Test Report

PERFORMANCE MEASUREMENTS OF A 3D IMAGER AND COLOR CAMERA VIEWING FORKLIFT TINES

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To Consortium CRADA Partners
Danaher Motion
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TABLE OF CONTENTS

1 BACKGROUND

As suggested by Danaher during a Consortium meeting at the NA2008 show (see Appendix A - Presentation at NA2008), NIST recently measured forklift tines using the CSEM/MESA SR3000 3D imager. The issue is that forklift tines can overhang the path of automated guided vehicles where 2D line scanning LADAR will not detect the tines. Figure 1 shows the issue of raised forks protruding into the intended vehicle path.

We also used a color camera and using software, overlaid the images to provide a clear view of the tines or other obstacles detected. All measurements were taken dynamically while moving the sensor towards the forklift tines, although 2D snapshot images are shown in this report. All data is available for review including videos of experiments as seen through the sensors. This report details the experiment including the test setup and results and ends with conclusions and appendices.

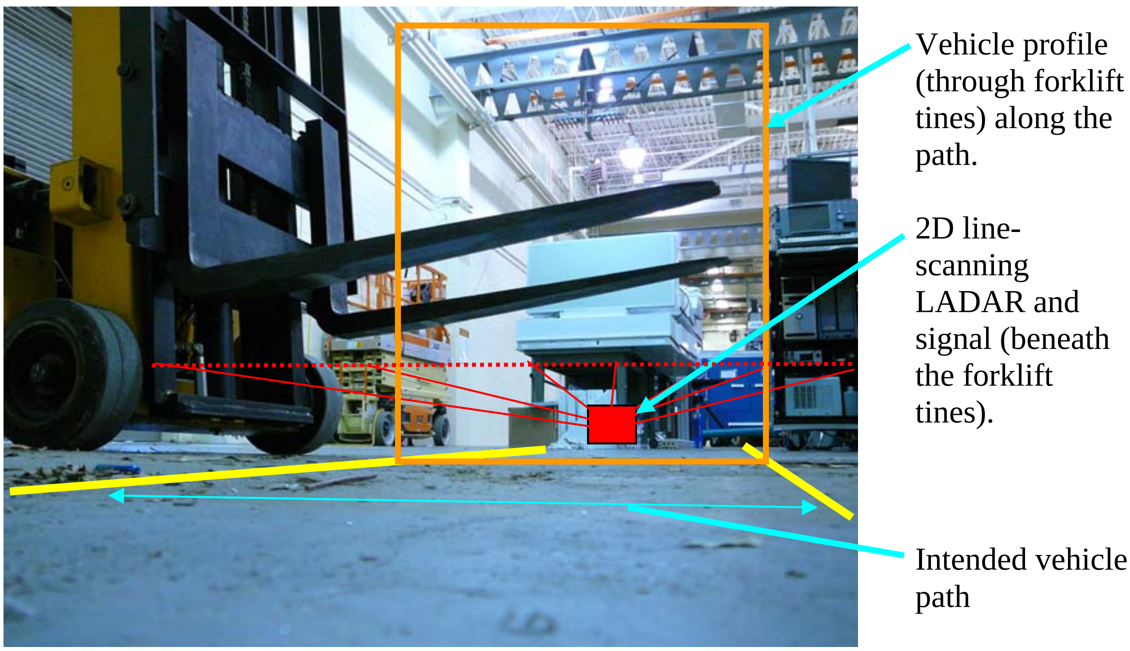


Figure 1: Raised forklift tines overhanging the vehicle path and above the typically measured 2D line scanning LADAR obstacle detect/safety sensor.

2 NIST EXPERIMENTS

2.1 Experimental Setup

2.1.1 Unprepared Tines and Floor Test Setup

A MESA SR3000 3D Flash Imaging sensor and a color camera were mounted together on a plate with the camera lens just behind the flash unit of the SR3000 (See figure 2). The sensor mount drawing is shown in Appendix B – Sensor Mount. The SR3000 specifications are: 176 x 144 pixels and 0.26 rad x 0.22 rad (47.5º x 39.6º) field of view (FOV). The camera FOV is slightly larger than the SR3000.

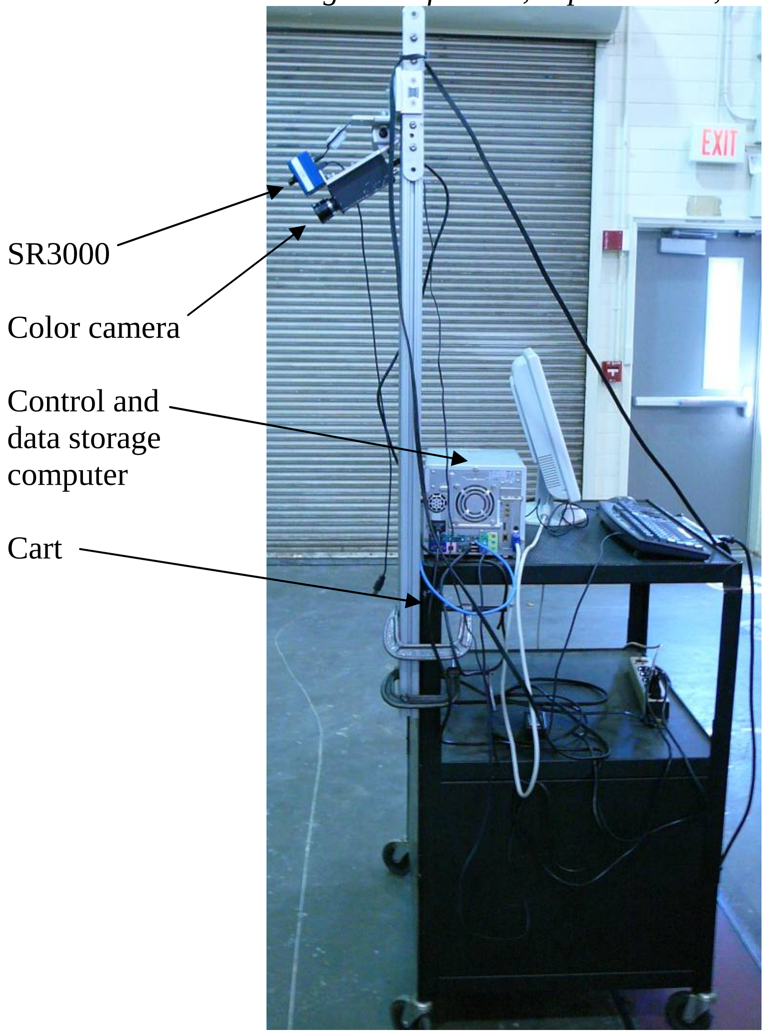


Figure 2: Cart with SR3000 & Color Camera sensors and control/data storage computer.

The two sensors were angled such that the SR3000 sensor upper field-of-view edge detected the floor at 6 m (20') max., as shown in Figure 3. This setting: allowed a known sensor-to-floor distance to be used in the data processing algorithm, eliminated the highly-reflective objects above the FOV, and eliminated the cluttered background and SR3000 modulation issue.

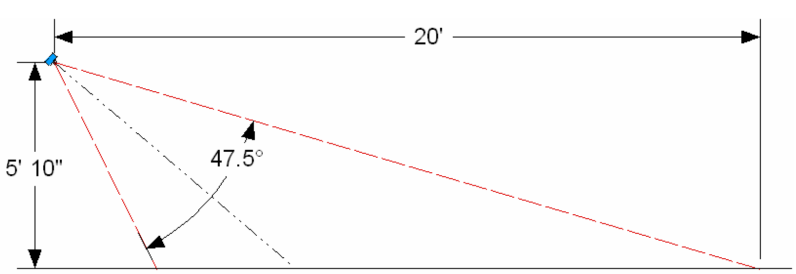


Figure 3: SR3000 imager angle with respect to the floor. The upper field-of-view edge was adjusted so that it detected the floor at 6 m (20') max. in front of the sensor/vehicle along the vehicle path.

Maximum start-point measurement distances were as follows and are shown in Figure 4:

Side 1 = 3.2 m to 1.1 m (10.5 ft to 3.5 ft) to tines (sensor to half of closest tine)
Side 2 = 4.1 m to 1.1 m (13.5 ft to 3.5 ft) to tines (sensor to half of closest tine)
Front = 3.9 m to 1.4 m (13 ft to 4.5 ft) to full image of tines

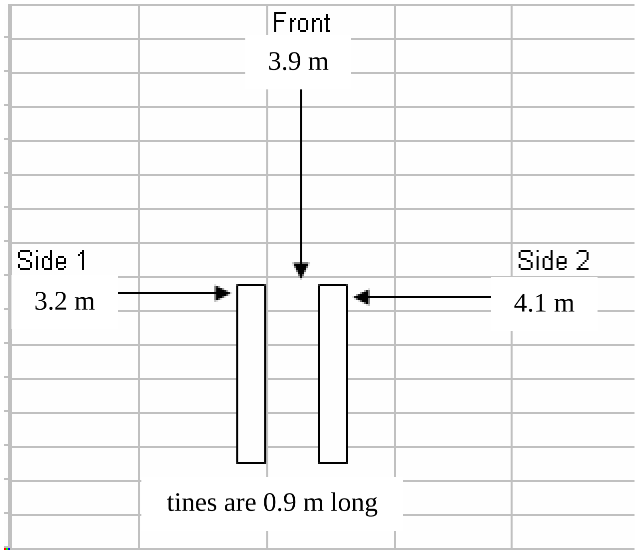


Figure 4: Viewing direction of sensors toward forks

Figures 5 and 6 show photos of the test setup for both the Side 1 and Front angles, respectively. Figure 7 shows the view from the sensors to the forklift tines for Side 2 experiments.

