

Target Tracking Using USS Signal Ways

Rajiv Sithiravel, Sivagnanam Sutharsan, Doug McEwan and David LaPorte

Abstract

Modern vehicles are equipped with various so-called “Driver Assistance Technologies” (DAT) to both aid the driver and enhance the safety of all passengers. Providing these technologies require the sensing vehicles to have an extensive perception of the vehicle’s surroundings. This insight is sensed via various sensing systems installed on the vehicle. One of the vital tasks of these sensing systems is the robust awareness of nearby obstacles. Whether in highway (high-speed) scenarios, or parking (slow-moving) scenarios, the sensing of obstacles must be performed precisely and quickly. Of particular interest in low-speed scenarios is the correct detection of “vulnerable road users” (VRUs) - i.e. pedestrians, cyclists, motorcyclists, which customarily has been a problematic issue in detection and tracking.

Various types of sensing systems are used in DAT, including radar, camera, and ultrasonic sensing systems (USS). In this paper we use static range measurements from ultrasonic sensor “signal ways” to support VRU detection and tracking in low-speed scenarios. The static range measurements are pre-processed using three methods: signal tracing (ST), intersection of signal fields-of-view (ISFOV) and intersection of ellipses (IE) to extract quasi measurements.

The results show that in low-speed scenarios within five meters of a host vehicle, the three USS Signal Ways processing methods can be reliable means of resolving ambiguities in VRU tracking.

Index Terms

USS Signal Ways based tracking, pre-process USS Signal Ways, DAT features

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I. INTRODUCTION

Self-Driving Vehicles (SDV) support numerous driver assistance technologies (DAT) by perception of the surrounding using sensors. Due to the capability limitations of the internal sensors in the SDV paved a way to use exteroceptive sensors, which are sensors that create measurements from external sources i.e., radars, cameras, LiDARs and ultrasonic sensing systems (USS).

Optical system-based sensors such as cameras and LiDARs are prone to weather. Radars compared to cameras and LiDARs very robust to bad weather, dust particles, vibration, and rough condition. Radars have the ability to measure the radial velocity instantly, which facilitates separation of moving and stationary environment. However, they usually carry disadvantages like interference problem and relatively low resolution in angles.

Sound based sensor such as USS has been used in many areas including in SDV. USS performs well in slow moving application for example valet parking and remote parking. Unlike the radar which has low tendency to detect or track road vulnerable users (RVU) (explicitly targets that are very close to the sensing vehicles), the USS can detect and track RVU at close proximity. This issue becomes much worst for larger sensing vehicles (lorry, bus, train, tramp, and heavy vehicle) due to line of sight of the radars.

However, LiDAR can be used to detect and track RVU at close proximity (up to 35 meters from the sensing vehicle), but currently LiDAR is used for ground truth purpose only and in term of marketability it is a very expensive unit. Also, this might be resolvable by using 360 degrees field of view (FOV) camera or surround cameras. Note, practically it is hard to mount the camera with 360 degrees FOV on sensing vehicles with line of sight of 360 degrees and also adding many cameras come with cost.

While each sensing technology has its limitations and cost, the USS sensors are available in all the modern vehicles and they are cheap. Valeo provides USS signals, which contains static feature points (SFP), dynamic features (DF), signal ways (Sways), line marks and a grid map. The mission is here to see what signal can be used to detect and track nonstationary RVU. Line marks and grid map are out of the contest and SFP is not useful. DF is only available with the addition of a Valeo camera system, so we left with only SWays.

The Sways are range-only measurements and can be monostatic, bistatic and multistatic. If the measurements are bistatic or multistatic then we can extract a pseudo measurement by solving multiple bistatic range observations. Measurements are computed based on signal tracing, intersection of ellipses (if there are more than one ultrasonic return) and intersections of FOVs. Results show that each method as well as a combination of methods can be used to detect VRUs within five meters of the USS sensor on the host vehicle.

The overall Multisensor setup is described in Section (II). A detail description of the Valeo's USS Signal Ways explained in Section (III). Finally, results and conclusions are given in Sections V and VI respectively.

II. SYSTEM OVERVIEW

The vehicle used for testing and evaluation is displayed in Figure (1), and is equipped with five radars, five mono digital cameras, twelve ultrasonic sensors and a LiDAR sensor. Additional sensors are used to geolocate the vehicle. These include RT3000 (high precision GPS device) and inertial measurement units (IMUs). The vehicle has the capability to capture and store sensor measurements for later offline analysis and replay.

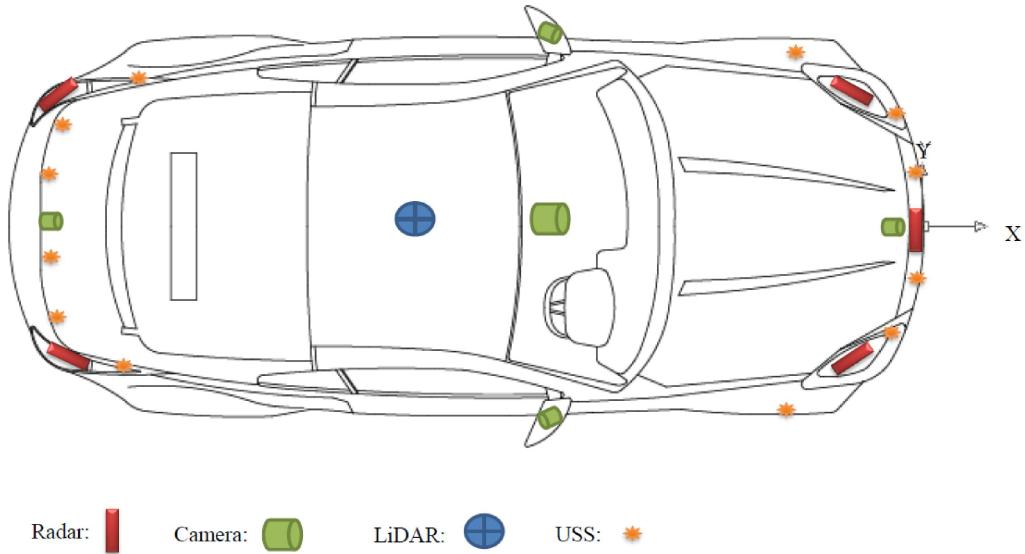


Fig. 1. Sensor vehicle system overview

A radar-tracking system developed by Aptiv provides object tracking results that are combined from two sub-trackers: one based on forward-looking radar and one based on a four-corner radar system (providing a 360-degree view of the vehicle's environment). The front radar track results are fused with a forward-looking camera sensor from MobilEye which provides image-based tracking results. These front fused tracker results are further fused with the four corner radar tracker results. LiDAR point clouds are used as a ground truth validation tool. The accuracy of the LiDAR performance was validated in advance by using RT3000 range tests in a controlled environment (test track). There are six pairs of ultrasonic sensors, which track stationary and non-stationary objects during low-speed maneuvers. Additional mono cameras support various features. All the tests are performed with pre-calibrated sensors.

III. ULTRASONIC MEASUREMENTS

Ultrasonic measurements are obtainable from a Valeo sensing system which provides static feature points (SFP), dynamic features (DF), signal ways (SWays), line marks and a grid map. Up to 240 SFPs are provided, which are all stationary obstacles. The DF is only available with the addition of a Valeo camera system with up to ten dynamic objects provided. The SWays are range-only measurements and can be monostatic, bistatic and multistatic. The line marks are stationary information and the grid map provides a discretized occupancy map of the surrounding environment.

