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16. Abstract

As a part of a research project sponsored by the Texas Department of Transportation, the Texas A&M Transportation Institute, along with Texas A&M University's (TAMU's) Transportation Services, Mobileye and Rosco Vision Systems, conducted a pilot of the Mobileye Shield+ pedestrian and bicyclist collision warning system using one TAMU bus on a campus route. The Shield+ system includes algorithms to track the distance and speeds of these pedestrians and bicyclists, which are continuously measured to calculate the risk of a collision. The pilot was conducted in early 2016. Changes were made to the machine vision algorithm after the pilot. This report summarizes a follow up assessment that was concluded in summer 2016 to reduce unnecessary warnings.

The follow-up assessment indicated that the system produced fewer warnings from the left and right rear sensors than during the pilot. Direct comparisons with the initial evaluation earlier in 2016 are difficult since the bus was operated on additional routes and data were recorded at a different time of the academic year when there is a much smaller student population on campus. The assessment further indicated that the Shield+ system continues to be very accurate at detecting pedestrian and bicyclists in close proximity to the equipped bus. The Shield+ system warnings never required a bus driver to make a corrective driving maneuver to avoid a collision.

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EXECUTIVE SUMMARY

As part of a research project sponsored by the Texas Department of Transportation (TxDOT), the Texas A&M Transportation Institute (TTI), along with Texas A&M University's (TAMU's) Transportation Services, Mobileye and Rosco Vision Systems, partnered to conduct a pilot of the Mobileye Shield+ pedestrian and bicyclist collision warning system using one TAMU bus. The sensor system identifies various potential dangers—vehicles, bicyclists, and pedestrians—in the path of the bus. It includes algorithms to track the distance and speeds of these objects, which are continuously measured to calculate the risk of a collision.

An initial pilot was conducted in January and February 2016 on the Texas A&M campus. The results of the assessment, which are documented in a TxDOT research report, indicated that the collision warning system was successful at identifying pedestrians and bicyclists that were in close proximity to the bus. After the initial study was complete, the Shield+ system received a software update to refine its algorithm with the intent of reducing unnecessary warnings. With the changes, TTI researchers were able to conduct a follow up assessment of the Shield+ system. Data for the follow up assessment were collected over 18 days of operation during the summer semester from June to August 2016.

The assessment indicated that the system produced fewer warnings from the left and right rear sensors than during the pilot. Mobileye/Rosco representatives confirmed that the algorithm sensitivity was decreased to reduce unnecessary warnings. Direct comparisons with the pilot earlier in 2016 are difficult since the bus was operated on additional routes and data were recorded at a different time of the academic year when there is a much smaller student population on campus.

Despite its accuracy at detecting pedestrian and bicyclists in close proximity to the equipped bus, the Shield+ system warnings never required a bus driver to make a corrective driving maneuver to avoid a collision. Almost half of the collision warnings were produced as the bus driver approached a bus stop with waiting passengers, which is a common occurrence on all bus routes. Further, several of the Texas A&M campus buses routinely operate in a congested campus environment in close proximity to many pedestrians and bicyclists.

INTRODUCTION

In a recently completed TxDOT project, *Autonomous and Connected Vehicle Test Bed to Improve Transit, Bicycle, and Pedestrian Safety*, TTI partnered with Texas A&M University's (TAMU's) Transportation Services, Mobileye and Rosco Vision Systems, to conduct a pilot of the Mobileye Shield+ pedestrian and bicyclist collision warning system on one TAMU bus. The Shield+ warning system and its components were installed on TAMU Bus #120, which typically operates on the on-campus Bonfire Route. These components included the cameras/intelligent vision sensors, the front center master camera, and three pedestrian displays. Four cameras are mounted as follows: one each on the right and left side at the front and rear of the bus. The sensor system identifies various potential dangers—vehicles, bicyclists, and pedestrians—in the path of the bus. It includes algorithms to track the distance and speeds of these objects, which are continuously measured to calculate the risk of a collision.

The initial pilot was conducted over 27 days of operations in January and February 2016 on the Texas A&M campus. The results of the evaluation indicated that the collision warning system was successful at identifying pedestrians and bicyclists that were in close proximity to the bus. Bus driver interviews indicated that the Mobileye warnings were helpful, especially for warnings originating from the sensors on the rear of the bus. The evaluation also provided useful feedback to Mobileye and Rosco Vision Systems by identifying several potential areas of improvement for their system, with respect to their machine vision algorithm and their web-based telematics event interface.