Figure 5a: Side view of Side 1 Experimental set-up with the SR3000 & Camera viewing the forklift tines. The red lines show an approximate sensor field of view.

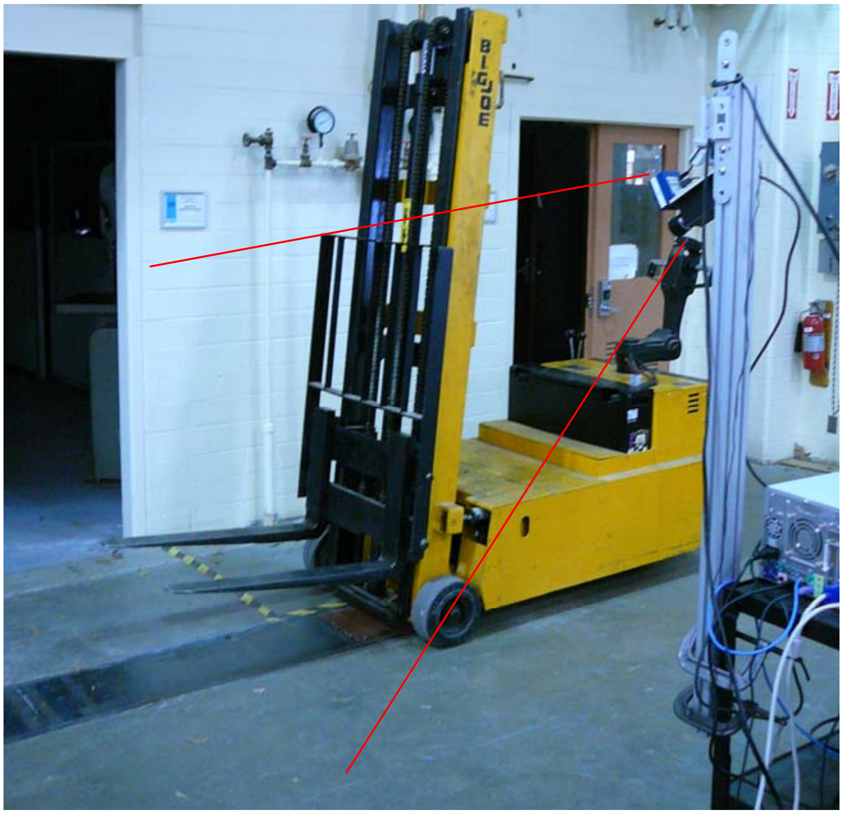


Figure 5b: Side 1 Experimental set-up (tine-to-camera view) with the SR3000 & Camera viewing the forklift tines. The red lines show an approximate sensor field of view.

Figure 6a: Camera view of Front Experimental set-up with the SR3000 & Camera viewing the forklift tines. The red lines show an approximate sensor field of view.

Figure 6b: <u>Front</u> Experimental set-up (tine-to-camera view) with the SR3000 & Camera viewing the forklift tines. The red lines show an approximate sensor field of view.

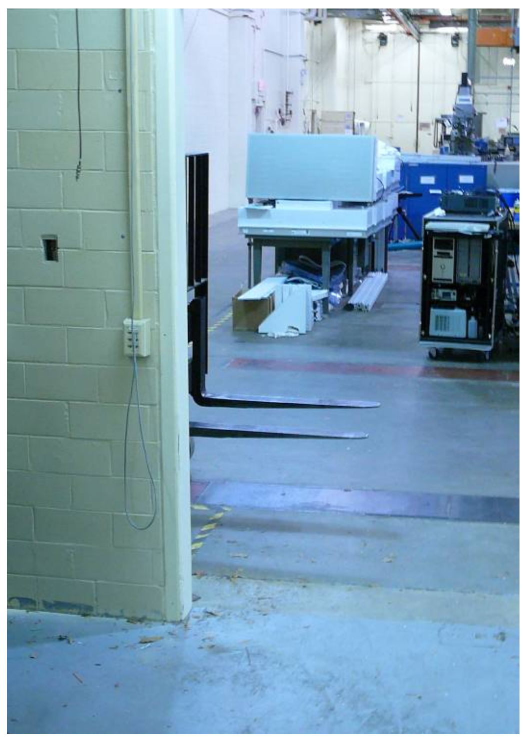


Figure 7: <u>Side 2</u> view from sensors to forks.

The forklift tines were set at two different heights 0.25 m (10 in) and 0.5 m (20 in). No preparation to the tines (e.g., paint, sand, etc.) was done. Below the tines was a cable access trough covered by unfinished, steel plate material similar to the forklift tines. In some cases, this trough cover was detected and appeared similar in color and reflectance to the fork tines.

The cart was pushed towards the forklift tines at approximately 0.09 m/sec (0.3 ft/sec) during most data captures and for one experiment the cart was pushed at 0.53 m/s (1.75 ft/sec).

2.1.2 Setup for Additional Tests

After reviewing the results from the unprepared tines and floor experiments, the researchers decided to do three additional tests, including: paint the tines with fluorescent paint, cover the floor and combine the painted tines with the covered floor to see what improvements, if any, could occur. For each of the additional tests, the same experiments as explained in 2.1.1 Unprepared Tines and Floor Test Setup, were completed.

Painted Tines: The two tines were painted on only their perpendicular edges to the sensors for two reasons: 1) this surface is the smallest, yet facing surface to the sensor, and 2) this surface is the least likely to have paint removed while the tines are in use (i.e., wear against pallets is minimal for this surface). Only slight overspray was on the top surface of the tines.

Covered Floor: Another experiment included covering the floor with either white poster boards or with gray paint. This created a bright, uniform surface that was less detectable than the unprepared floor.

Combined Painted Tines with Covered Floor: And yet a third additional experiment included both painted tines and covered floor. Figure 8 shows a photo of painted tines over painted floor where in the foreground remains unpainted floor and a steel cable cover that resembles the unpainted fork tines. As will be shown in the results, this cable cover provided false readings of an obstacle with the sensor FOV.

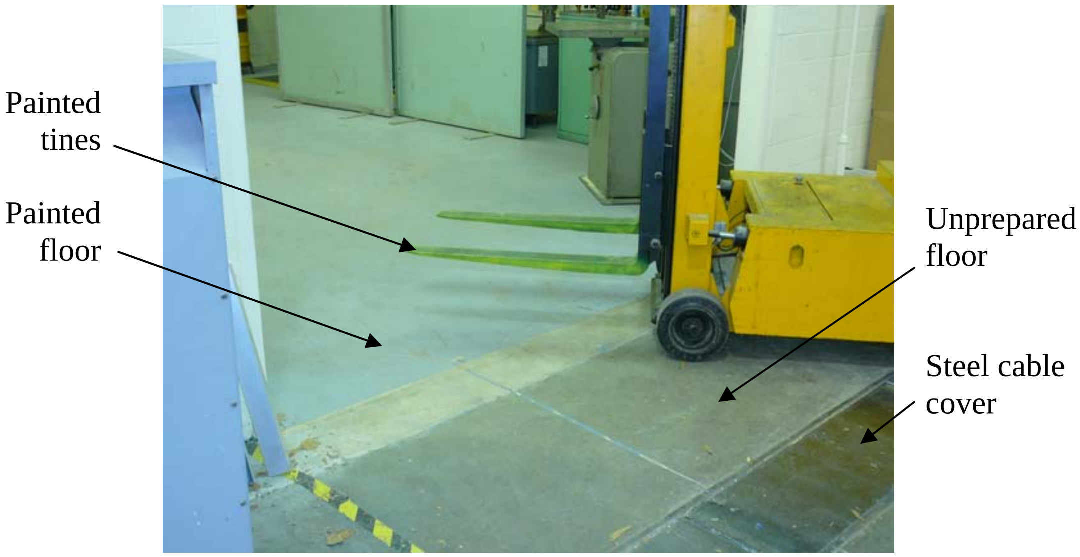


Figure 8 – Photo of the test set up for the painted tines and covered floor test.

2.2 Sensor Moving Towards Tines Experimental Results

2.2.1 Unprepared Tines and Floor Results

To establish experimental results, researchers reviewed each experimental data set (video), i.e., all combinations of front, side, 0.25 m (10 in), 0.5 m (20 in), far, close that were collected. Then, the results were tabulated in time tables to conclude the approximate amount of time that the sensor did or did not detect the tines. The results are summarized in Table 1: Comparison of Tines Detect Times. The experimental results videos can be mailed upon request to each Consortium organization for review or further analysis.