Note, the scope here is to track non-stationary vulnerable road users (VRUs). SFPs cannot be used since they only deal with stationary objects. DFs depend on Valeo's camera and the data comes from Valeo's camera or fused ultrasonic observations and camera. The line marks and grid map are out of scope here. Sways are range-only measurements which will be used to see how well they can be used for VRU tracking.

IV. USS SIGNAL WAYS

The ultrasonic's Sways observations are range-only measurements and can be monostatic, bistatic and multistatic. There are maximum of 14 Signal-Ways. If the measurements are bistatic or multistatic then we can extract a pseudo measurement by solving multiple bistatic range observations. For simplicity, as shown in Figure (2) we only consider the front of the host vehicle. The possible signal ways pairs are described in Table (I).

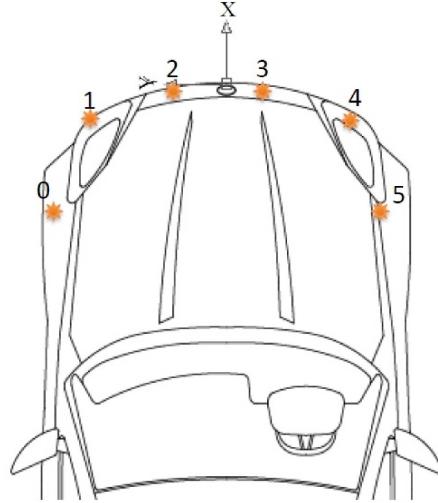


Fig. 2. Front USS Sensor Layout

TABLE I
SIGNAL WAYS PAIRS AT THE FRONT OF THE HOST

Sensor ID	0	1	2	3	4	5
0	(0,0)	(0,1)	—	—	—	—
1	(1,0)	(1,1)	(1,2)	—	—	—
2	—	(2,1)	(2,2)	(2,3)	—	—
3	—	—	(3,2)	(3,3)	(3,4)	—
4	—	—	—	(4,3)	(4,4)	(4,5)
5	—	—	—	—	(5,4)	(5,5)

As shown in Table (I) the signal from USS Signal-Ways can be retraced. The USS sensors are calibrated and their locations and fields of view (FOVs) are known. One of the ways to compute the intersection is by solving ellipses whenever the

observation is bistatic or multistatic. Figure, (3) illustrates a technique normally used in active/passive radar applications, where the platform with emitter serially fires pulses and is observed by a receiver platform. The bistatic range measurement can be computed with:

$$R_b = \frac{R_T + R_R}{2} \quad (1)$$

where L , R_T , R_R and $2a$ are distance between sensor platforms, range between the emitter and target, range between target and receiver and the major axis. The major axis and minor axis R_b can be used to create ellipses. If the static measurements are bistatic or polystatic then we can create ellipses and solve for their intersections, which are the detections. The same principal applied in radar can be also applied for USS signal ways to compute the range and heading of detected objects. In addition,

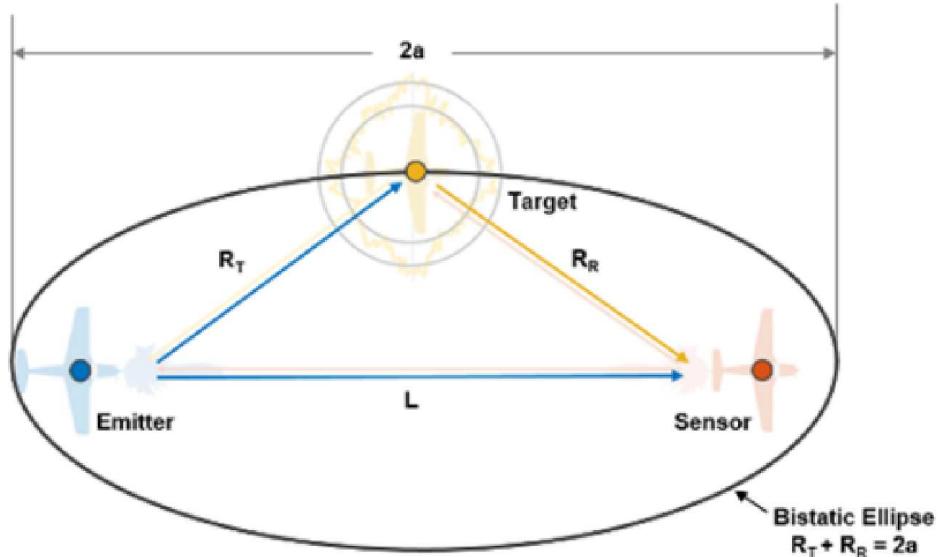


Fig. 3. Static measurement

we can also compute the intersection by using FOV intersections. For monostatic only observations, traced information can be used as the intersection.

Figure (4) depicts a case where a person is walking longitudinally toward the host vehicle. LiDAR, radar and RT3000 are used for performance validation. Here we only focus on the front of the host vehicle where one of the USS signals is transmitted and received by the same sensor (3). The location of the detections can be anywhere in the arc of sensor 3's FOV. Another signal is transmitted by sensor 2 and received by sensor 3. The detections can be anywhere within the arc of the combined FOVs of sensor 2 and 3. Note, the same procedure can be applied to the rear of the host to extract pseudo measurements at the rear of the host vehicle.

