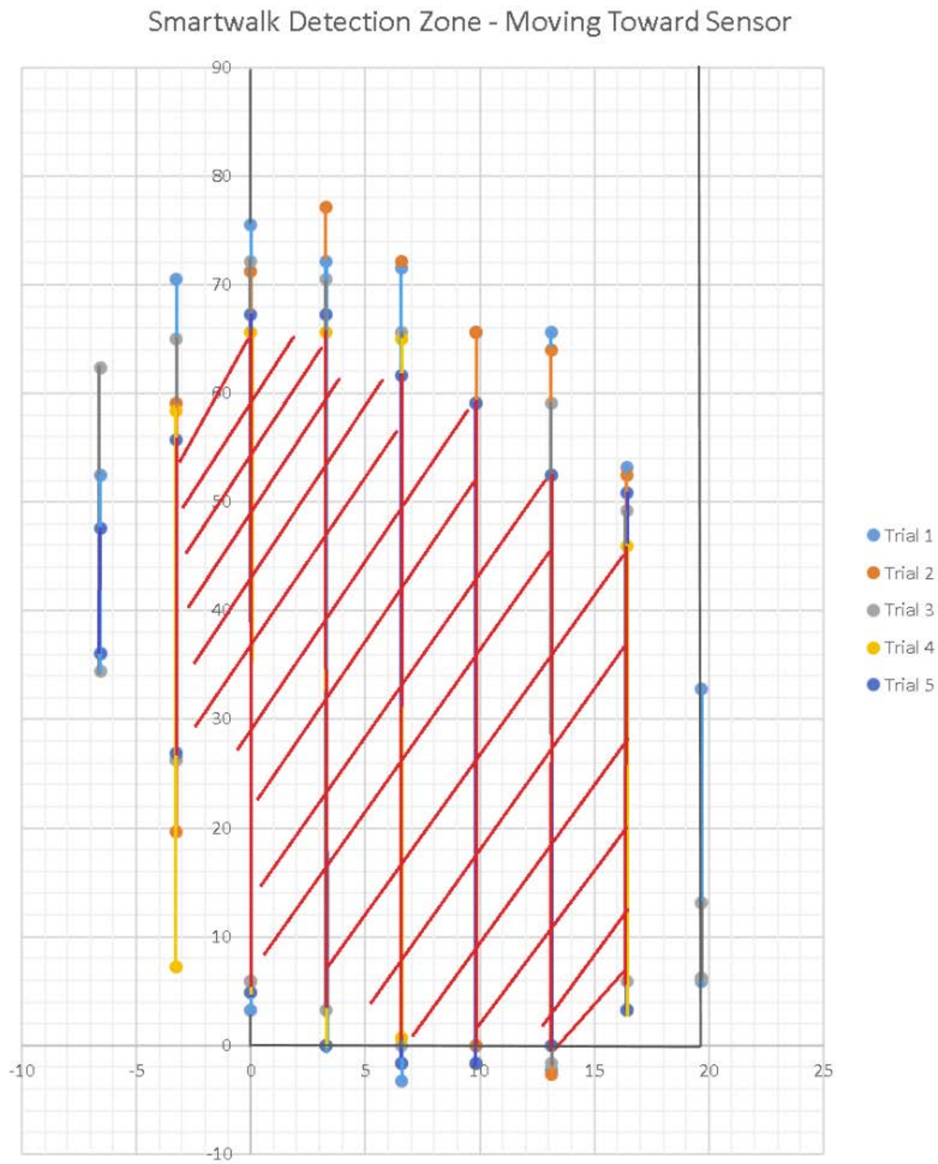

Figure B.12: Detection zone when moving toward the sensor (dimension in feet)

The process of obtaining Figure B.12 is the same as for Figure B.11, each trial data point was input onto the graph. The red zone is the always-detected zone.

The maximum width achieved in the always-detected zone is 19.6 feet, which is 4.6 feet more than the given manufacturer specification.

The maximum length achieved in the always-detected zone is 62.3 feet which is 7.3 feet more than the given manufacturer specification.

Minimum Detection Speed

The SmartWalk XM specification sheets do not have a minimum speed threshold. Testing was conducted to determine how well the sensor detects in low-speed settings.

When the walking speed is below 0.5 m/s (1.64 ft/s), the sensor does not detect consistently.

When the walking speed is below 0.18 m/s (0.59 ft/s), the sensor does not detect at all.

In addition, although the sensor does not pick up consistently for walking speed below 0.5 m/s, the sensor is sensitive to hand movements. For instance, if the person is swinging their arms while walking, the sensor will pick up this motion and stay activated.

Detection LEDs

There is no LED to indicate relay activation.

Detection Mode

FAIL SAFE OFF
#4 OFF

PIN 1........ 12V to 24V AC/DC+
PIN 2........ 12V to 24V AC/DC-
PIN 3........ N/A
PIN 4........ Relay Normally Closed (N.C.)
PIN 5........ Relay Common (COM)
PIN 6........ Relay Normally Open (N.O.)

Dip Switch Settings

SW	SWITCH DESCRIPTION	SWITCH 'OFF'	SWITCH 'ON'
1*	Detection Direction	Unidirectional Motion detection	Bi-directional Motion detection
2	Pedestrian Motion Sensitivity	Pedestrian Motion More Sensitive	Pedestrian Motion Less Sensitive
3	Not Used	Not Available	Not Available
4	Fail Safe State	Fail Safe Disabled	Fail Safe Enabled
5	Not Used	----------	Must Leave in 'ON' Position
6*	Approach/Depart	Approach	Depart

SW 6 is override when SW 1 is ON

Figure B.13: Detection mode options

The fail safe off option was chosen for this test.

Although the sensor detects bi-directionally, the performance for each direction is different. From the results before, moving away from the sensor has a longer range of detection than moving toward the sensor.

The pedestrian sensitivity is selected to be more sensitive to motions. However, if a car is in the range of detection (e.g. when car is turning right), the sensor might mistake the car motion for pedestrians. Sensitivity testing should be conducted further to determine what range of motions the sensor picks up.

In order to change these settings, the SmartWalk XM cover has to be opened. Figure B.14 shows the interior of the sensor.