A post processing algorithm and user interface was developed and used to align the camera and SR3000 video frames. The user can select how much overlaid SR3000 data to show on top of the camera data. This allowed the researchers an easy way to review that data and show when the SR3000 did and did not detect the tines. Frame by frame data each ¼ sec was reviewed. Snapshots shown in Figures 8 through 11 and in Appendix C – Test Images of the far (3.7 m (12 ft)) and close (1.2 m (4 ft)) ranges are accurate to ~ +/- 0.5 m (18 in). The snapshots were simply selected as single frames from the videos of each experiment for this report and shown as examples of the data collected from the sensors. Figures 9 and 10 show snapshots of good data (detected forks) collected of the forklift tines at close range from the front and side, respectively. Figures 11 and 12 show snapshots of bad data (undetected forks) collected of the forklift tines at far range, from the front and side, respectively. Both close range snapshots show good results of the forklift tines. Far range measurements show bad results where the tines are mostly undetected. More snapshots are shown in Appendix C – Test Images. Below is a legend of the figure captions and an explanation of the images within the figures.

Legend of captions:

Far = ~ 7.3 m (12 ft) separation between camera and tines
Close = ~ 1.2 m (4 ft) separation between camera and tines
0.25 or 0.5 m (10 in or 20 in) = the tines height above the floor
Front or side = view of tines (i.e., front view or side view of tines)
Side 1 – vehicle left (as seen from forklift driver)
Side 2 – vehicle right (as seen from forklift driver)

The left four images show range (upper left), The left four images show range (upper left), intensity (upper right) and data from the color camera including: Y vs. Z plot of camera data (lower left) and X vs. Z plot of camera data (lower right). The right image is an overlaid image of the obstacle detection using only range data from the SR3000 overlaid onto the color camera image.