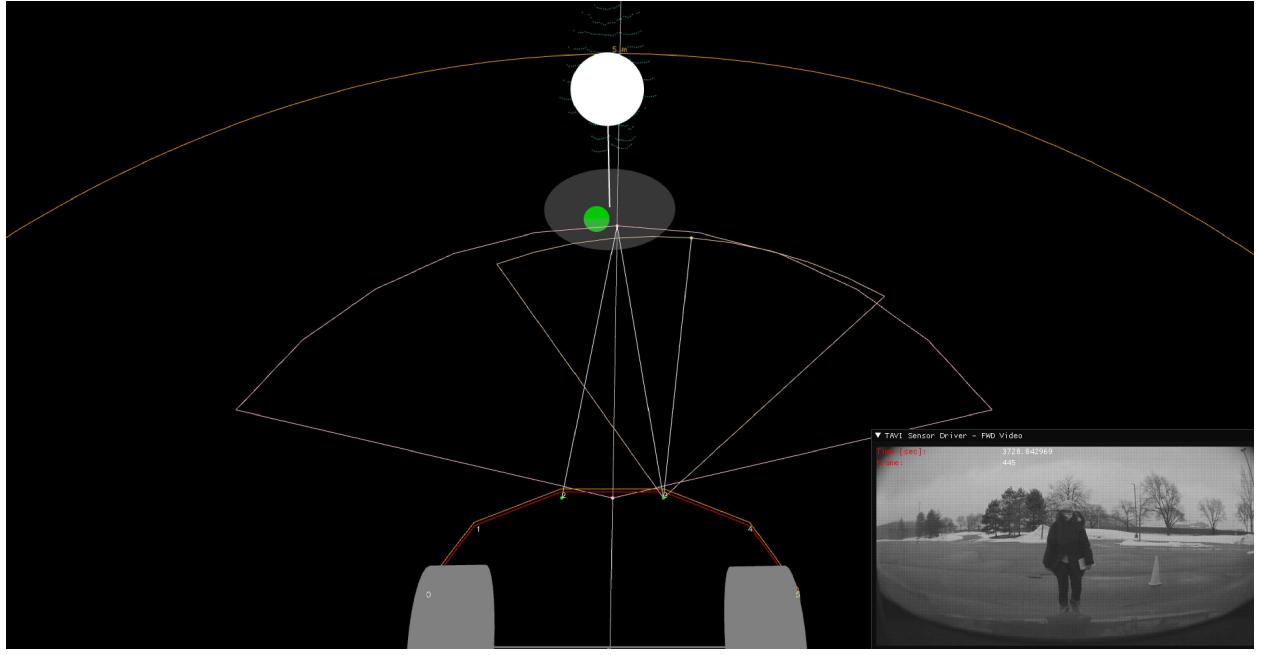


Fig. 4. Signal Tracing and FOVs at the front of the host (Signal trace: gray lines, FOVs: pink pie, RT3000: white sphere, LiDAR: light-blue cloud, Radar's detections: green dot, sensor locations: $[0, \dots, 5]$, gating: gray circle)

As shown in Figure (5) each USS signal can be traced, its longitudinally maximum travelled position is the detection. Some detections can come from noise. The signal tracing is related to the presence of non-stationary targets. A higher number of non-stationary tracks will result in a higher number of traced signals.

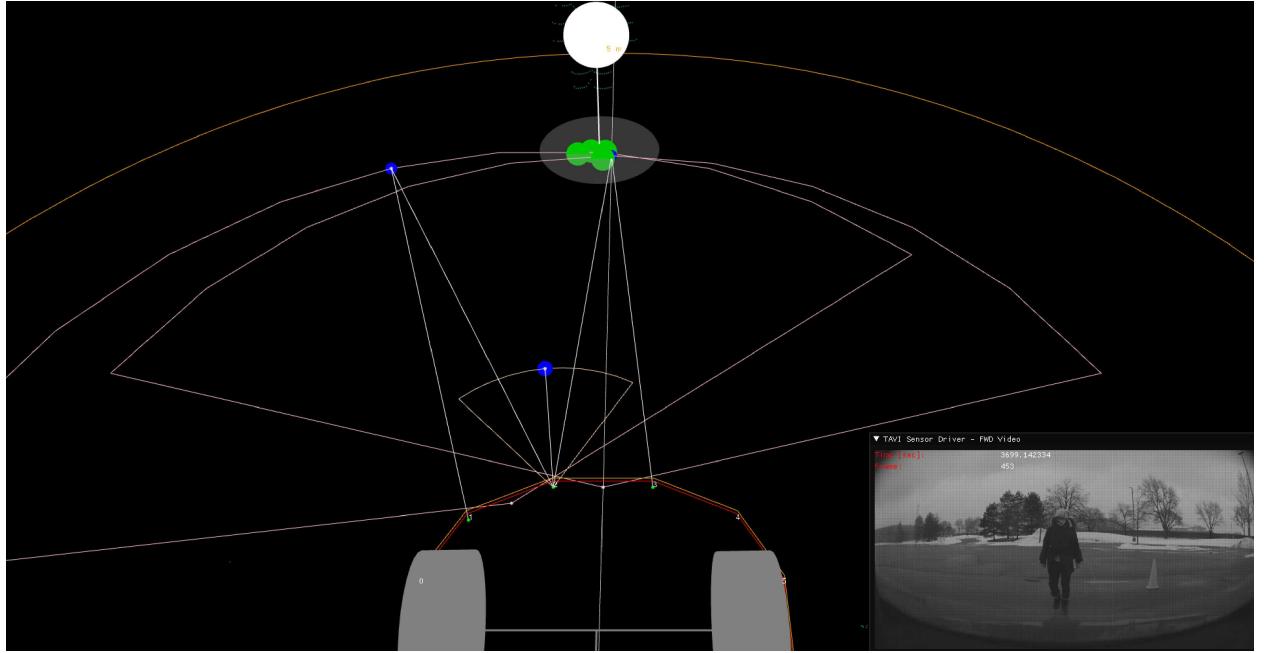


Fig. 5. Intersections of signals tracking at the front of the host (Signal trace: gray lines, FOVs: pink pie, RT3000: white sphere, LiDAR: light-blue cloud, Radar's detections: green dot, Sensor locations: $[0, \dots, 5]$, detections: blue dots, gating: gray circle)

Using signal FOVs as shown in Figure (6) we can compute the intersection. The difference between ellipse intersection and FOVs intersections is the way major and minor axis are determined. Later uses signal's FOV or combined FOVs and the other follows the (3) radar's technique.

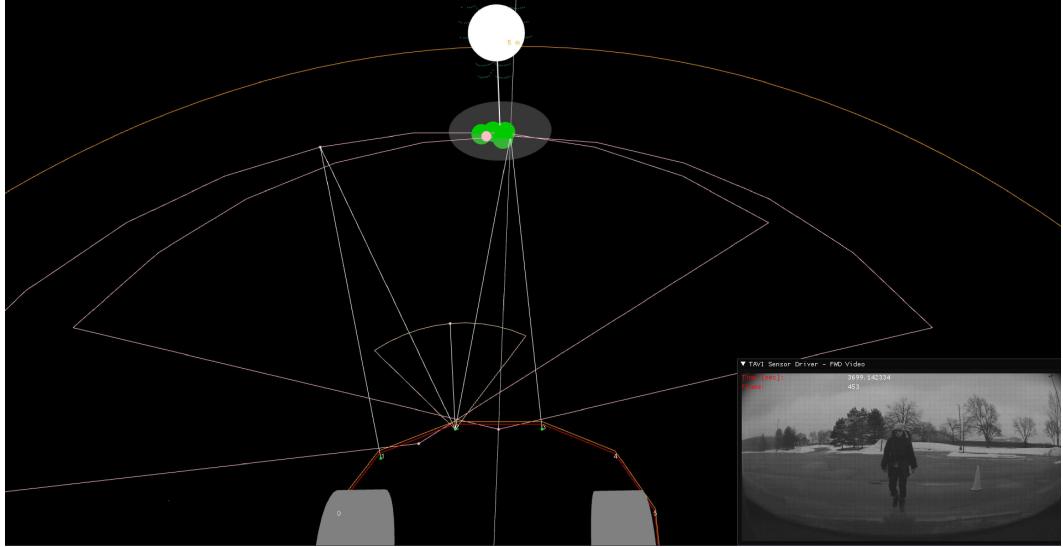


Fig. 6. Intersections of signals FOVs at the front of the host (Signal trace: gray lines, FOVs: pink pie, RT3000: white sphere, LiDAR: light-blue cloud, Radar's detections: green dot, Sensor locations: $[0, \dots, 5]$, detections: pink dots, gating: gray circle)