After the initial study was complete, the Shield+ system received a software update to refine its algorithm. With the changes, TTI researchers were able to conduct a follow-up assessment of the Shield+ system. Data for the follow up assessment of the Shield+ system and enhanced algorithm with TAMU Bus #120 were collected over 18 days of operation during the summer semester from June 2 to August 2, 2016. Data were gathered from video cameras on the bus and telematics from the Mobileye/Rosco vendor website.

APPROACH AND METHODOLOGY

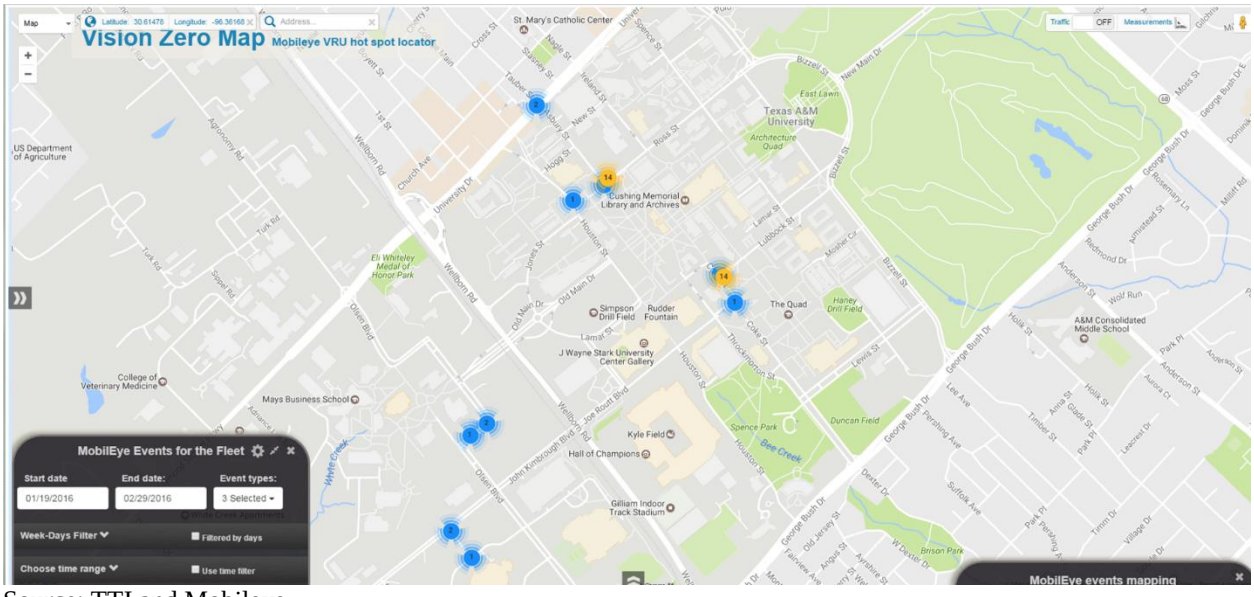
This assessment followed the same methodology used in the pilot assessment and examined the accuracy of the Mobileye Shield+ collision alerts as compared to actual on-the-street conditions. Every time the Shield+ system issued a collision alert, the analysis examined if a pedestrian or bicyclist was in close proximity to the bus such that a collision could possibly occur.

The primary measure for system accuracy is the false alarm rate, defined as:

$$False\ Alarm\ Rate\ (\%) = \left[\frac{Total\ number\ of\ false\ alerts}{Total\ number\ of\ alerts}\right]$$