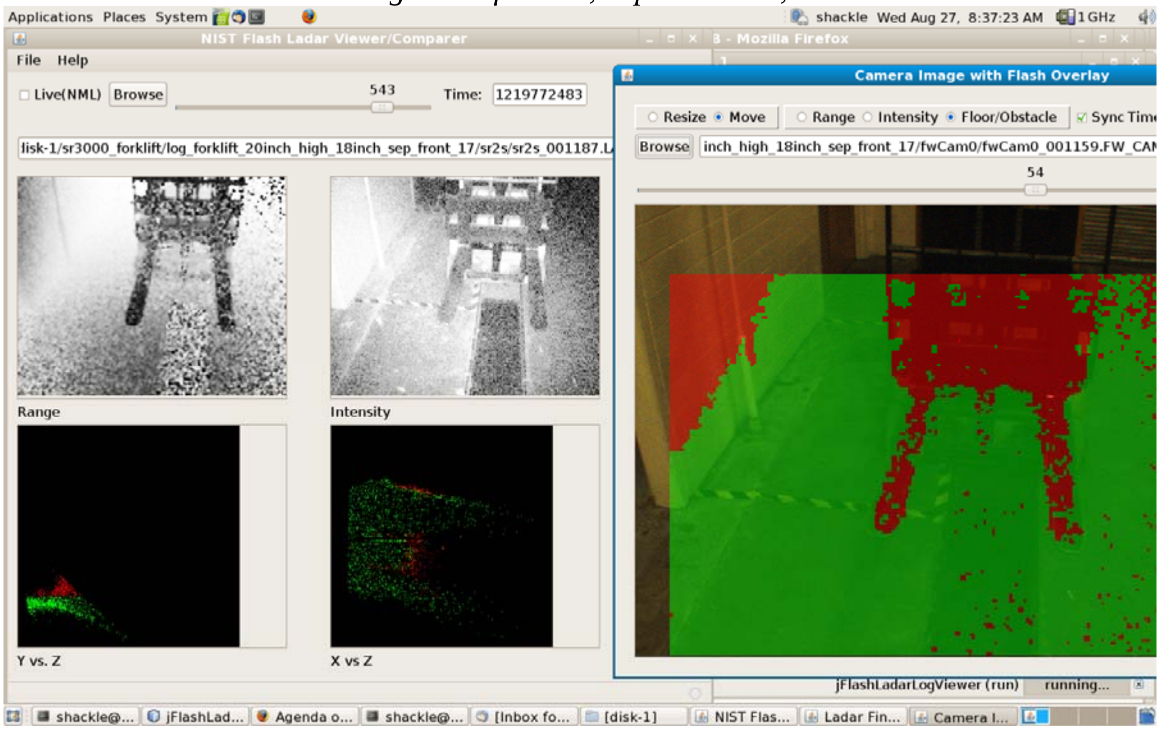


Figure 9: 20” front close

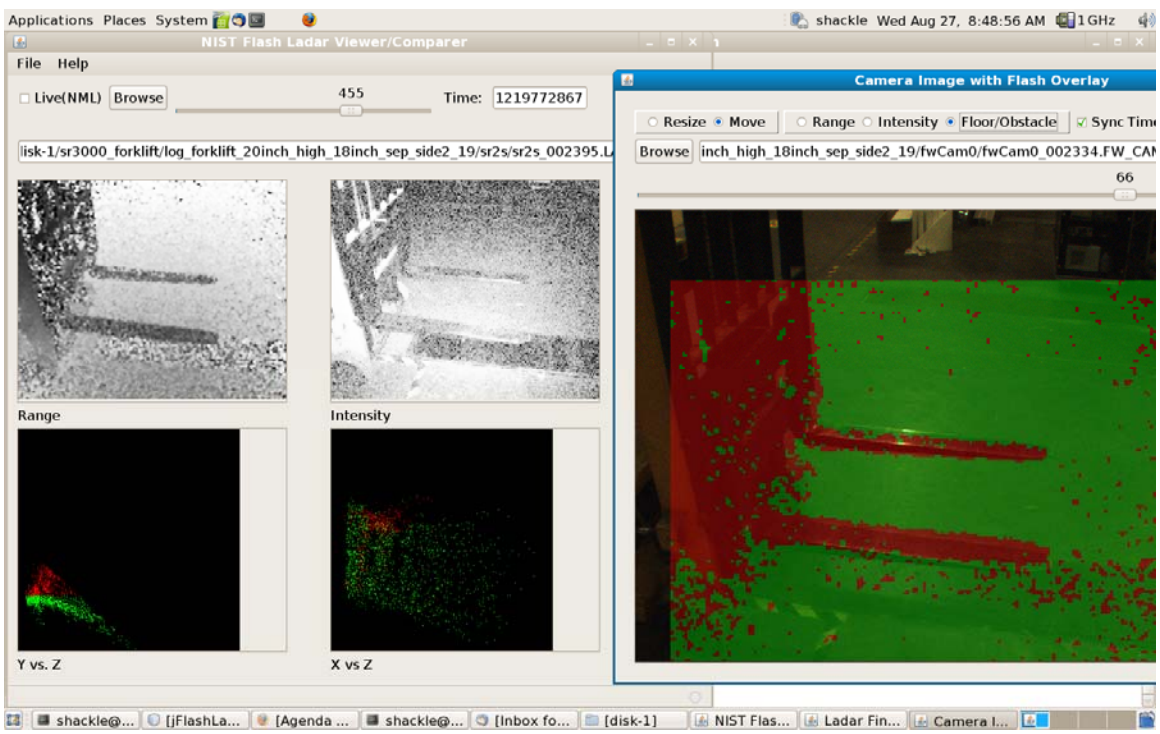


Figure 10: 20” side 2 close

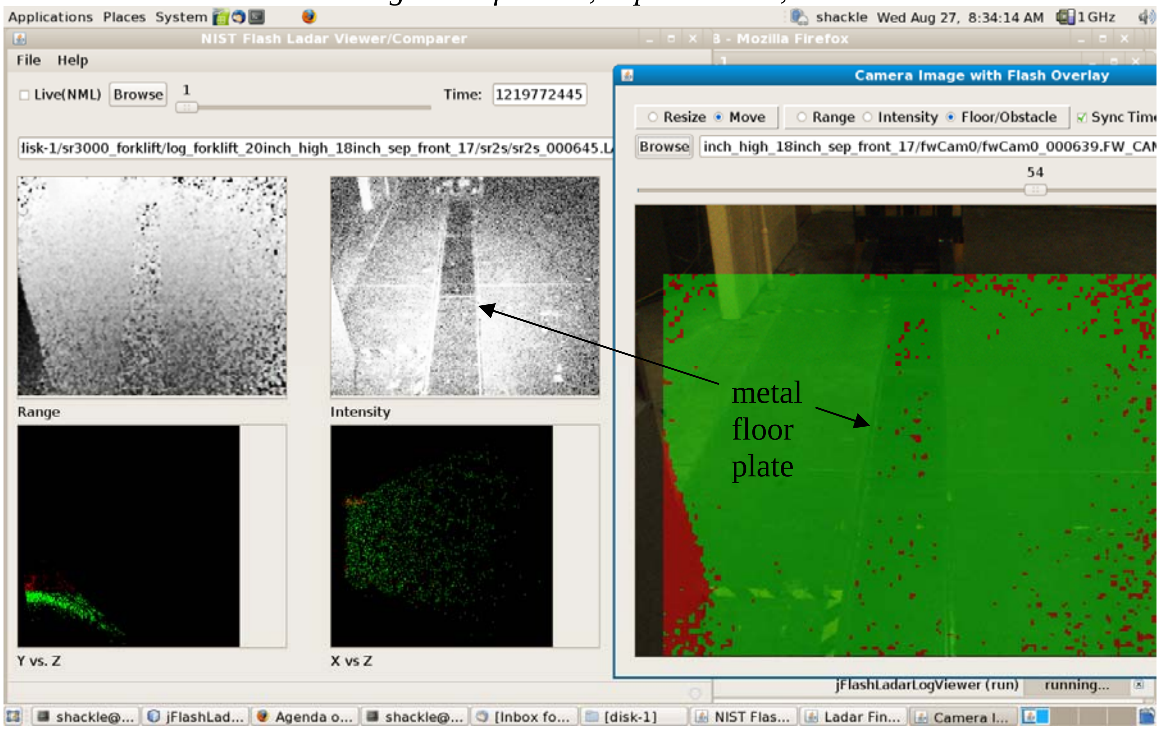


Figure 11: 20" front far. Note the data points of the metal floor plate.

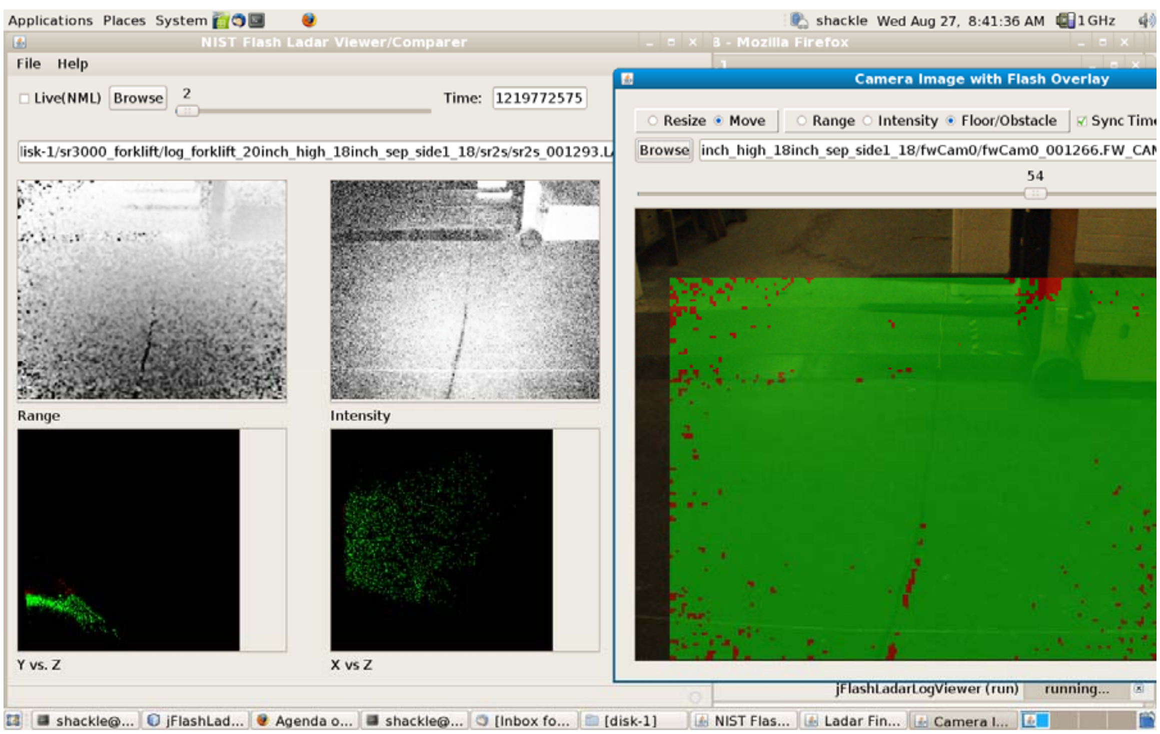


Figure 12: 20" side 1 far

Bad data collected was based substantially on subjective reasoning of when we thought the forklift tines were detected. Each data set (video) was reviewed and determined that a significant amount of SR3000 pixels must be clustered on the forklift tines to be considered 'detected.' The time that the sensors took to reach the forks is correlated with the range to the tines is graphically shown in Figure 13 and summarized in Table 1.

A key issue is that the SR3000 sensor processing program uses a height threshold to remove noise from beneath the forklift tines. Without it, the noise would show data from the floor and the tines may not appear different than the noise, therefore being undetected. The noise was therefore cut-off at approximately 10" above the floor or higher leaving two of the tests that resulted in 0% detected (Side 1, 10" and Front, 10") basically out of the data mix. Instead, it may be wise to develop a new data filtering program that would allow the threshold to be lowered. This is not an easy task as the noise from the floor and floor plates (as shown in Figure 11) are difficult to remove.

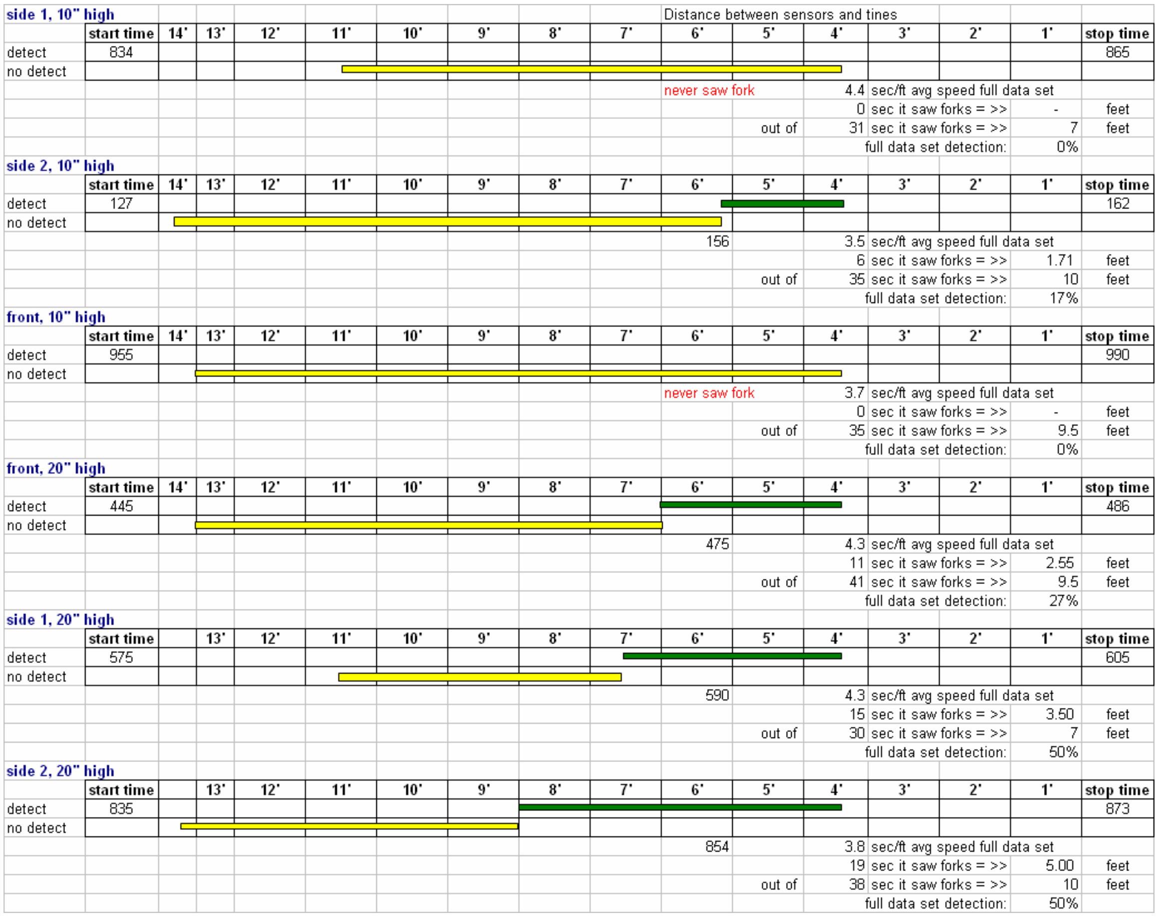


Figure 13: Tine Detect Chart for each of the six data sets graphically showing the detect distances (green bar) of forklift tines and the non-detect distances (yellow bar).