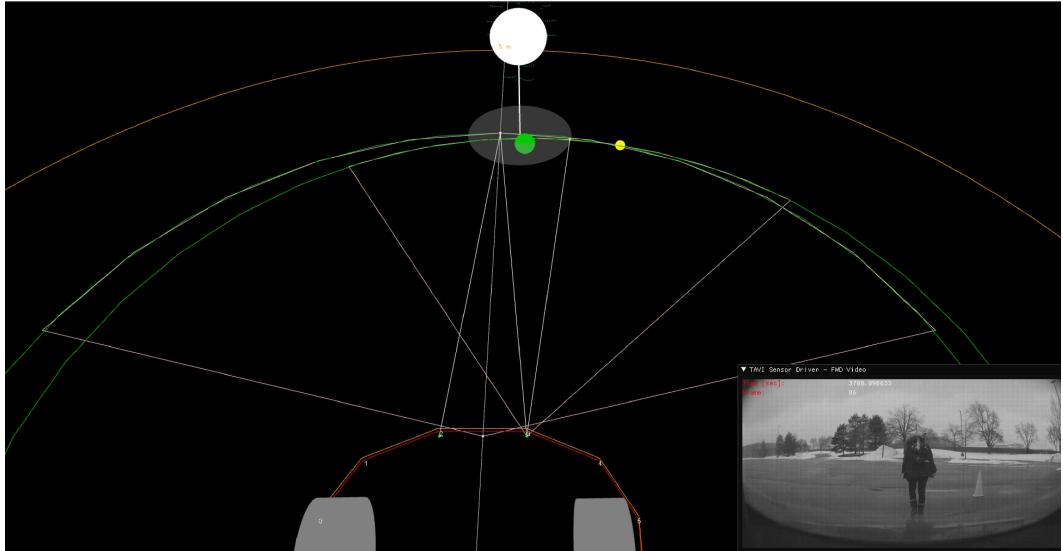


Fig. 7. Intersection of ellipses at the front of the host (Signal trace: gray lines, FOVs: pink pie, RT3000: white sphere, LiDAR: light-blue cloud, Radar's detections: green dot, Sensor locations: $[0, \dots, 5]$, ellipse: green circle, detections: yellow dots, gating: gray circle)

As shown in Figure (7) the detections can be computed whenever the observations are bistatic or multistatic. The performance accuracy is related to not only the ambiguities rooted within USS signal-ways, but also on the performance of the ellipse intersection algorithm. Some important possible ellipse configurations are represented in Figure (8). In this paper we do not go into detail regarding the ellipse intersection algorithm, but it is a difficult problem to solve and we have developed multiple versions of the algorithm.

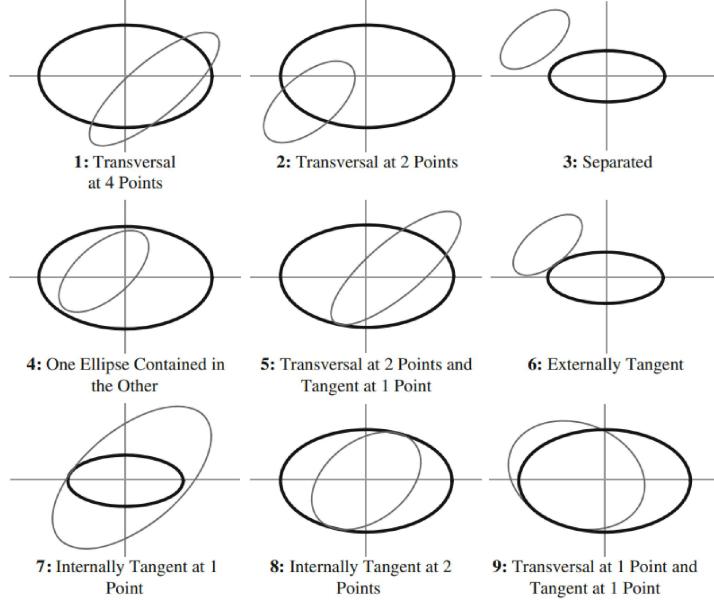


Fig. 8. Possible ellipses configurations

Figure (9) shows the collection of all the detections at one instant. The pink, yellow and blue dots represent the detections from signal FOVs, ellipse intersections and signal tracing, respectively. The total number of observations is a random occurrence and the detections can come from true-targets and false alarms (noise). Here, the point-source assumption doesn't apply, and a single target can produce multiple detections. As shown in Figure (10), multiple detections can be clustered to compute the pseudo measurement.

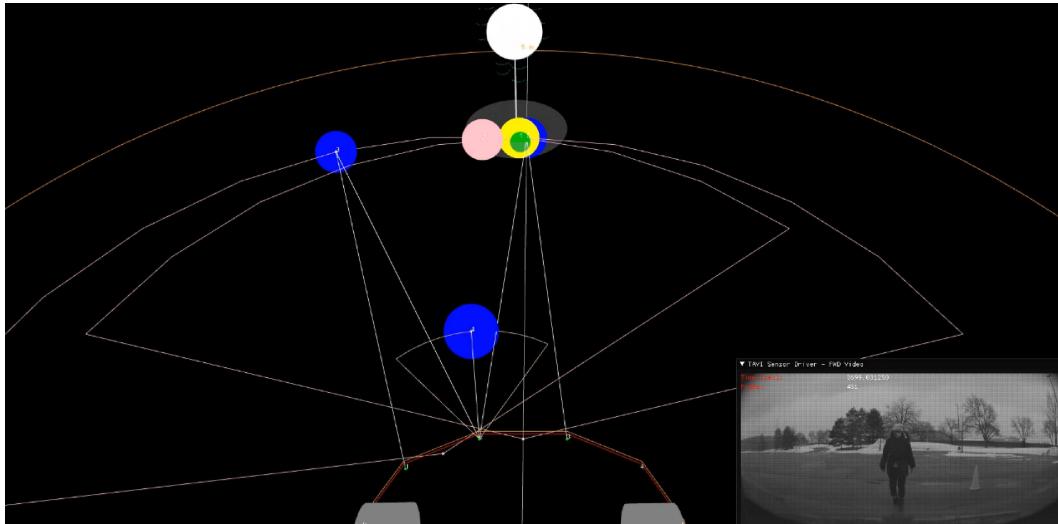


Fig. 9. Intersection from all the methods (Signal trace: gray lines, FOVs: pink pie, RT3000: white sphere, LiDAR: light-blue cloud, Radar's detections: green dot, Sensor locations: $[0, \dots, 5]$, detections from FOVs: pink dots, detections from intersection of ellipses: yellow dots, detections from signal tracking: blue dots, gating: gray circle)

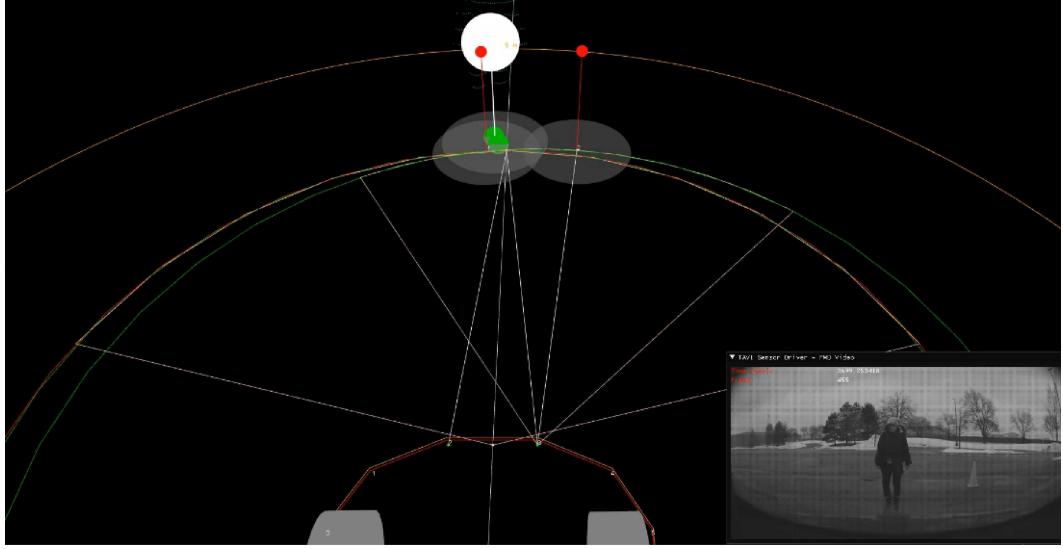


Fig. 10. Fused processed detections (Signal trace: gray lines, FOVs: pink pie, RT3000: white sphere, LiDAR: light-blue cloud, Radar's detections: green dot, Sensor locations: $[0, \dots, 5]$, fused detections: red sphere, gating: gray circle)