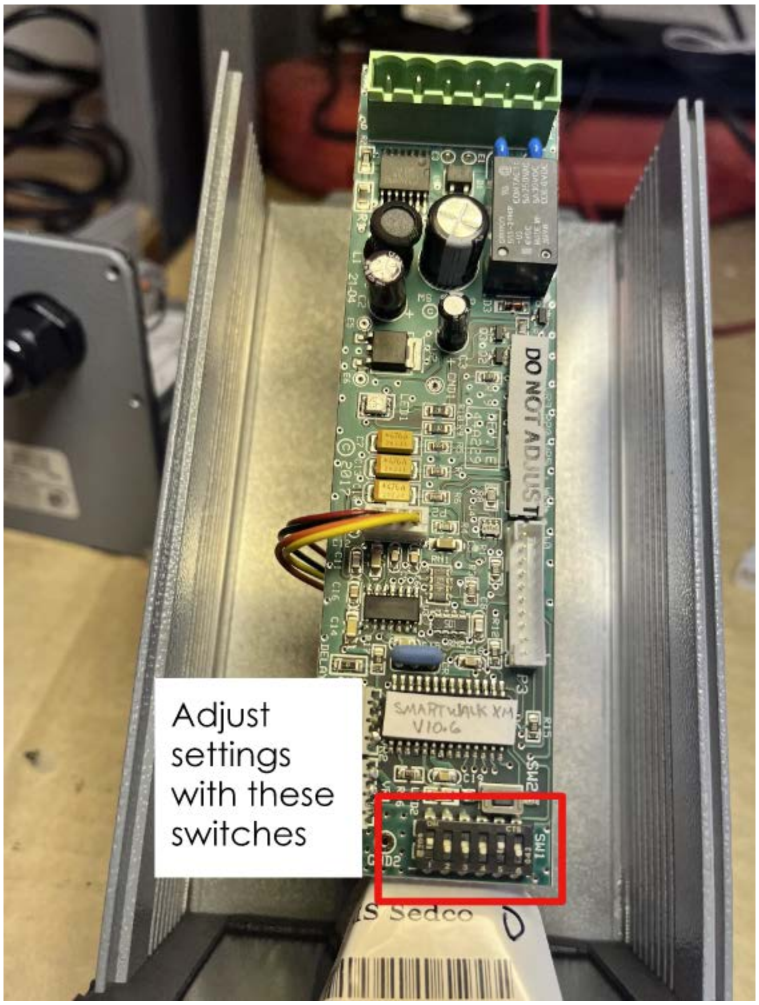

Figure B.14: Internal components of SmartWalk XM

Opening covers to adjust settings is inconvenient for a large installation with numerous sensors.

Extension Time Range and Accuracy

The SmartWalk XM has a hold time after pedestrian has exited the crosswalk of approximately 1 second.

Since SmartWalk XM is a microwave-based motion sensor, its relay picks up changes in the microwaves. Thus SmartWalk XM does not have the ability to distinguish between pedestrian and vehicle motion. SmartWalk XM can pick up a vehicle motion and add unnecessary walk time.

Appendix C:
iComs TMA-011 LV evaluation draft

Specifications provided by the manufacturer

iComs is one of three sensors to be evaluated in this research. Its notable features include: adjusting detection range, operating in all weather conditions, and activating warning LEDs in the presence of cyclists or pedestrians. Tables C.1 and C.2 provide iComs TMA-011 LV manufacturer specifications.

Table C.1: Sensors physical comparison

Physical attributes			
Sensors	**AGD 326**	**SmartWalk XM**	**iComs TMA-011 LV**
Dimensions	4.3"W x 6.9"H x 2.8"L 109x175x71 mm	4"W x 4"H x 7"L 101x101x178 mm	2.7"W x 3.9"H x 4.7"L 68x99x119 mm
Weight	1.4 lb 0.650 kg	4 lb 1.814 kg	0.77 lb 0.350 kg
Material	Black polycarbonate	Powder coated aluminum	N/A
Coating	IP56	N/A	IP65

Table C.2: iComs manufacturer specifications

Method	Radar
Frequency	24.165 to 24.235 GHz
Range	Adjustable lengths: 8, 12, 16, and 30 meters No information on width range
Speed threshold	0.5 km/h to 100 km/h 0.14 m/s to 27.8 m/s
Mounting height	Minimum: 3.5 m Maximum: 4.5 m
Power	12 VDC
Operation temp	-40°C to 60°C
Weight	0.77 lb/0.350 kg
Hold time	750 milliseconds

The dials on the unit are adjustable to set desired range (Figure 1). Tables C.3 and C.4 show the dial settings.

Figure C.1: Front view of iComs sensor, the dials are at the center bottom

Table C.3: Dial settings on the left, iComs front view

Parameter	Value																Units
Detection distance	8				12				16				30				m
Encoder position	*0*	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F	

Factory setting = 0

Table C.4: Dial settings on the right, iComs front view

Parameter	Value															
Uni/bi-directional	Bi-directional								Uni-directional							
Direction	BI				BI				IN				OUT			
RF channel	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Encoder position	*0*	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F

Factory setting = 0

Table C.4 illustrates different RF channels. When multiple iComs sensors are being installed near one another, it is recommended that the RF channel for each sensor is different so radar frequencies do not interfere.

In addition, to fully protect iComs from all weather conditions, a sticker must be placed over the dials and LEDs (Figure C.2). The protective stickers should be included with the sensor packaging for protection and to preserve the manufacturer's warranty.

Figure C.2: Protected sticker must be placed after adjusting settings

iComs comes with bright warning LED lights (Figure C.3). However, the protective sticker was not used for this evaluation. Thus the LEDs may not be as bright once the sticker is applied in actual application. In addition, when the self-monitoring feature detects an error, the two LEDs will blink quickly (two or four quick flashes followed by a 1-sec break, depending on the detected error). The radar will reset one hour after a detected error.