Table 1: Percentage of Tines Detect Times

	Detect%		
Experiment	*full distance*	*last 3'*	*last 1.7'*
Side 1, 10"	0%	0%	0%
Side 2, 10"	17%	57%	100%
Front, 10"	0%	0%	0%
Side 1, 20"	50%	100%	100%
Side 2, 20"	50%	100%	100%
Front, 20"	27%	85%	100%

2.2.2 Painted Tines Results

By painting the tines sides, the results began to show promise where the tines were detected much more often than with unprepared tines. Figure 14 graphically shows the results with green bars representing detection and yellow bars representing no distinguishable detection of the tines from the floor or other obstacles. Again, when a substantial number of obstacle detect pixels were clustered on the tines, as is the case in Figures 9 and 10, the researchers called it a "detect." The top graph in Figure 14 shows very little tines detection as the noise-limiting threshold height was set very low. This caused quite a bit of floor noise to be detected where the tines were not distinguishable from the noise. As the threshold was raised, as shown in the center and bottom graphs of Figure 14, the floor noise appeared less and less, respectively.

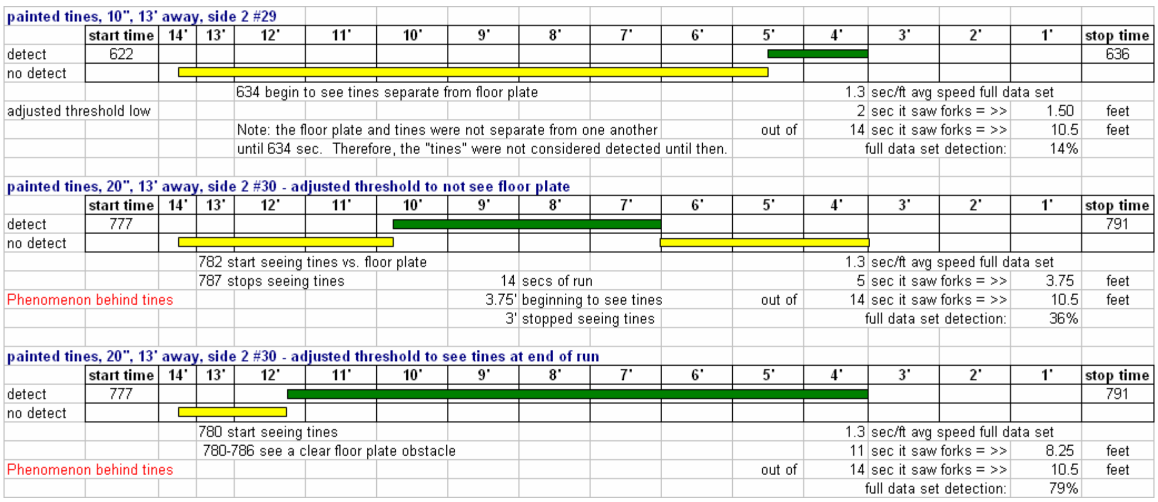


Figure 14 - Graphical representation of 3D imager detection of painted forklift tines above an unprepared floor while moving the sensor towards the forklift tines. The results are shown for three different thresholds at (top) ground height, (middle) no floor plate cover detection, and (bottom) tines detection at the end of the test.

2.2.3 Covered Floor Results

Since the results of painting the tines showed promise, the researchers then decided to also remove, if possible, the floor noise by using floor coverings. Figure 15 shows 3D imager data overlaid onto a photograph of unprepared fork tines above white posterboard-covered floor and also painted and unprepared floors are shown. Note that the red wall to the left is clearly shown, as well as a clear distinction of how the data was thresholded at a height above the floor to mask out floor noise. This threshold height is parallel to the floor and is why barely any fork tines are seen by the imager in the figure (i.e., the tines are near the threshold height). We found that the floor noise was so bad when the threshold was lowered, that the floor would appear as an obstacle to the sensor. This was much more evident for the unprepared floor but, still evident for the painted floor. Figure 15 lower, right side versus the white posterboard area shows 'some' versus 'no' floor noise, respectively.

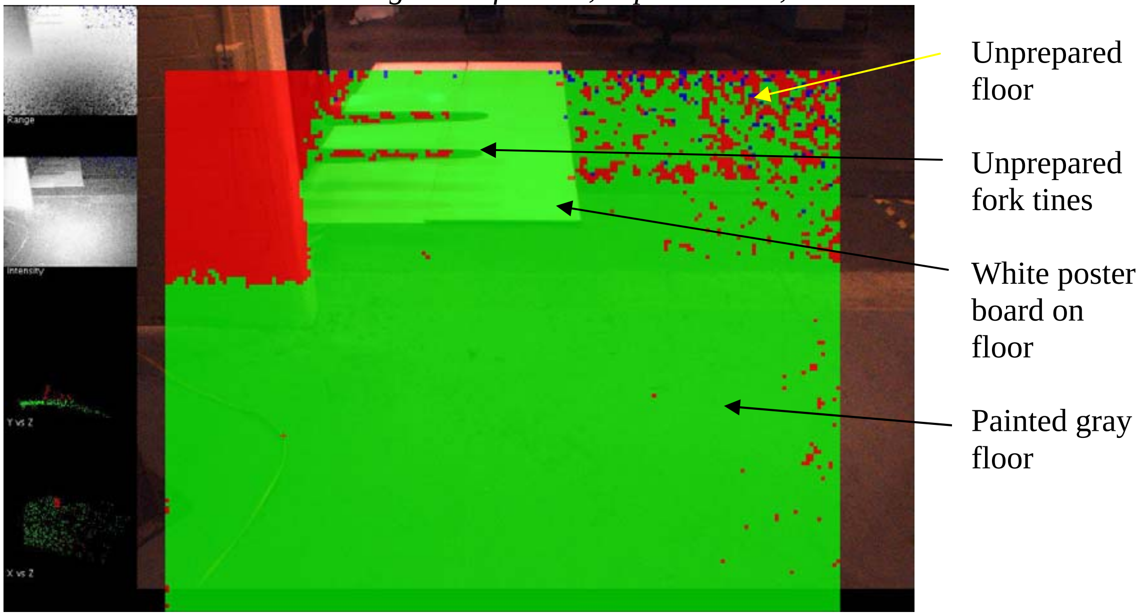


Figure 15. 3D imager data overlaid onto photograph of unprepared fork tines above white poster covered floor and also painted and unprepared floors are shown.

2.2.4 Combined Painted Tines with Covered Floor Results

Combining the painted tines with the prepared (covered) floors beneath the tines provided the best results. The painted tines were detected very well above the covered floor as can be seen in Figure 16. Our focus was mainly on the closest tine to the imager as it must to be detected first. Behind the closest tine was less important but, brought up a phenomenon of sporadic noise beside, between and behind the tines. The snapshot in Figure 16 shows some noise on the floor but, perhaps could be filtered to only detect the tines. The painted gray area shown in Figure 15 is the same as that shown in Figure 16 detected from the opposite angle. Note that without the forklift tines in the image of Figure 15, the painted floor is nearly noise free where as in Figure 16, there is noise in front of and behind the tines as if it were an unprepared floor. Strangely, the unprepared floor in the foreground appears clearer of noise than that behind the forks in the painted floor area. What is significant here is how clear and detectable the painted tines appear on the painted floor.