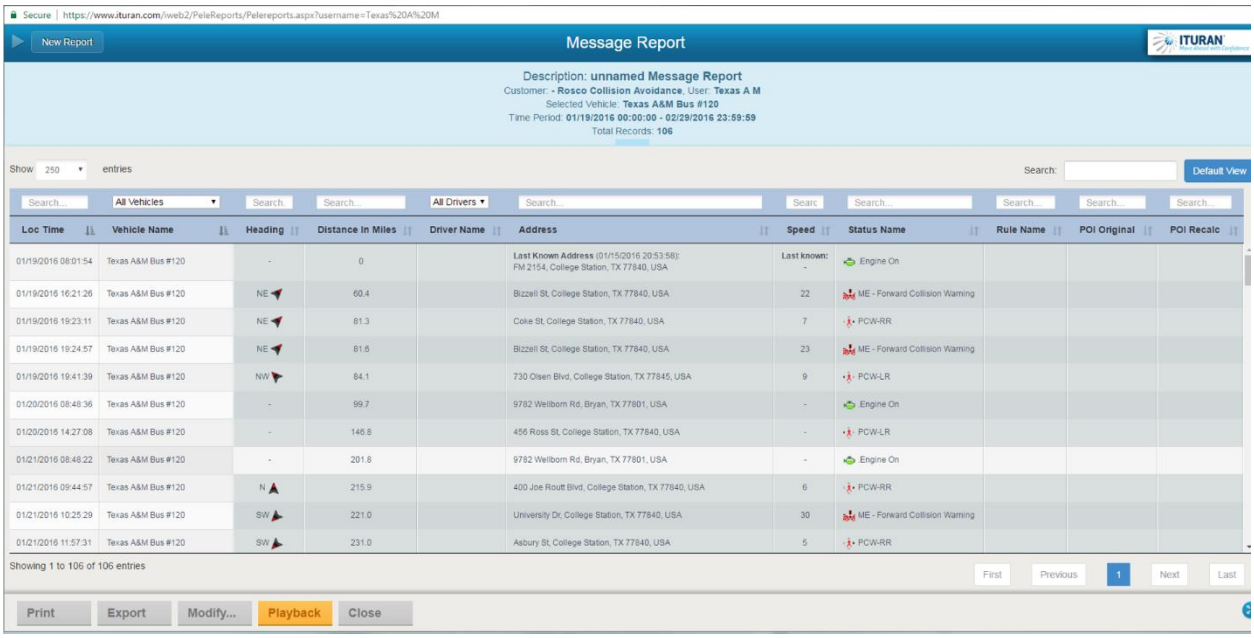
A *false alert* occurs when the Shield+ system provides a collision alert (which occurs when the time to collision between the bus and pedestrian/bicyclist is less than 1.5 seconds) and that condition has not been met. It was not possible to calculate a time to collision with the video in the pilot. As a result, a close proximity was defined to mean that the bus passes near a pedestrian or bicyclist where the trajectories could result in a collision. Video of the bus travel path was collected independently of the Shield+ system and was used to evaluate all Shield+ system alerts. These benchmark values from independently collected video was considered ground truth and was compared to the Shield+ system's event log from a telematics website report to determine when and if a false alert occurred.

During the pilot, Mobileye and Rosco Vision Systems provided TTI with access to a telematics website where data for specific events can be plotted on a map, as captured in Figure 1, and specific system event and alert data could be downloaded into a spreadsheet-based report with user-selected fields. Figure 2 presents an example of an available report. The sample report captures information at the time of alert: event time, heading, speed, warning type (Status Name), latitude, and longitude.



Source: TTI and Mobileye.

Figure 1. Screen Capture of Mobileye Vision Zero Map with Hotspots.



Source: TTI and Mobileye.

Figure 2. Screen Capture of Event Report from Rosco/Mobileye Telematics Website.

SUMMARY OF FINDINGS

During the initial pilot, there were 37 total reviewable alerts and no false alerts. During the follow-up assessment period, the telematics website recorded 40 reviewable alerts. Video review showed there was a pedestrian or bicyclist in close proximity to the bus during 36 of the 40 alerts. There were four alerts where no video indication of a pedestrian or bicyclist was present. This results in a 10 percent false alarm rate for the follow-up assessment study.

$$False\ Alarm\ Rate\ (\%) = \left[\frac{Total\ number\ of\ \ false\ alerts}{Total\ number\ of\ alerts}\right] = \frac{4}{40} = 10\%$$

Data collected during the follow-up assessment show that Pedestrian Collision Warnings (PCWs) were predominantly set off by people or bicyclists in front of the bus. Of the 36 established warnings, only two came from a location other than the front sensor. Both of those were warnings from the left rear sensor of the bus while in a right-hand turn. Occasionally, the bus would be operating in what would be considered routine conditions and a warning would go off, typically for a person in a crosswalk or a pedestrian waiting at a bus stop while the bus enters a loading area. In these 36 cases, there never appears to be an abrupt, reactive, or corrective type maneuver made by a driver as a result of the situation that caused the warning.

As mentioned, there were 36 warnings with associated video showing pedestrians or bicyclists in close proximity to the bus. The algorithm uses time-to-collision and relative speeds to indicate a warning. Researchers reviewing the video do not have the time-to-collision data and are limited to estimating the minimum distance between the bus and the bicyclist or pedestrian to best determine if the alert is substantiated. Table 1 shows a summary of the number of warnings by proximity, and Figure 3 shows a map of these warning locations.

Table 1. Proximity of Bus to Pedestrian or Cyclist.