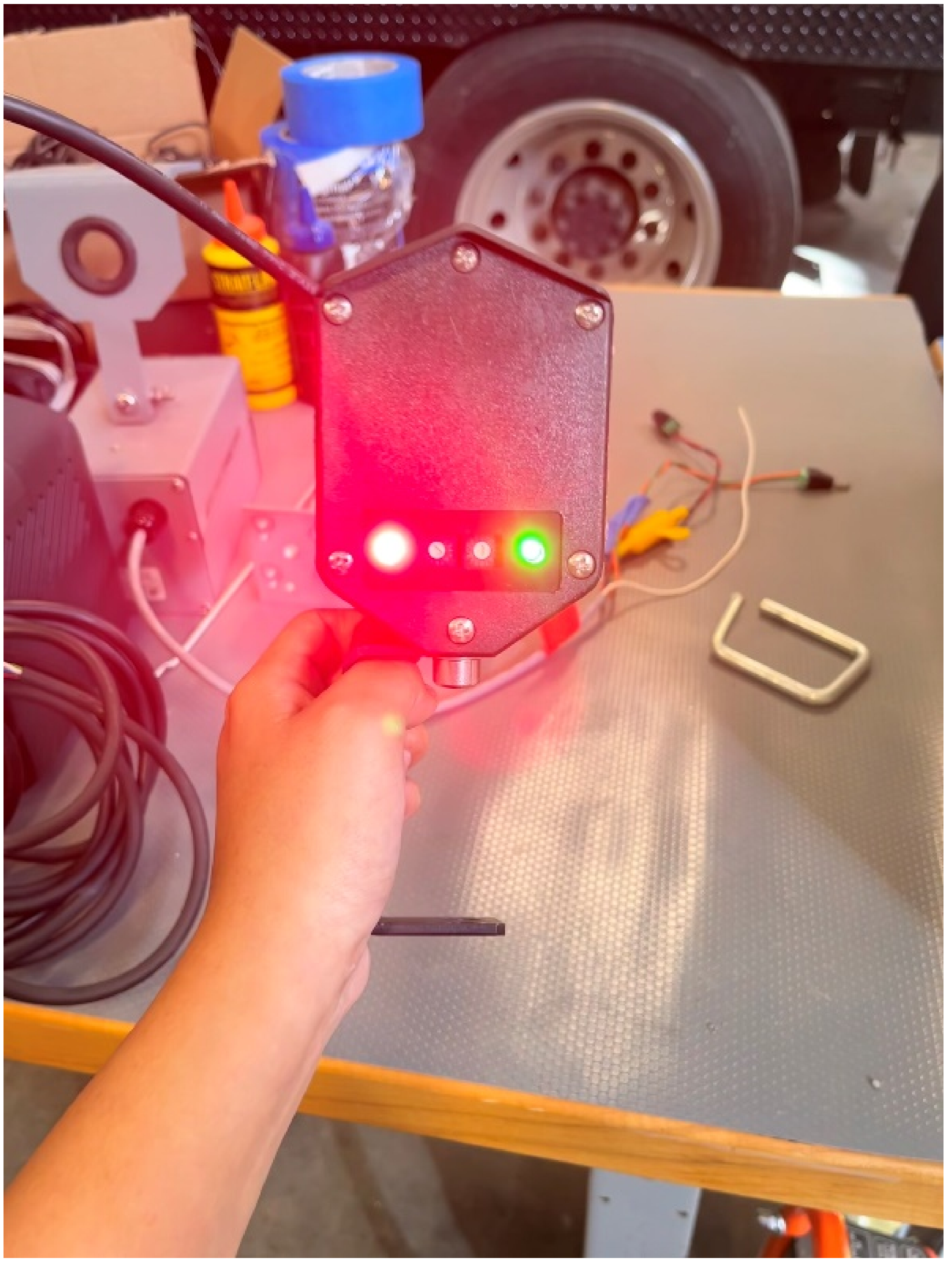

Figure C.3: Activated warning LEDs without the protective stickers

The manufacturer provided the detection zone test in the user manual (Figure C.4). However, the selected range was 16 meters. In this evaluation, AHMCT used iComs maximum detection range (30 meters).

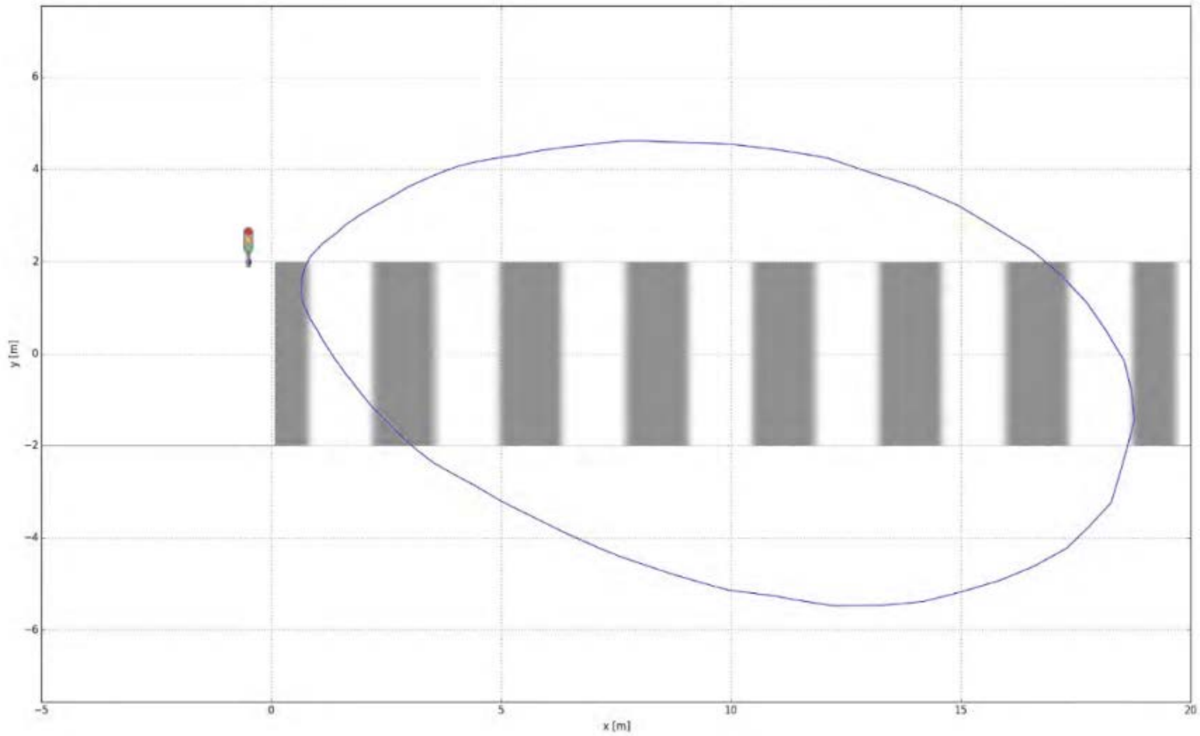

Figure C.4: Manufacturer detection zone testing

The settings for Figure C.4 are: detection zone at 0.5 meter distance from the pavement, sensor mounted to the traffic light at the height of 3.5 meters, 10 degrees vertical tilt angle, and selected detection distance 16 meters. Figure C.4 helps in determining the pattern to expect for the iComs detection zone.

Testing procedure

The testing plan for iComs sensor is similar to that for the SmartWalk XM. The manufacturer conducted testing by mounting iComs at the corner of the crosswalk. However, AHMCT conducted testing by mounting the iComs at the center of the test track, as AHMCT wanted to keep horizontal tilt angle to be 0 degrees. The manufacturer did not indicate the horizontal tilt angle used in Figure C.4.

Planning

An approach was developed to evaluate the crosswalk. The sensor was mounted on a fixed, rigid apparatus to ensure there is no instability from environmental factors. For testing, the apparatus was set up on a truck for convenient mounting and transporting. It is challenging to park the truck so that the sensor aligns as intended.