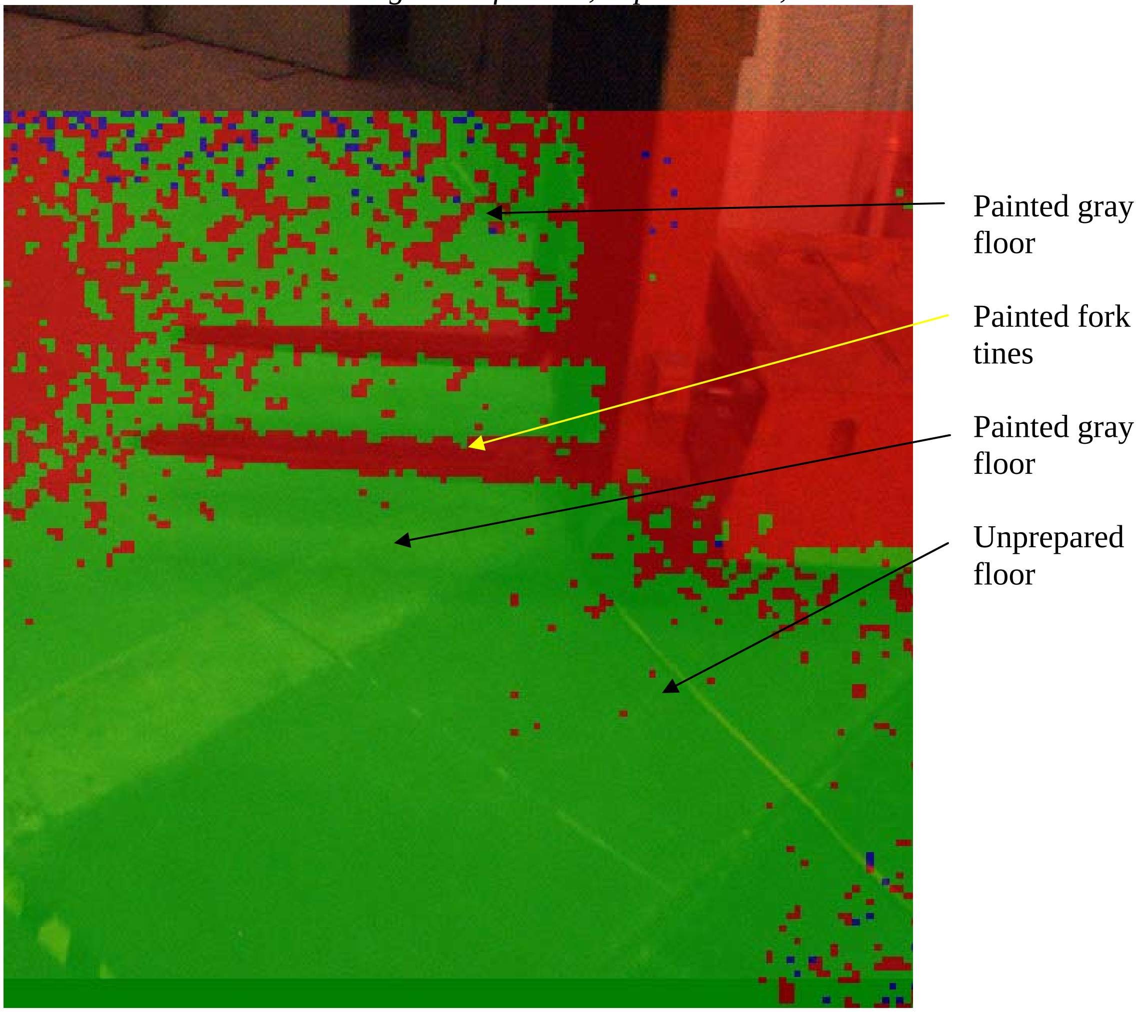


Figure 16. 3D imager data overlaid onto photograph of painted fork tines with covered and unprepared floors.

Figure 17 shows a graphical representation of the 3D imager data detecting painted forklift tines above a uniformly covered floor with white posterboards. The data shows very good results of three tests having 93%, 100% and 67% detection, respectively. Comparing these results to the unprepared tines and floor test results from Figure 13, the results are by far, an improvement. The 67% detection is as a result of moving the sensors toward the tines at 0.5 m/sec (1.75 ft/sec) as opposed to an average of 1.1 ft/sec for the first two tests.

Figure 18 shows a graphical representation of the 3D imager data detecting painted forklift tines above a uniformly painted gray floor. The data again shows very good results of three tests having 80%, 92% and 58% detection where the latter test is low due to the tines being out of the sensor FOV at the beginning of the test. Again the results show improvement over unprepared tines and floors.

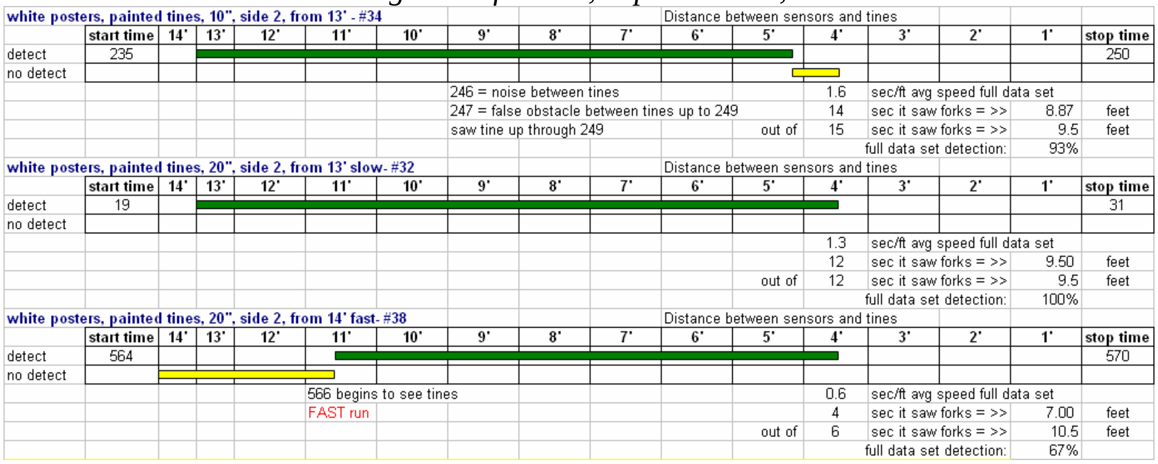


Figure 17 – Graphical representation of 3D imager detection of painted forklift tines above a uniformly covered floor with white posterboards while moving the sensor towards the forklift tines.

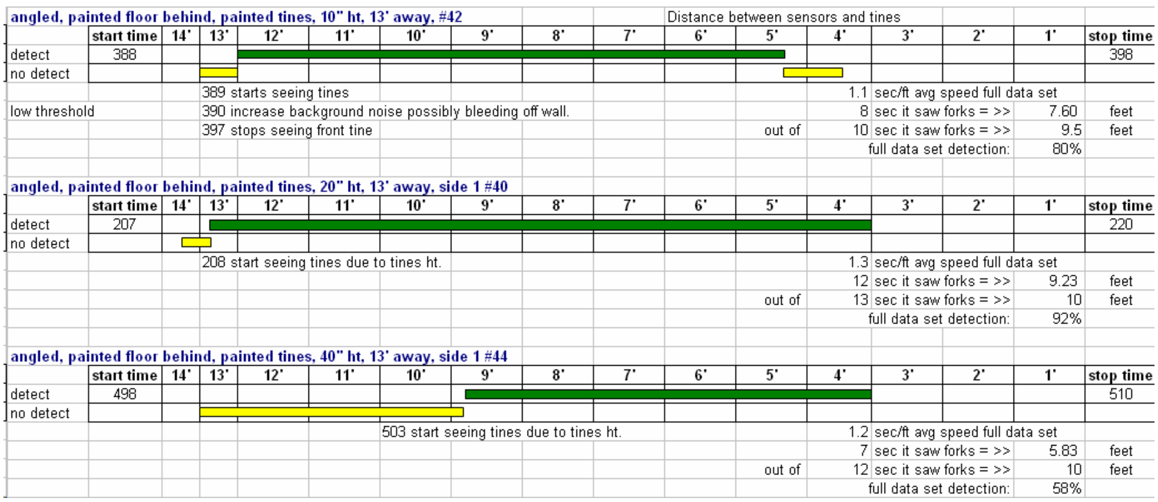


Figure 18 - Graphical representation of 3D imager detection of painted forklift tines above a uniformly painted gray floor while moving the sensor towards the forklift tines. The results are shown for three different tines heights of 0.25 m, 0.5 m, and 2 m (10 in, 20 in and 40 in) shown from top to bottom.

2.3 Tines Moving Vertically with Stopped Sensor Results

2.3.1 Unprepared Tines and Floor Results

Figure 19 shows a graphical representation of the 3D imager data detecting unprepared forklift tines above an unprepared floor while moving the tines up and in front of a stopped sensor 1.5 m (5 ft) away from the tines. The data shows results of 54% detection beginning at approximately 0.6 m (24 in) above the floor. The tines moved up at a rate of approximately 12 cm/sec (0.4 ft/sec) average throughout the height of 1.1 m (44 in) measured from the floor. Floor noise was an issue and the threshold was set relatively high to limit noise interference.

moving unpainted tines up from floor - #23, from 5'																
	start time	0'			1'			2'		3'		4'				stop time
detect	751															775
no detect																
			762 began seeing tines									0.5	sec/in avg fork movement speed full data set			
								movement from 0' to 44"				13	sec it saw forks = >>	23.83	inches	
											out of	24	sec it saw forks = >>	44	inches	
													full data set detection:	54%		

Figure 19 - Graphical representation of 3D imager detection of moving unprepared tines up above an unprepared floor.

2.3.2 Painted Tines Results

Only one test was done for this setup since results were expected to be similar to results shown in section 2.2.2 Unprepared Tines and Floor Results within the section 2.2 Sensor Moving Towards Tines Experimental Results.

Figure 20 shows a graphical representation of the 3D imager data detecting painted forklift tines above an unprepared floor while moving the tines down and in front of a stopped sensor 1.5 m (5 ft) away from the tines. The data shows results of 80% detection ending at approximately 0.9 m (35 in) above the floor. The tines moved up at a rate of approximately 12 cm/sec (0.4 ft/sec) average throughout the height of 1.1 m (44 in) measured from the floor. Floor noise was again an issue and the threshold was set relatively high to limit noise interference. However, the threshold raised was quite different from the unpainted tines test in 2.2.2.

moving painted tines down, no floor cover - #26, from 5', from 46" high																
	start time	4'			3'			2'		1'		0				stop time
detect	377															392
no detect																
			saw tines from beginning				389 stopped seeing front tine					0.3	sec/in avg fork movement speed full data set			
threshold raised due to floor noise												12	sec it saw forks = >>	35.20	inches	
											out of	15	sec it saw forks = >>	44	inches	
													full data set detection:	80%		

Figure 20 - Graphical representation of 3D imager detection of moving painted tines up above an unprepared floor.