V. RESULTS

A feasibility study has been conducted to see whether USS Signal Ways can be used for detecting and tracking slow moving VRUs for use in parking lot based Driver Assistance features. As described in Section (II) the sensor platform senses the surrounding environment via six pairs of Valeo's USS sensors. Note that LiDAR, cameras and RT3000, RT ranges and radars are used as ground truth sources. A number of test cases have been designed to study the outcome as shown in Section (V-A).

A. Test cases:

1) Case I:

- Host vehicle is parked.
- Place a cone at the front of the host vehicle on the right side.
- Place it at 2m – 10m (longitudinally varying) from the front bumper of the host.
- From the center of the bumper varies the cone position laterally (1m – 9m).

2) Case II:

- Host vehicle is parked.
- Place a cone at the front of the host vehicle on the left side.
- Place it at 2m – 10m (longitudinally varying) from the front bumper of the host.
- From the center of the bumper varies the cone position laterally (1m – 9m).

3) case III:

- Host vehicle is parked.
- A moving walker.
- Moving parallel to the front bumper from varying longitudinal distance.

- Moving vertical to the front bumper from varying lateral distance.
- Moving with varying speed.

4) case IV:

- Host vehicle is parked.
- A moving walker.
- Moving parallel to the front bumper from varying longitudinal distance.
- Moving vertical to the front bumper from varying lateral distance.
- Place a cone at the right side of the host with varying longitudinal and lateral distance.

5) Case V:

- Host vehicle is parked.
- A moving walker.
- Moving parallel to the front bumper from varying longitudinal distance.
- Moving vertical to the front bumper from varying lateral distance.
- Place a cone at the left side of the host with varying longitudinal and lateral distance.

6) Case VI:

- Host vehicle is parked.
- 2 or more (max 5) moving walkers.
- Moving parallel to the front bumper from varying longitudinal distance.
- Moving vertical to the front bumper from varying lateral distance.

Data has been collected at the parking lot of Building 2 at the Ford Dearborn Product Development Campus. This was during a winter month and the parking lot was empty of other vehicles. There were a lot of tests conducted and studied, but the main focus applied to cases 4 – 6. The host vehicle had LiDAR, RT3000, RT ranges and cameras for ground truth purpose. Test subjects ground truths were also collected using RT-range instruments. As performance validation a gating around obstacle's RT ranges were put in place i.e., 0.5m. Any detections that fell inside the gating area are considered a valid detection.

Root mean squared error (RMSE) values were computed to validate the algorithm's performance. As shown in Figures (V-B) and V-C) the results were analyzed visually and quantitatively, where on the left side of the figures longitudinal and lateral position of detections along with ground truth, position RMSE and number of detections information are available for validation. On the right a visualization shows information regarding the host's internal and external environment. The remaining are a camera view of the test subject, some performance validation parameter interfaces, and results of the algorithm.

B. Single target

In this case a sensor platform was parked at the parking lot throughout the testing and a pedestrian moved horizontally and vertically in front of the sensor platform. Also, for both cases a stationary object was placed either to the right or left side of the host vehicle. For nearly all of the test cases the algorithm was unable to detect the stationary objects.

As shown in Figure (11) a pedestrian walked in front of the host longitudinally back and forth. The longitudinal position (brown line) matched with the RT ground truth (blue line) and the lateral position (brown line) deviated slightly from the ground truth (blue line), but the overall position RMSE (yellow line) is below 0.30 meters. As the test subjects approached toward the host the number of detections (green line) increased, where the white line refers to the extracted number of detections. Within five meters from the front of the host bumper the algorithm worked very well. During the testing out of a total of 807 scans there were 175 missed detections and the average position RMSE was 0.26022 meters.