Proximity	# of Warnings
0–5 Ft	1
5–10 Ft	19
10–15 Ft	11
15–20 Ft	3
20–30 Ft	2
False Alarm	4
Grand Total	**40**

While the warnings are dependent on the projected trajectory of the bus, the projected trajectory of the pedestrian (or bicyclist), and the calculated time-to-collision, there were different ranges when the warning was activated depending on where and how quickly a person or cyclist was moving. Table 2 tabulates the relationship between the bus trajectory, sensor location, and the proximity of the reason for the warning. In the campus environment, as might be expected, pedestrians made up a majority of the collision warnings (34 of the 36 warnings), with two bicyclist warnings making up the two 20–30 foot indications.

Table 2. Bus Trajectory, Proximity, and Warning Location.

	Left Rear (PCW-LR)	Forward (ME – PCW)					Grand Total
Proximity	**Right Turn**	**Left Turn**	**Right Turn**	**Straight Ahead**	**Sweeping Left Turn**	**Sweeping Right Turn**	
0–5 Ft	1						**1**
5–10 Ft	1	2	3	8	5		**19**
10–15 Ft		1		9	1		**11**
15–20 Ft		1			2		**3**
20–30 Ft				2			**2**
False Alarm						4	**4**
Grand Total	**2**	**4**	**3**	**19**	**8**	**4**	**40**

Table 3 presents the characterization of locations where warnings occurred. Bus stops and crosswalk locations were the most common and have a nearly even distribution while the other category includes two bicyclists and one pedestrian that came out from behind a truck that was not located near a crosswalk or bus stop.

Table 3. Bus Trajectory and Characterization of Warning Location.

Locale/Reason	Left Rear (PCW-LR)	Forward (ME – PCW)					Grand Total
	Right Turn	**Left Turn**	**Right Turn**	**Straight Ahead**	**Sweeping Left Turn**	**Sweeping Right Turn**	
Bus Stop							
Pedestrian	1	2	3	3	8		**17**
Crosswalk							
Pedestrian		2		14			**16**
Other							
Bicycle				2			**2**
Pedestrian	1						**1**
False Alarm						4	**4**
Grand Total	**2**	**4**	**3**	**19**	**8**	**4**	**40**

As a result of the TAMU bus operating on multiple routes, warning indications are spread out across the campus with a high density along Olsen Boulevard. Olsen Boulevard has a large number of swing in type bus stops where the bus turns toward the waiting riders and then continues to maneuver into the loading/unloading zone. Olsen Boulevard also has numerous crosswalks between large parking lots and heavily attended classrooms that create heavy pedestrian traffic flow. Table 4 shows the roads where these warnings occurred sorted by frequency and categorized by sensor location and bus trajectory.

Table 4. Roads Where Collision Warnings Occurred.

	Left Rear (PCW-LR)	**Forward (ME – PCW)**					**Grand Total**
Roadway	Right Turn	Left Turn	Right Turn	Straight Ahead	Sweeping Left Turn	Sweeping Right Turn	
Olsen Blvd.	1	3	1	6	5		**16**
Routt Blvd				4			**4**
Kimbrough Blvd				4			**4**
Coke St.		1	1	1			**3**
University Dr.	1		1		1		**3**
Throckmorton St.						2	**2**
George Bush Dr.				1		1	**2**
Ross St.				2			**2**
Bizzell St.				1		1	**2**
Gene Stallings					1		**1**
Asbury St.					1		**1**
Grand Total	**2**	**4**	**3**	**19**	**8**	**4**	**40**

Figure 3 displays the map locations of the warnings summarized in Table 4. As shown in Figure 3, there is one warning with coordinates showing it to have occurred on the golf course. Video review of the warning shows the bus traveling along Bizzell Street past Mosher Lane by the golf course. This is one of the warnings in the construction zone identified to be a false alarm.