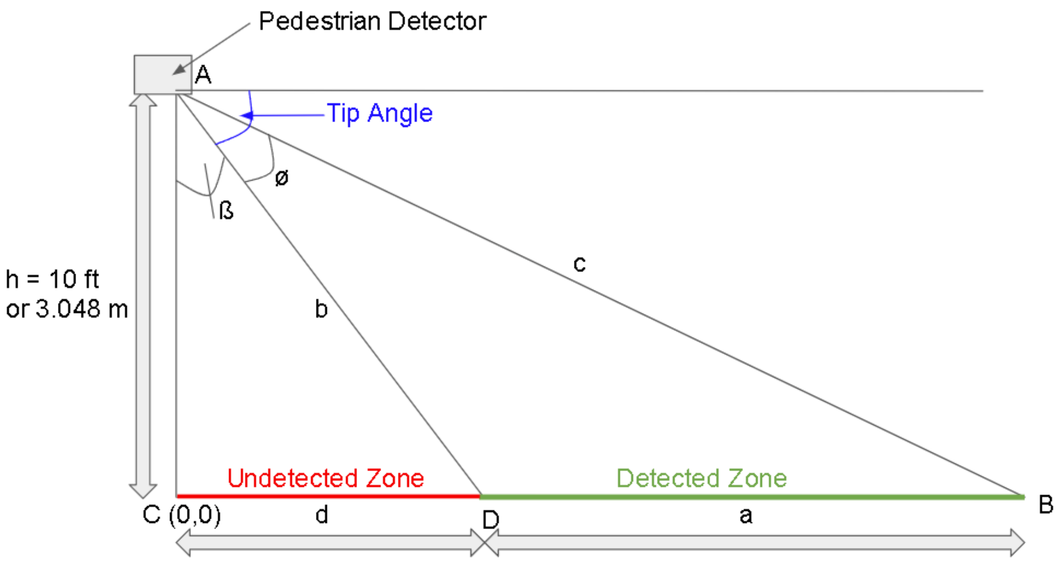

Figure C.5: Front view of the setup

β - Undetected angle

φ - Sensor's spread angle

Tip angle - Sensor's angle with respect to the horizontal plane, φ/2

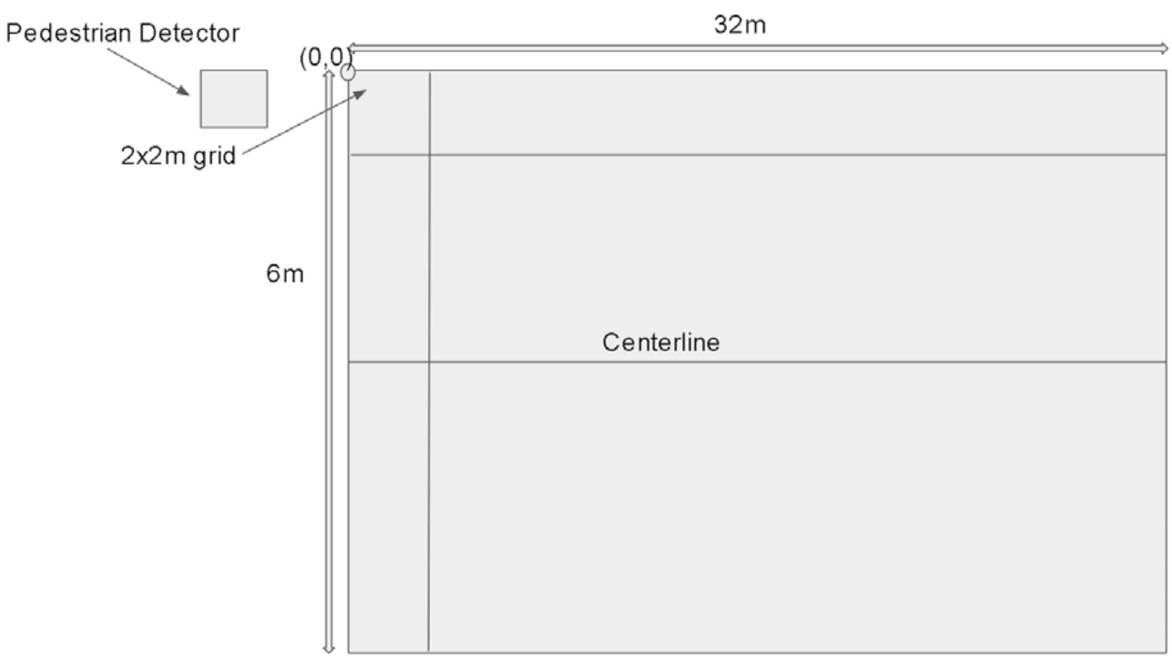

Figure C.6: Top view of the setup

For testing, a custom cable with an LED indicator was made. A camera was set up so that it captured the testing being conducted in the field as well as the customized LED indicator.

Figure C.7 shows how the sensor and the customized LED indicator were powered.

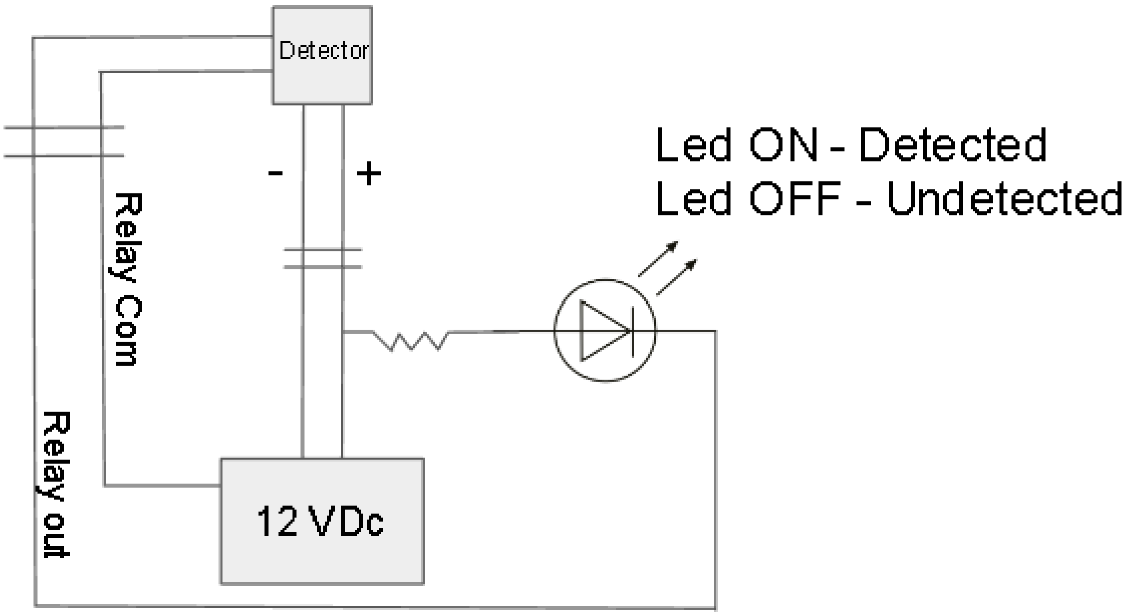

Figure C.7: Circuit diagram for crosswalk sensor(s)

Procedure

Set up the apparatus

Figure C.8 shows the components of the setup.