2.3.3 Covered Floor Results

To be consistent and thorough in our report, we added this section. No test was done for this setup since the floor coving is exactly the same as that shown in section 2.2.3 Covered Floor Results within the section 2.2 Sensor Moving Towards Tines Experimental Results.

2.3.4 Combined Painted Tines with Covered Floor Results

Figure 21 shows a graphical representation of the 3D imager data detecting painted forklift tines above a uniformly covered floor with white posterboards while moving the tines up in front of a stopped sensor 1.5 m (5 ft) away from the tines. The data shows results of 77% detection as compared to 54% detection with unprepared tines above unprepared floors from section 2.3.1. The tines were detected beginning at a height of approximately 0.25 m (10 in) above the floor. The tines moved up at a rate of approximately 12 cm/sec (0.4 ft/sec) average throughout the height of 1.1 m (44 in) measured from the floor. Floor noise was less of an issue where the threshold was set relatively low to limit noise interference as compared to section 2.3.1.

moving painted tines up from poster - #28, from 5'																
	start time	0'			1'			2'		3'		4'				stop time
detect	694															707
no detect																
			697 - first see tine									0.3	sec/in avg fork movement speed full data set			
							13	= 44" movement from 0' to 44"				10	sec it saw forks = >>		33.85	inches
							10.15385	= first saw front tine			out of	13	sec it saw forks = >>		44	inches
													full data set detection:		77%	

Figure 21 - Graphical representation of 3D imager detection of moving painted tines up above a uniformly covered floor with white posterboards.

3 SR3000 PHENOMENON

Figure 16 showed 'bleeding' of obstacle detect data between, behind and in front of the tines. It also showed the tines being detected. Figure 21 shows the forklift tines being detected and also shows 'bleeding' of data perhaps from the left wall onto the floor. Figures 21 (front view) and 22 (overhead view) show the front and rear tines being detected but, that a large obstacle is also included with the rear tine. These figures show the painted tines with the floor covered with white poster boards where another strange phenomenon was detected as the rear tine was made into a large obstacle. Since the front tine was detected, during our evaluation of fork tine detection we determined that this phenomenon did not change our detection results. Therefore, our results show that during this test the SR3000 did detect the front tine.

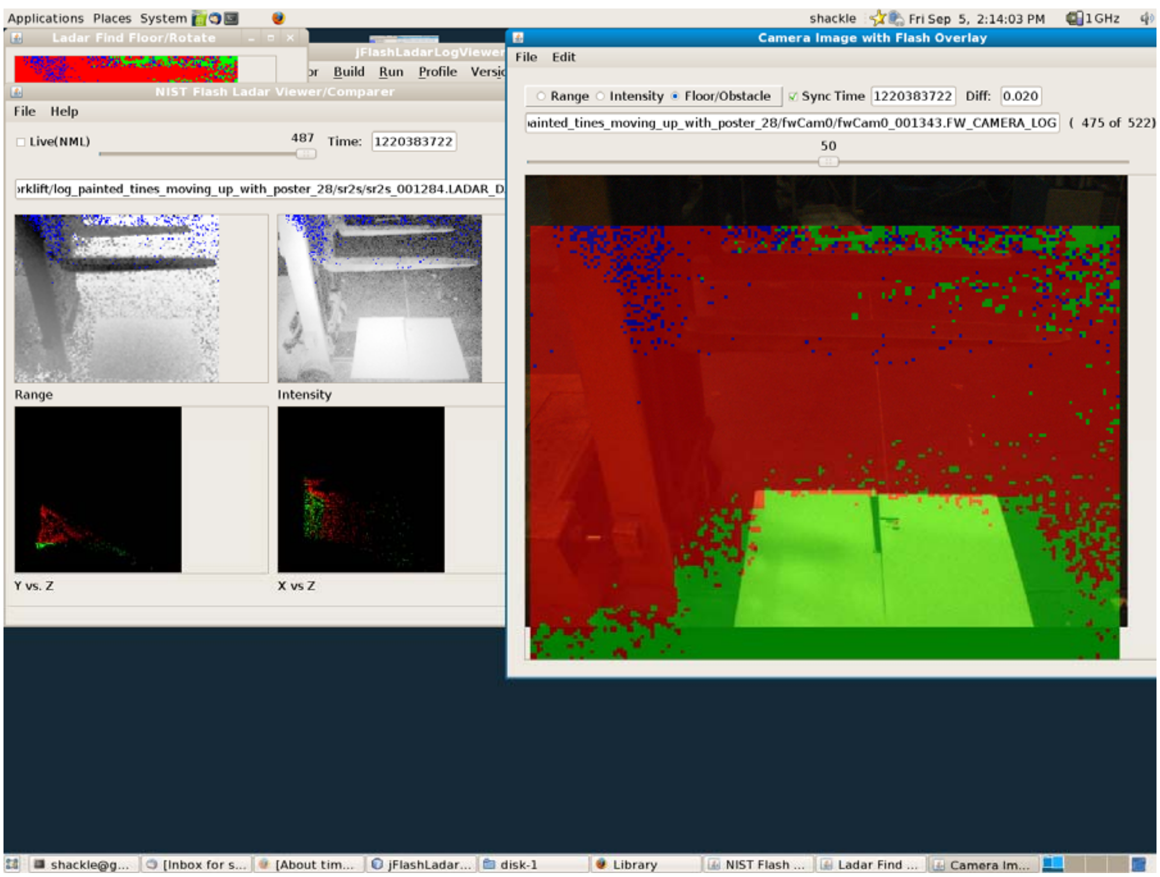


Figure 21 - fullview_overhead_tine_with_large_obstacle

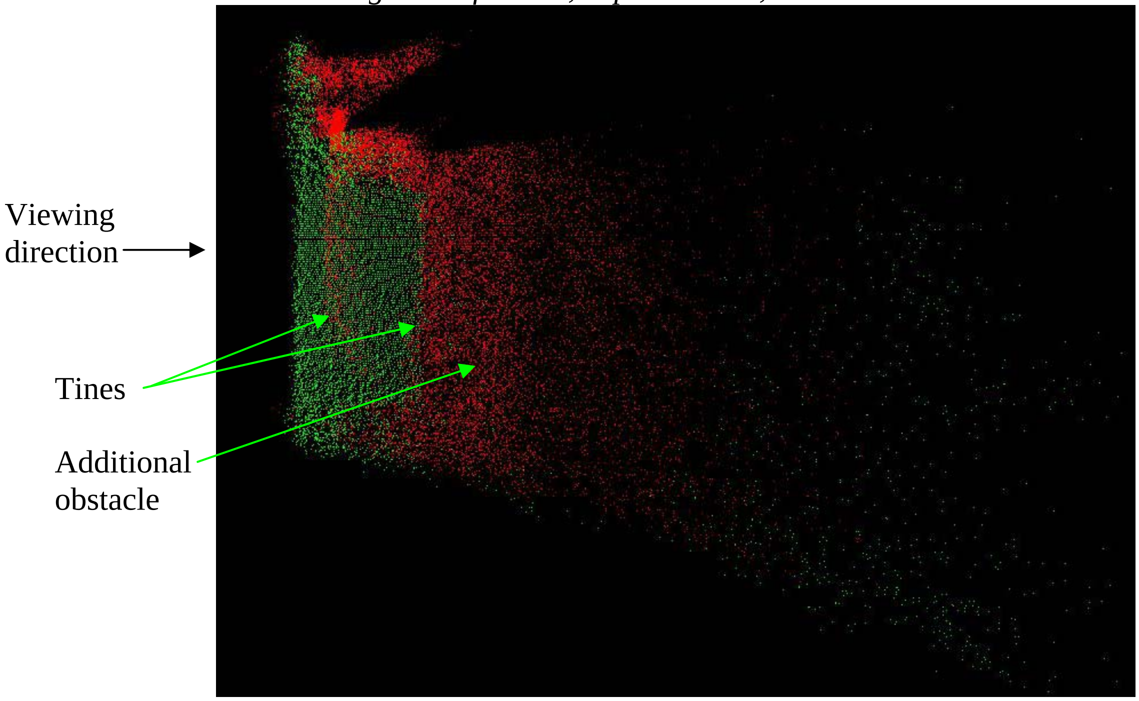


Figure 23 - overhead_tine_with_large_obstacle

4 VARIABLE SOFTWARE LIMITS FOR A 3D IMAGER

Although not necessarily a goal of this test report but, a part of the Consortium statement of work, was for NIST to show that a 3D imager can be adjusted so as not to flag obstacles outside of a chosen area. This is useful for when the sensor is attached to a vehicle and the vehicle is driving along a narrow path and/or approaches a turn and the wall or obstacle in front of the vehicle prior to the turn is detected as an obstacle and in turn, stops or slows the vehicle. Figure 24 shows blue areas on the right and left sides of the vehicle path that have been thresholded out of the image – i.e., not being flagged as obstacles by the imager. Although forklift tines appear to be beyond the right threshold, they are not. Some of the tines are shown as blue and some are red. The viewpoint is from the imager and not along the threshold line. Sighting along the line would indicate that some of the tines do protrude beyond the threshold. However, the red portion of the tines does not protrude beyond the thresholded right side. The threshold can be set for any side or range from the sensor and can be varied for complex paths and volumes if needed. Slow or stop thresholds can be set in the same manor and simultaneously.