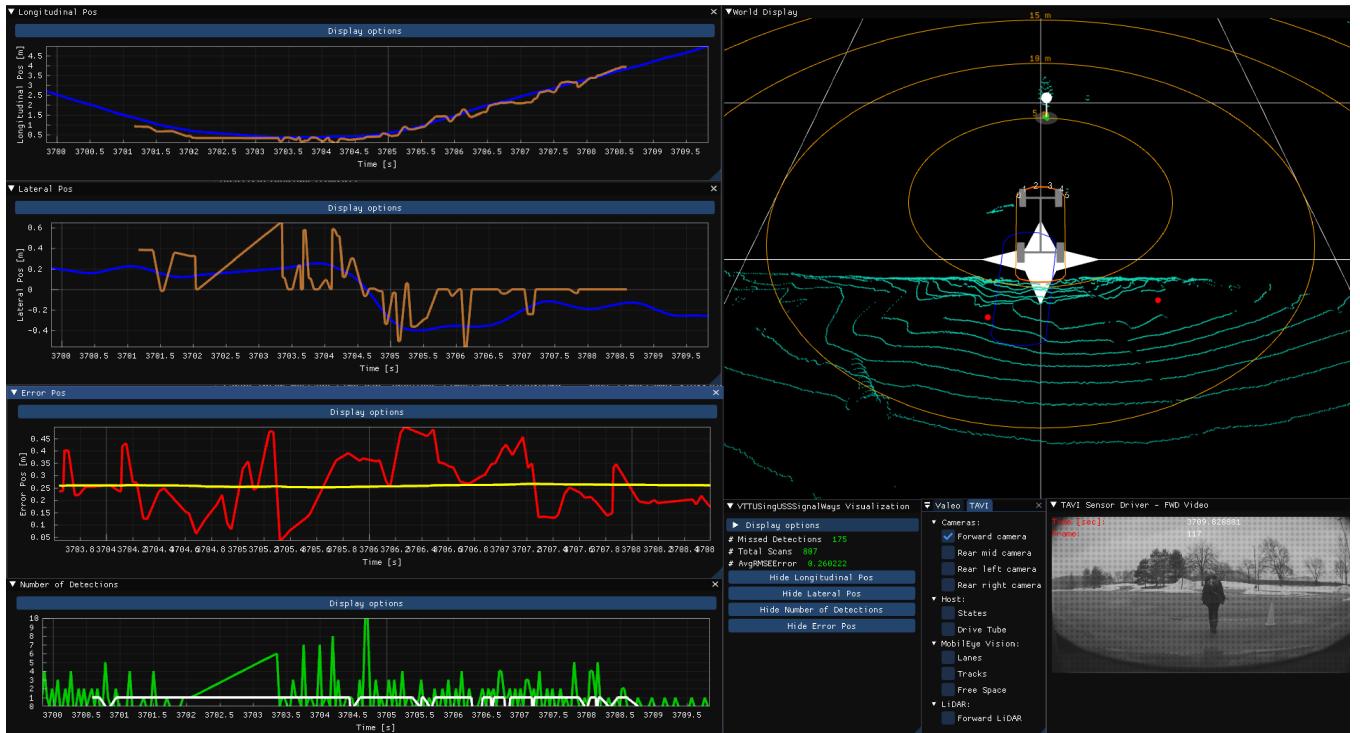


Fig. 11. Walking longitudinally in front of host

In the next test as shown in Figure (12) the VRUs walked laterally in front of the host at specific longitudinal positions from one end to other. As with the first case, the host vehicle was parked throughout the test. Ground truth from host and VRU were collected. As show in Figure (12) the lateral position (brown line) matched with RT ground truth (blue line) and longitudinal position (brown line) deviated somewhat from the truth (blue line), but the overall RMSE (yellow line) is below 0.30 meters. As the test subjects approached toward the host the number of detections (green line) increased, where the white line refers to the extracted number of detections. Again, as in the previous case, within five meters of the front of the host bumper the algorithm worked very well. From a total of 745 scans there were 494 missed detections and the average position RMSE was 0.266839 meters.

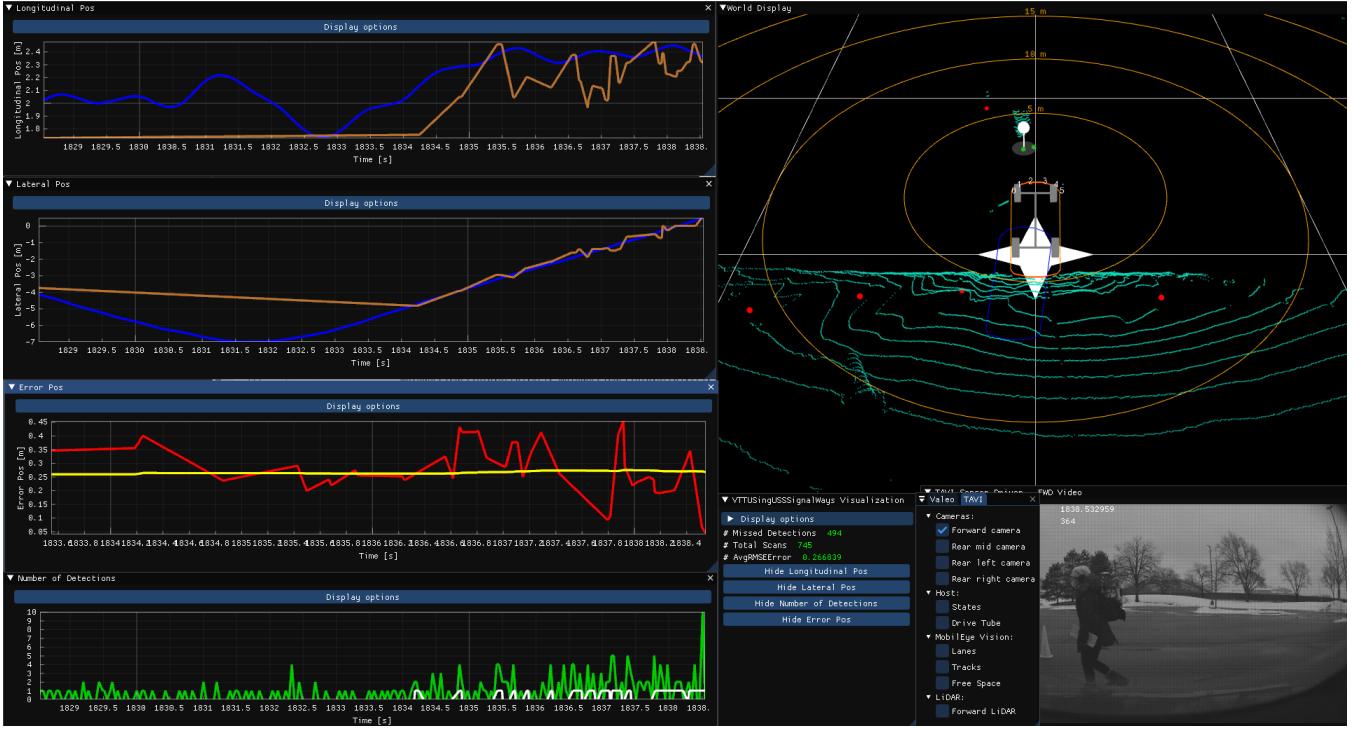


Fig. 12. Walking laterally in front of host

C. Multitarget

Tests were also conducted with more than two VRUs. During all of the tests there was a stationary obstacle either to the right or left side of the host. The host vehicle was parked throughout the test and the platform sensed the environment using radars, LiDAR, cameras, RT ranges and RT3000. Other than USS sensors the rest were used for ground truth purposes. The VRU test subjects' locations were collected using RT-Range instruments. As in the single target cases, test subjects moved longitudinally or laterally in front of the host vehicle. Performance analyses were taken with respect to a single target due to closely spaced target ambiguities.

As shown in Figures (13) and (14) both VRUs were walking back and forth in front of the host in different lateral positions. As shown in both figures longitudinal position (brown lines) matched with RT ground truth (blue or red line) and lateral position (brown lines) deviated somewhat from the truth (blue or red line), but the overall RMSE (yellow line) is below a desired 0.30 meter threshold. As the test subjects approached toward the host the number of detections (green line) were increased, where the white line refers to the extracted number of detections. Within five meters from the front of the host bumper the algorithm worked very well.

Next, as like the single target scenario two VRUs walked laterally in front of the host at specific longitudinal positions from one side to the other. Ground truth from the host vehicle and VRUs were collected.

As show in Figure (15) and (16) both VRU's lateral positions (brown lines) matched with RT ground truth positions (blue or red line) and longitudinal positions (brown lines) deviated somewhat from the ground truth (blue or red line), but the overall RMSEs (yellow lines) are within the 0.30 meter threshold. As the VRUs approached toward the host the number of detections (green lines) were increased, where the white lines are referred to the extracted number of detections.