Figure C.8: Apparatus setup

On the left of the iComs sensor, a phone control camera was setup to capture the walking process on the grid as well as the lightbulb indicator. The system was powered by the portable charger.

Set up the grid

Figure C.9 depicts the spray-painted grid on the left and demonstrates the grid labeling system on the right. There are 16 rows and 3 columns (R is right, L is left, and C is center). Each square is 2x2 meters.

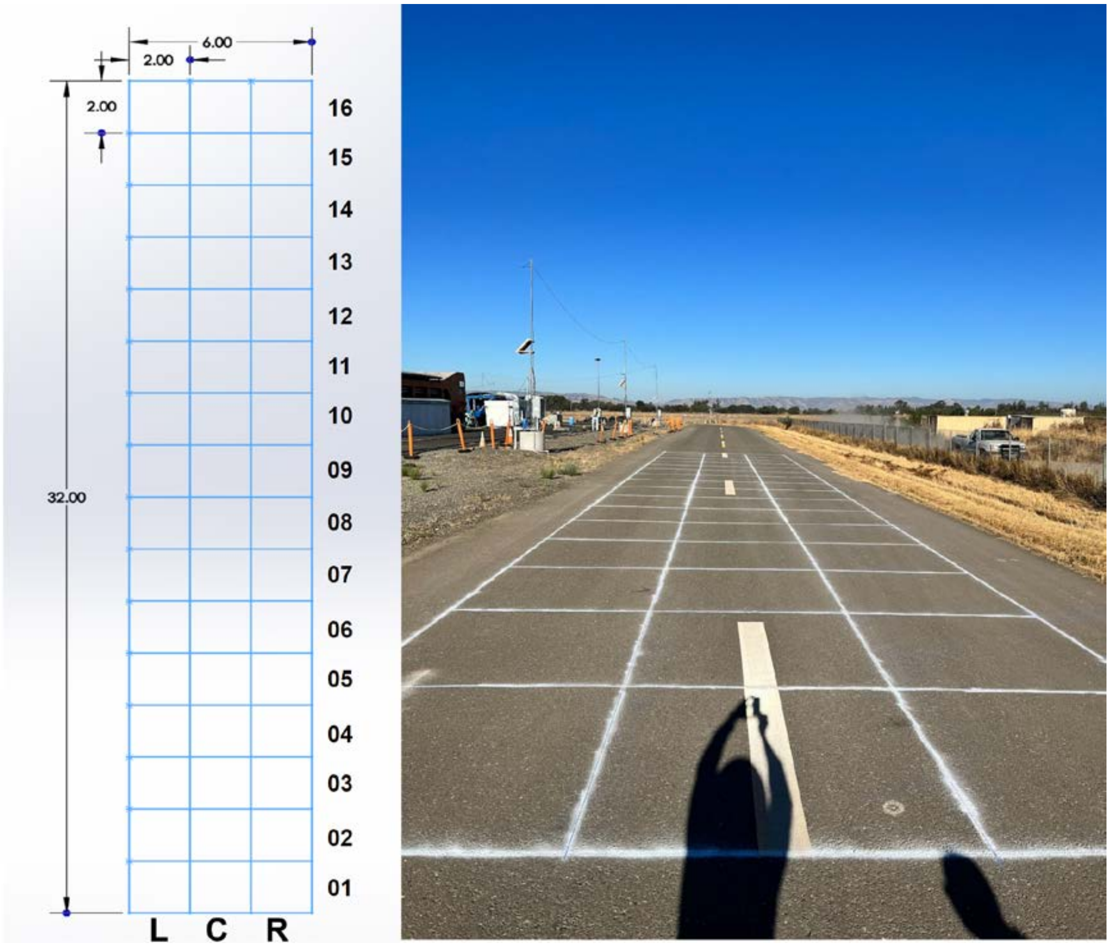

Figure C.9: Spray-painted grid and its labeling system

Note that the left and right orientation can be swapped based on perspectives. For instance, if pedestrian starts walking from where the shadows are to the end of the track, then the orientation would result as shown in Figure C.9. If pedestrian starts walking from the end of the track to the shadows, then left and right orientation would swap.

Drive the truck to the grid

Although the desired position for the sensor is at the centerline of the grid, it is challenging to park the truck at that exact location. The truck was parked as close to the planned location as possible.

Based on Figure C.4, the undetected zone is 1.65 feet from the sensor to the grid. However, the camera angles would be limited if the truck was parked only 1.65 feet away. The closest distance that enabled the camera to capture the whole grid is estimated to be 119.3 inches or 9.94 feet.

The distance from the sensor to the centerline of the grid was estimated to be 1.25 inches or approximately 0.1 feet. It was difficult to achieve high accuracy because the test track is not perfectly flat. With these parameters, the sensor placement was as shown in Figure C.10.

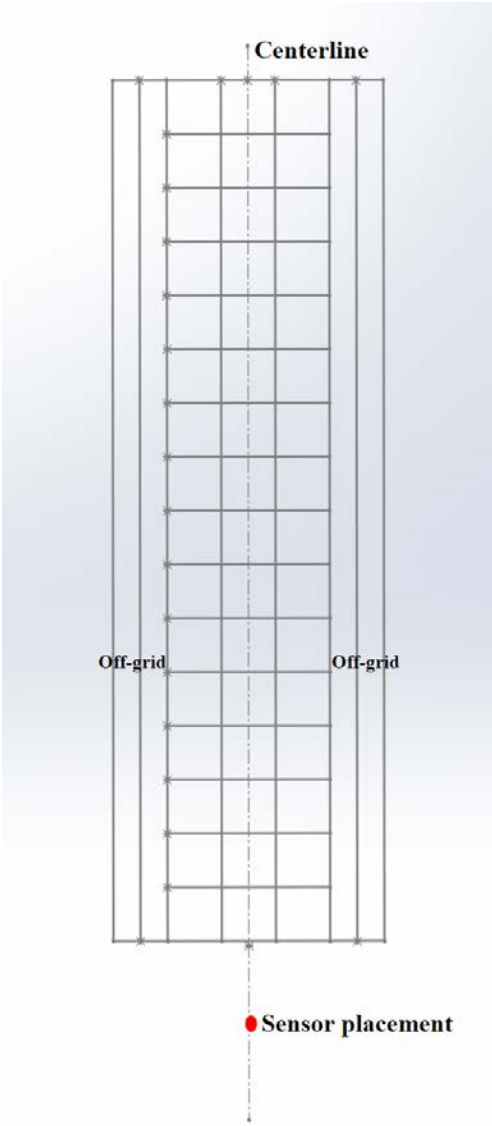

Figure C.10: Sensor placement during the testing

Achieving exactness for the sensor parameters is also challenging. The truck is parked on an uneven surface, which might cause the sensor to have a larger tip angle than anticipated. The tip angle of the sensor is 24.3 degrees, the tip angle of the truck is 2.9 degrees, which totals the tip angle to be 27.2 degrees. The sensor tilts to the right at 2 degrees. Figure C.11 demonstrates the angle parameters visually.