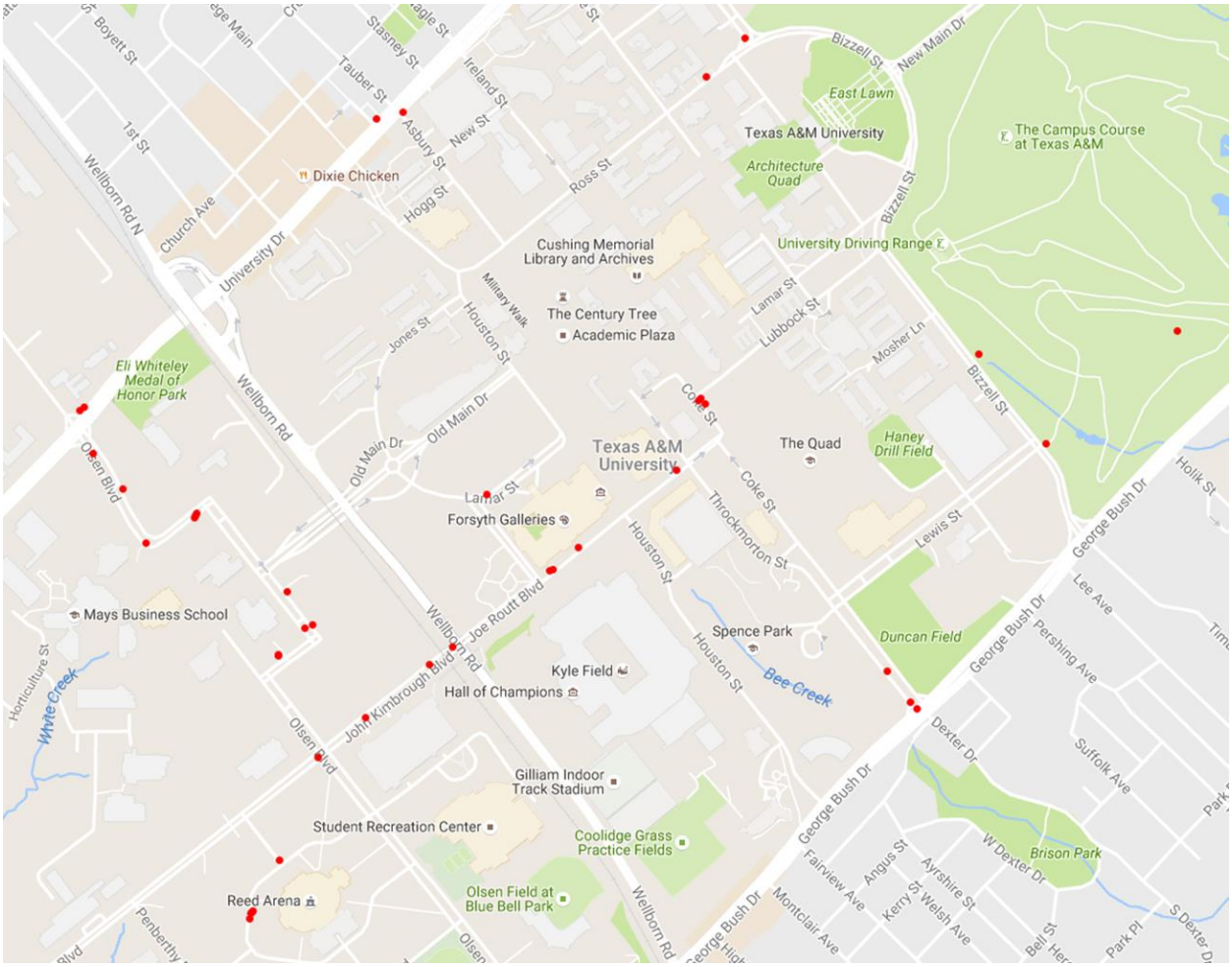


Figure 3. Map of Pedestrian Collision Warning Locations.

Data collected for the follow-up assessment of the Shield+ system with the enhanced algorithm indicated that the system produced fewer warnings from the left and right rear sensors than during the pilot. Mobileye/Rosco representatives confirmed that the sensitivity of the algorithm was decreased to reduce unnecessary warnings. Direct comparisons with the pilot earlier in 2016 are difficult since the bus was operated on additional routes and data were recorded at a different time of the academic year when there is a much smaller student population on campus.

The Mobileye Shield+ system accurately detected pedestrians and bicyclists in close proximity to the bus in most cases. The telematics reports indicated the bus had 40 PCW during the 18 days of bus operation in the follow-up assessment period. Nearly all (36 of 40) the warnings showed a pedestrian or bicyclist in close proximity to the bus. The four warnings where a bicyclist or pedestrian was not present in the video occurred in an area where the bus was in a construction zone where lanes were marked by tall narrow traffic cones. Video review showed there was a pedestrian or bicyclist in close proximity to the bus during 36 of the 40 warnings resulting in a 10 percent false alarm rate.

Despite its accuracy at detecting pedestrian and bicyclists in close proximity to the equipped bus, the Shield+ system warnings never required a bus driver to make a corrective driving maneuver

to avoid a collision. Almost half of the collision warnings were produced as the bus driver approached a bus stop with waiting passengers, which is a common occurrence on all bus routes. Further, several of the Texas A&M campus buses routinely operate in a congested campus environment in close proximity to many pedestrians and bicyclists.