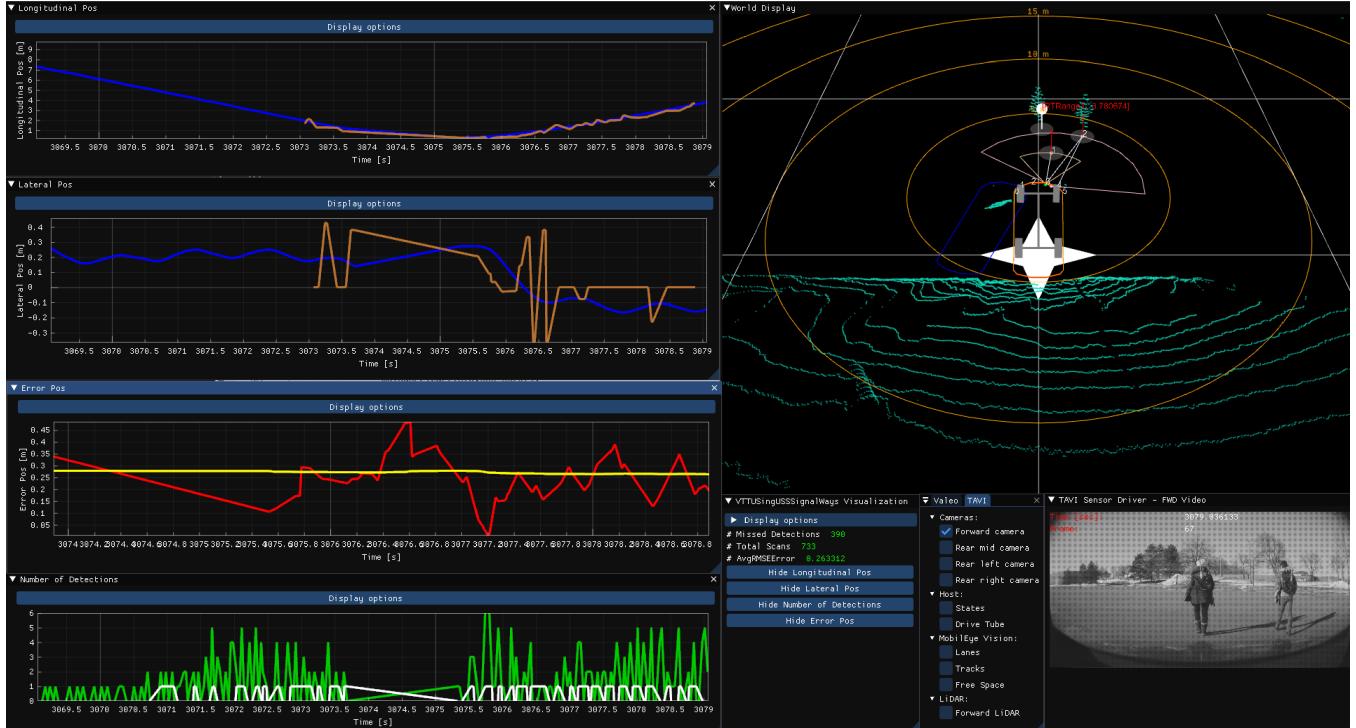


Fig. 13. Walking longitudinally in front of host (first target)

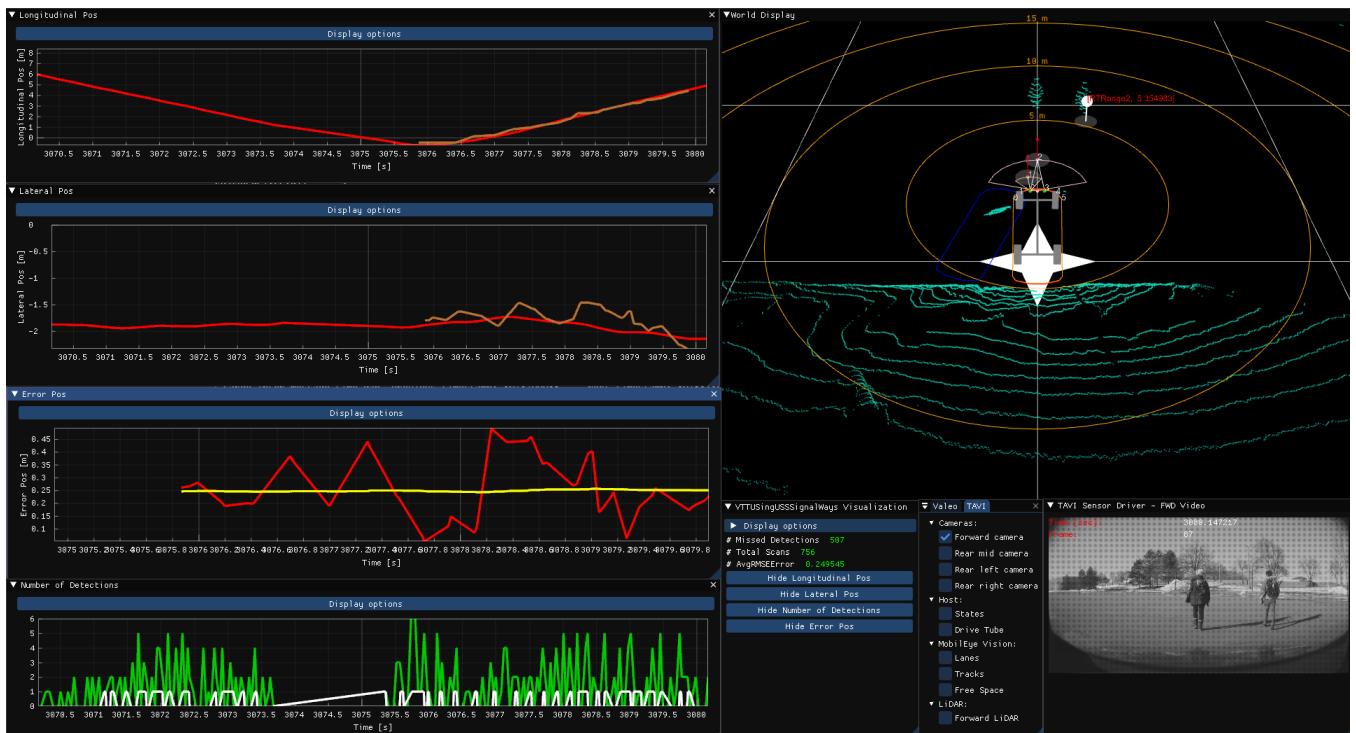


Fig. 14. Walking longitudinally in front of host (second target)