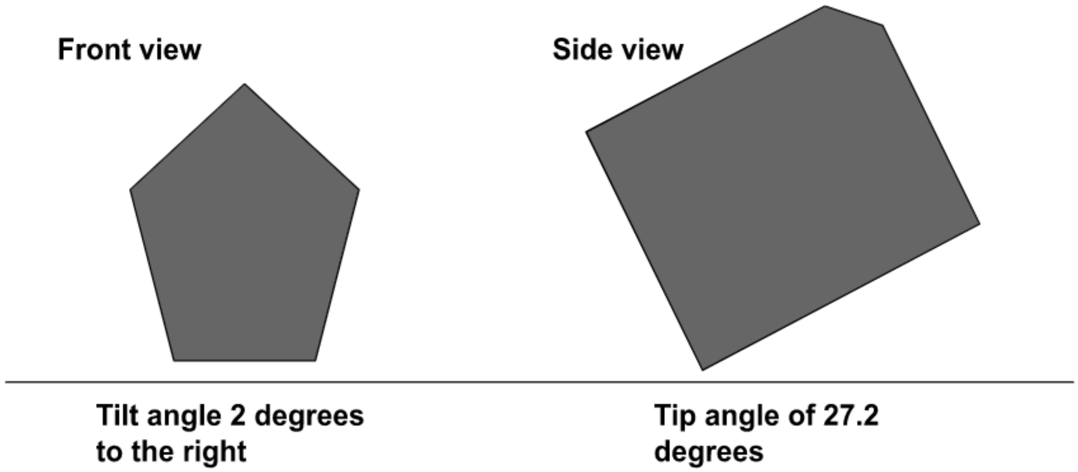

Figure C.11: Visualization of the angles mentioned above

Record the testing process

Mark the starting point and ending point of detection based on the recordings. Figures C.12 and C.13 demonstrate the process.

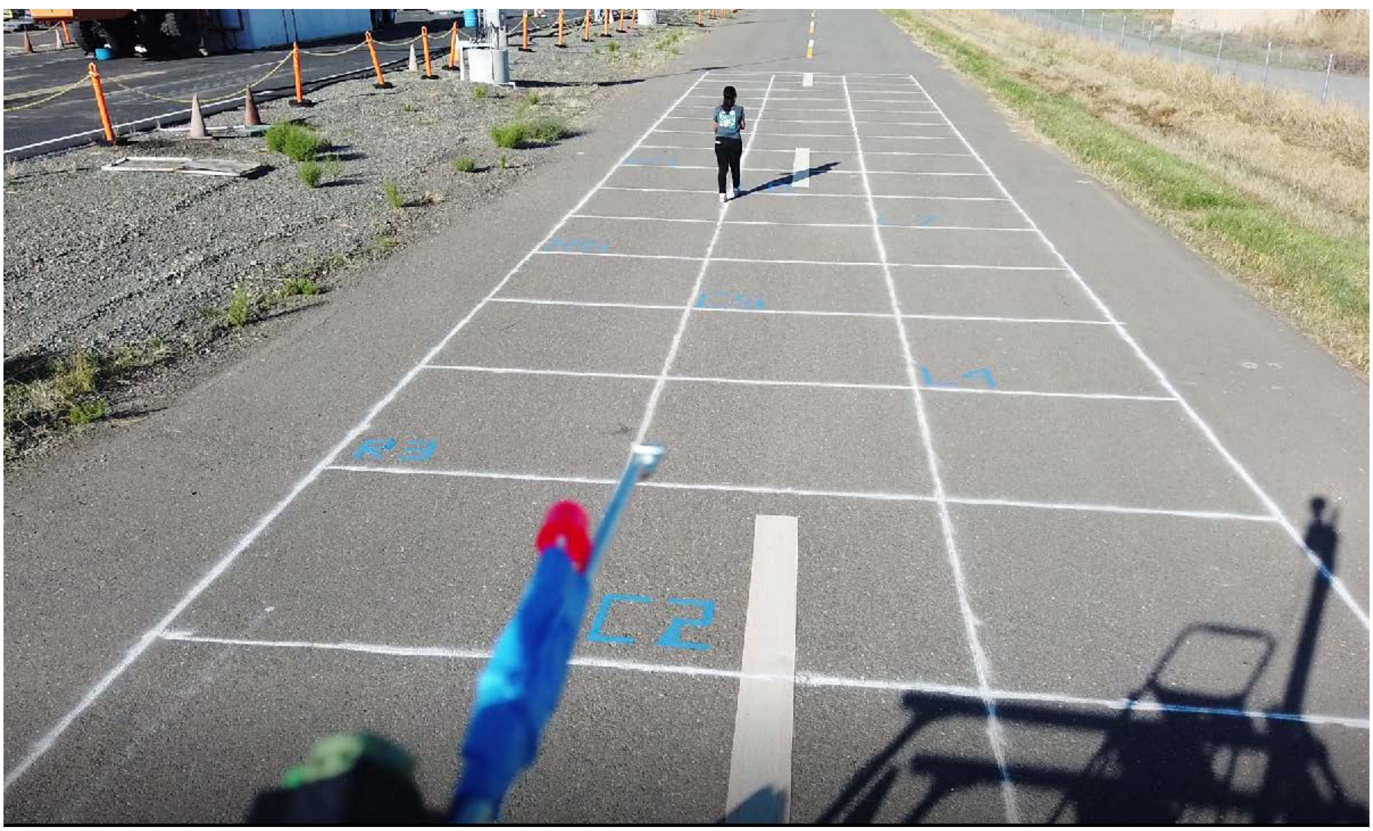

Figure C.12: An excerpt of the test recording

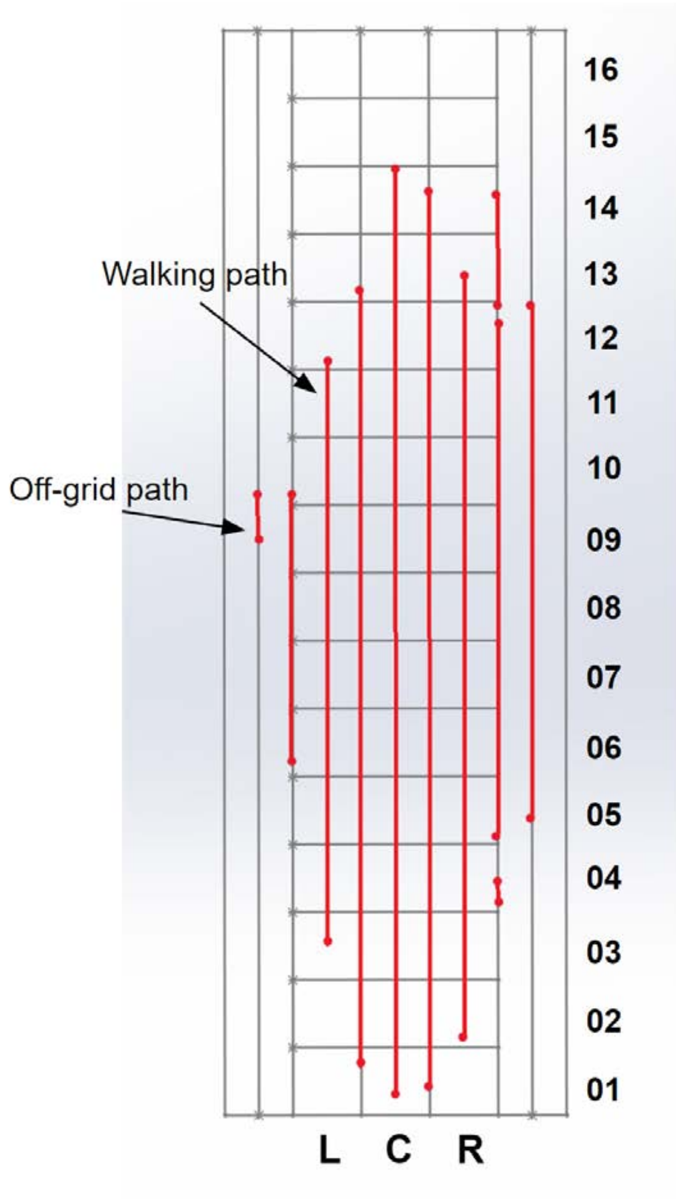

Figure C.13: Sample detected zones marked on the grid

Based on the recordings, the grid was marked as shown in Figure C.13. The walking path was straight from the starting point to the ending point. In addition, off-grid testing was conducted to ensure the detection range was fully covered.

There were five trials to ensure the accuracy of the results.

Results of evaluated features

Detection Range

Moving away from sensor

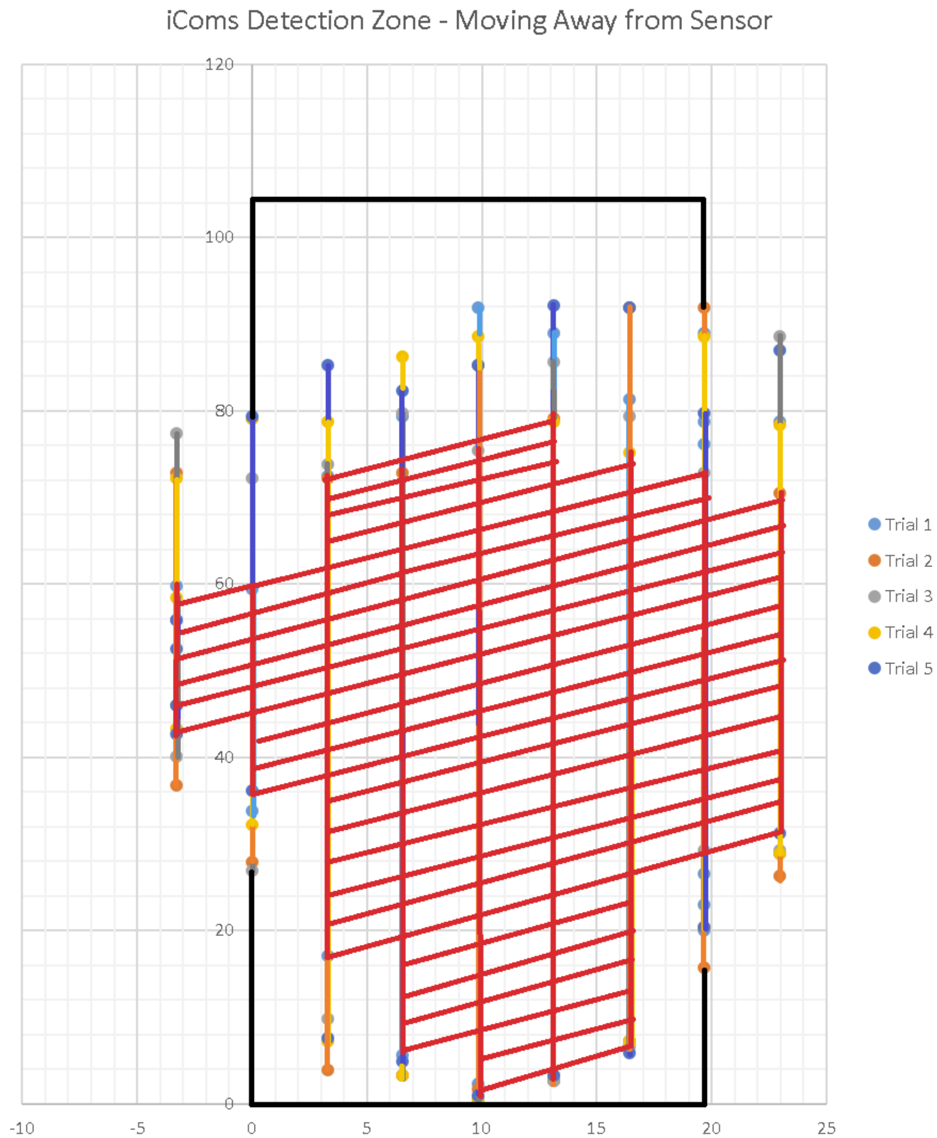

Figure C.14: Detection zone when moving away from sensor (dimensions in feet)

In Figure C.14, each trial data point was input onto the graph. The black outline is the grid. As mentioned, there is off-grid testing to ensure the detection range is fully covered. Data points outside of the black outline are off-grid. The red cross-hatching shows the always-detected zone.

The maximum width achieved in the always-detected zone is 8 meters. The maximum width achieved is 26.25 feet. The manufacturer manual does not list the maximum width range.

The maximum length achieved in the always-detected zone is 23 meters, which is 7 meters less than the given manufacturer specification. The maximum length achieved is 75.46 feet.