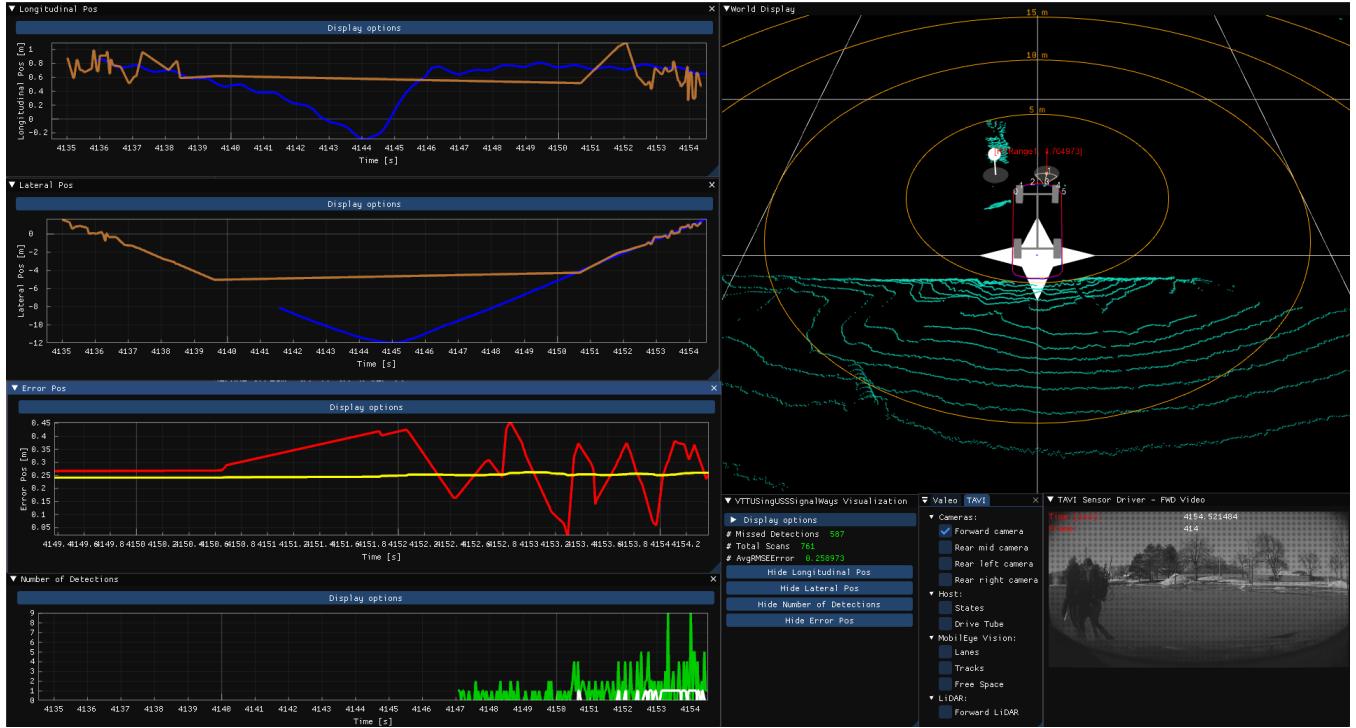


Fig. 15. Walking laterally in front of host (first target)

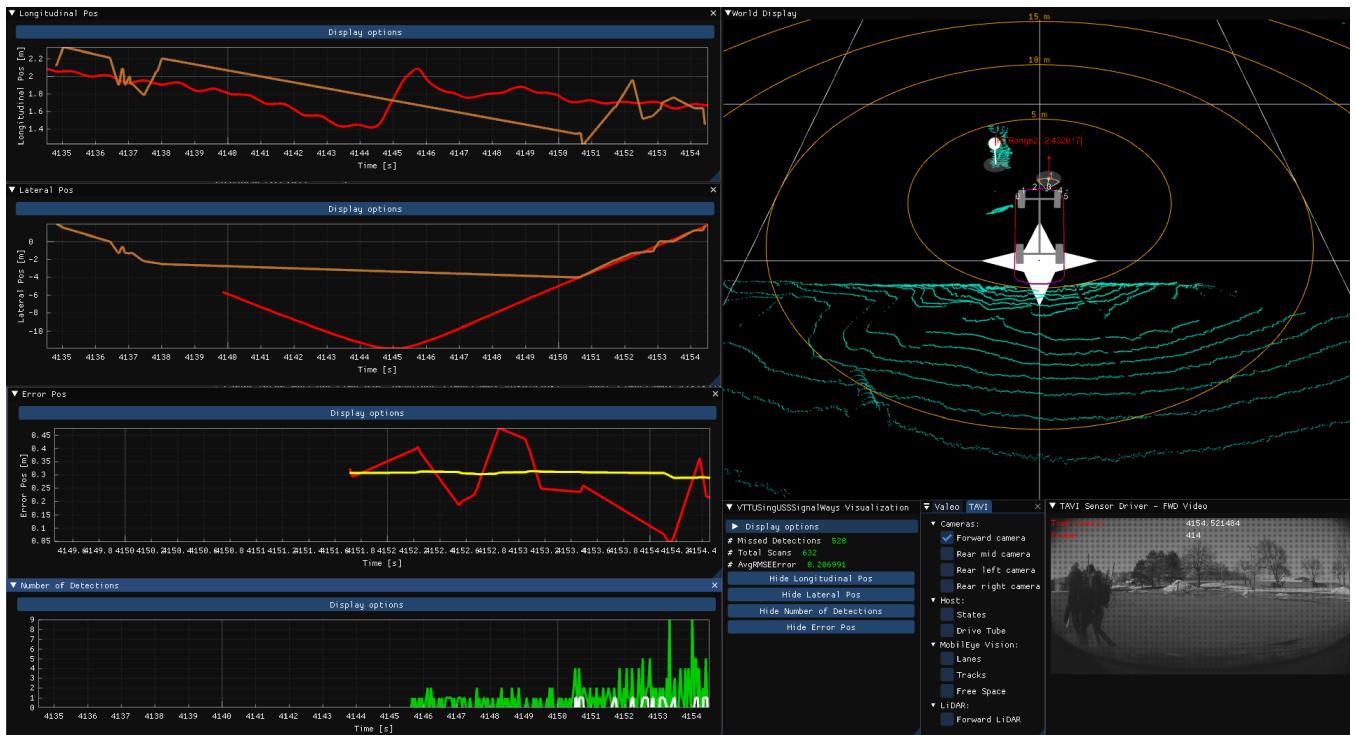


Fig. 16. Walking laterally in front of host (second target)

Finally, the performance of signal tracing, detection from intersection of ellipses and detections from intersections of FOVs were analyzed for the non-stationary single target case.

As shown in Tables (II) and (III) the performance of signal tracing, ellipse and FOVs intersection method were quantitatively analyzed for a single target cases. The first test was related to Case IV (walking in front of the host back and forth longitudinally). As shown in the table, missed detections and average position RMSE were used as performance metrics. All of the implementation methods performed well in terms of positional RMSE, but fused results had the lowest RMSE. By fusing the results further can improve the detections by removing uncertainties. The importance of the signal tracing method is reflected in the results. Note, we do not always have bistatic or multistatic range measurements and even if there are bistatic or multistatic signals, no intersections mean no detections. Signal tracing provides valuable information when we do not detect any intersections. Because the ellipse intersection method and signal FOV method deal with different geometric coordinates, they have different levels of performance accuracy.

TABLE II
PERFORMANCE: WALK VERTICALLY IN FRONT OF THE HOST

CASE IV	Signal Tracing Method	Detection from signals FOV	Intersection of Ellipses	Fused
Missed Detections	69	62	33	60
Total Scans	319	151	93	311
Average Position RMSE m	0.259475	0.255823	0.277137	0.252181 m

Table (III) deals with Case V where a single target moved laterally in front of the host from side to side at a specific longitudinal position. The ellipse intersection method provided a lower positional RMSE than the rest of the methods including the fused/clustered method. Note, the signal tracing method has the highest RMSE and also has the most missed detections.

TABLE III
PERFORMANCE: WALK HORIZONTALLY IN FRONT OF THE HOST

CASE V	Signal Tracing Method	Detection from signals FOV	Intersection of Ellipses	Fused
Missed Detections	341	71	73	342
Total Scans	500	140	143	493
Average Position RMSE m	0.261534	0.22807	0.214079	0.259315

VI. CONCLUSIONS

This initiative has taken place to support/enhance the use of USS Signal Ways in VRU detection and ultimately VRU avoidance. The focus of this study was at the front of the host vehicle, but similar methods can be applied to the rear as well. The monostatic, bistatic, and multistatic range information from USS Signal Way's data was used to compute detection pseudo measurements. These post processed measurements can be used for VRU tracking purposes. Observations are computed based on signal tracing, intersection of ellipses (if there are more than one ultrasonic return) and intersections of FOVs. The algorithm can provide fused detections and clustered fused detections. Results show that each method as well as a combination of methods can be used to detect VRUs within five meters of the USS sensor on the host vehicle.