The maximum length achieved was 27.3 meter in trial 1. However, the long range detection of 30 meters was not consistent as shown in Figure C.14.

Moving toward the sensor

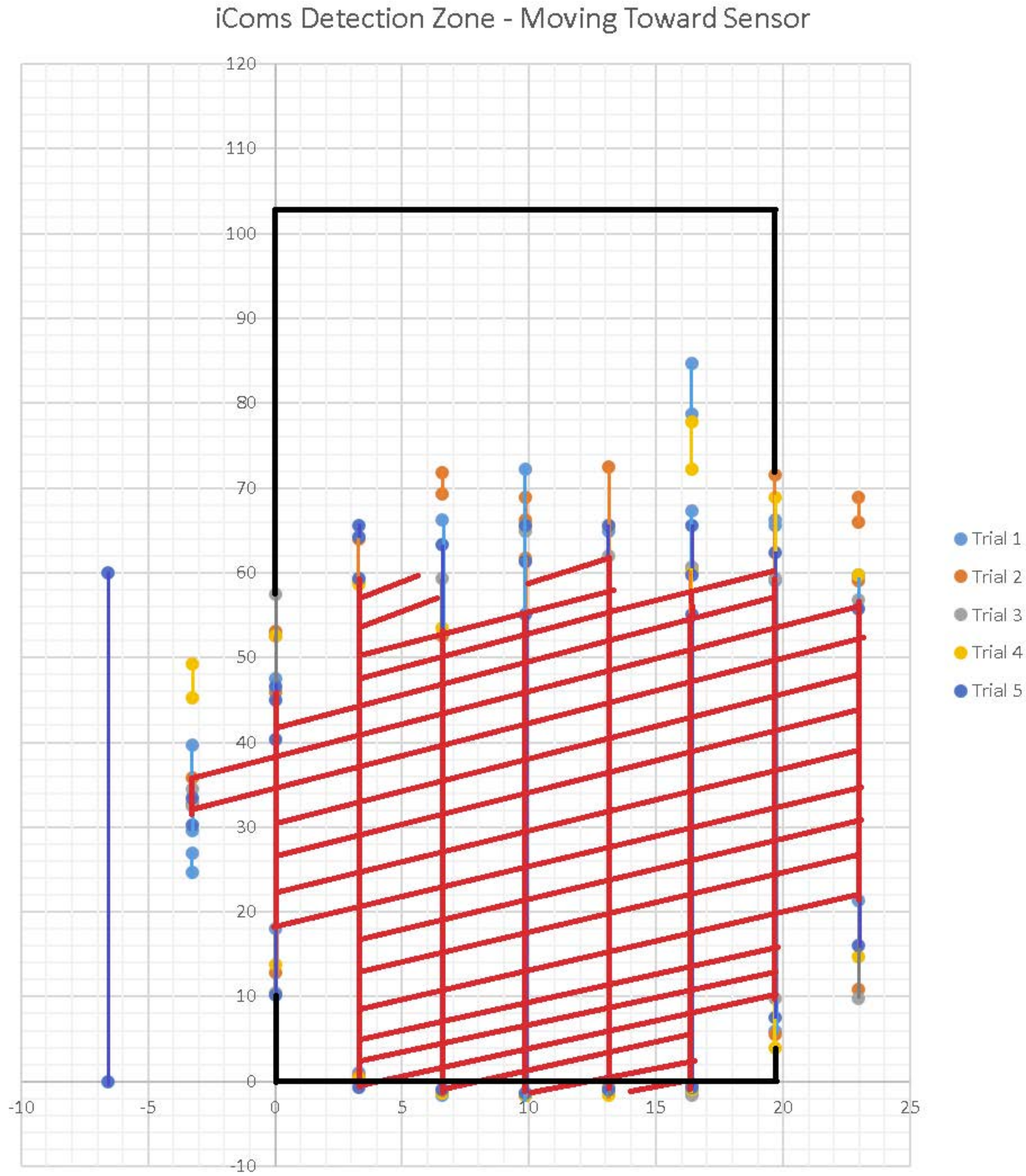

Figure C.15: Detection zone when moving toward sensor (dimensions in feet)

The red cross-hatching shows the always-detected zone. The process of obtaining Figure C.15 is the same as for Figure C.14, each trial data point was input onto the graph.

The maximum width achieved in the always-detected zone is 8 meters. The maximum width achieved is 26.25 feet. The manufacturer manual does not list the maximum width range.

The maximum length achieved in the always-detected zone is 19.1 meters which is 10.9 meters less than the given specification. The maximum length achieved is 62.66 feet.

In trial 5, there was a long off-grid detection in blue (Figure C.15). However, the sensor did not pick up detection in all other trials. The sensor was also detecting when the pedestrian had already exited the crosswalk for approximately 3 seconds, which was not expected according to the sensor specification. In addition, the detections made next to the blue line were brief. Therefore, this unexpected long off-grid detection should not be considered.

The sensor performed better when the pedestrian was moving away from the sensor, as compared Figure C.14 to Figure C.15.

Minimum Detection Speed

The iComs specification sheets state the sensor has 0.5 km/h or 0.14 m/s (0.46 ft/s) minimum speed threshold, and 100 km/h or 27.8 m/s (91.2 ft/s) maximum speed threshold.

In addition, testing was conducted to determine how well the sensor detects in low-speed settings.

When walking speed is below 0.25 m/s (0.82 ft/s), the sensor does not detect consistently.

In addition, iComs picked up a non-pedestrian motion (Figure C.16). Because iComs is a radar-based motion sensor, its relay picks up changes in the reflected RF signal. Thus iComs does not have the ability to distinguish between pedestrian and vehicle motion. iComs can pick up a vehicle motion and add unnecessary walk time.

Figure C.16: iComs sensor picked up the truck motion

Detection LEDs

iComs has warning detection LEDs on its body. However, a protective sticker must be placed over the LEDS to ensure the unit is weather-proof. The sticker may diminish the brightness of the LEDs.

Detection Mode

iComs detection mode can be controlled by the dials as mentioned before. iComs maximum detection range can be adjusted to 8, 12, 16, and 30 meters. This feature can be helpful in terms of adapting detection range to the size of the crosswalk. The AGD 326 also has a maximum detection range adjustment feature with smaller increments. The SmartWalk XM does not have a maximum detection range adjustment feature.

Extension Time Range and Accuracy

iComs has 750 milliseconds hold time after the pedestrian has exited the crosswalk. During testing, iComs hold time exceeded the manufacturer specification by up to 3 seconds.

As mentioned, iComs does not have the ability to distinguish between a pedestrian and vehicle motion. This characteristic can be a disadvantage since a vehicle can get into the sensor detection range and add unnecessary walk time.