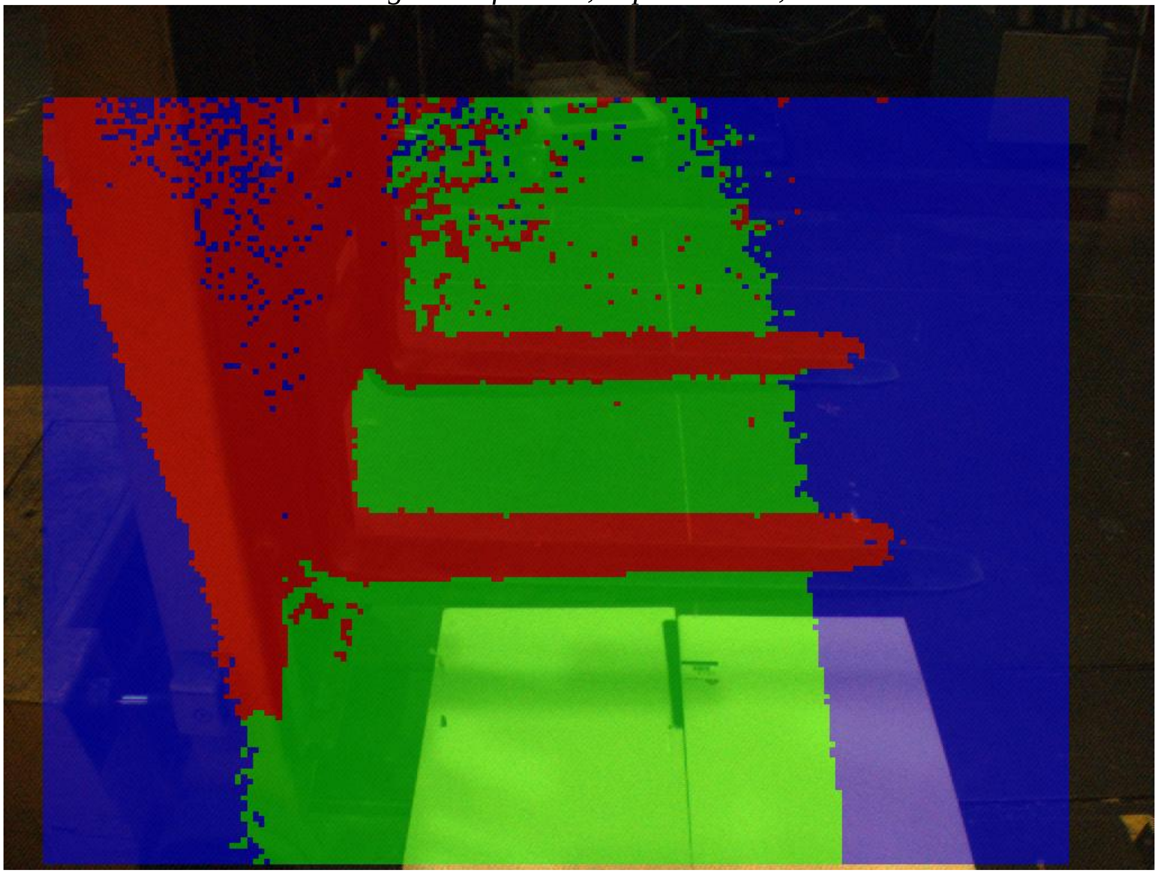


Figure 24 – Data from the 3D imager overlaid onto a color camera image after being thresholded (blue areas) using a software algorithm that flags when obstacles are between the thresholds (vehicle path) and not flag obstacles outside the thresholds.

5 CONCLUSION

The Percentage of Tines Detect Times shown in Table 1 provides a clear percentage of time the tines were detected with higher percentage on the closer ranges. The snapshots and the percentage of detected tines data show that the 3D imager is not robust enough to detect black forklift tines 100% of the time.

Close range (last 3') to the tines provides much more robust tines detection than beyond 6' range. The combination of sensors having close range to tines and a high threshold height above the floor provides excellent tines detection results. Higher tines are detected more often than lower tines due to a height threshold used to remove floor noise.

When the tines sides were painted with reflective yellow paint and the floor was covered with white poster board, the sensor performed very well. Slightly lower performance results were found when the floor was painted with light gray paint. Other color floor paints may provide similar results. However, high contrast between the tine and floor paint colors is suspected to provide the best results.

Recommendations:

1. The simplest and easiest method for causing the SR3000 sensor to work properly is to paint the forklift tines edges with reflective paint. Tines come from the factory painted black. Tines paint is worn off during use but, mainly on the top and bottom.

Black paint is the worst case color to paint tines for optical sensor detection of the tines. Inexpensive reflective paint on tines edges would allow both optical sensors and humans to detect the tines.

2. A second possibility would be to paint the floor to remove the need for noise filtering algorithm modification. Only the vehicle path needs to be painted and would provide inherent floor noise beside the vehicle path which would appear as an obstacle to avoid by the vehicle.
3. A third possibility is to produce a better filtering algorithm on the sensor data. As the threshold was raised and lowered for the tests performed, it was clear that the reviewer could adjust the results to be good or bad. An automatic threshold adjust algorithm, a better floor noise filtering algorithm or perhaps both could possibly be written and tested to provide better forklift tines results.
4. Perhaps a fourth possibility is to test the newest SR4000 sensor. The newest MESA SR4000 sensor, as shown in the appendices, may perhaps provide better results than the SR3000. Specifications appear similar to the SR3000 with max. range limited to 5 m. Figure 25 shows a photo, copied from the data sheet, of the new sensor.

Figure 25 – SR4000 sensor

Below is an email reply from Paul Sphikas of MESA Imaging AG explaining the current SR3000 and SR4000 cost and delivery. A comparison between the SR3000 and SR4000 sensors is shown in Appendix E.

Dear Roger

Thank you for your E-Mail dated 27th August and the interest shown in our new SR4000 TOF-camera. The launch of the SR4000 generated an overwhelmingly positive resonance and a large number of enquiries, hence the slight delay in responding to your request; for which we offer our sincere apologies.

The information requested is as follows:

1. A copy of the SR4000 data sheet and a comparison between the SR400 and the SR300 are attached for your perusal.
2. The SR3000 costs USD 7’500. We currently have a small number in stock available for immediate shipment.

3. The SR4000 costs USD 9’000 and is available 10 weeks after receipt of order.

Please let me know if you need an official quotation? In the meantime, should you have any questions, or if we can be of any assistance, please do not hesitate to contact me.

Best Regards

Paul Sphikas

MESA Imaging AG

Technoparkstrasse 1

8005 Zurich

T: +41 (44) 508 1824

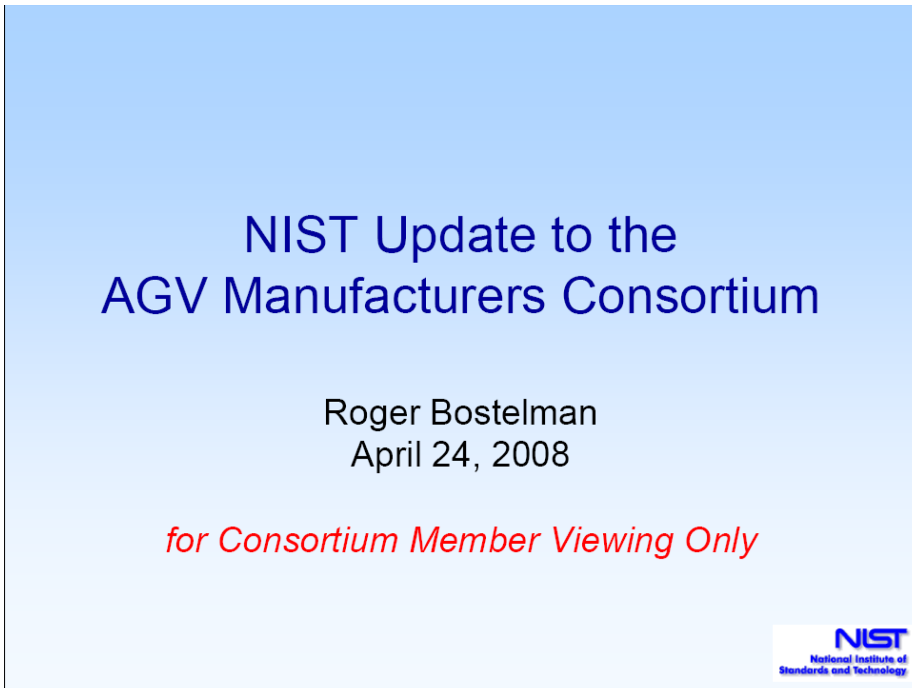
F: +41 (44) 508 1801

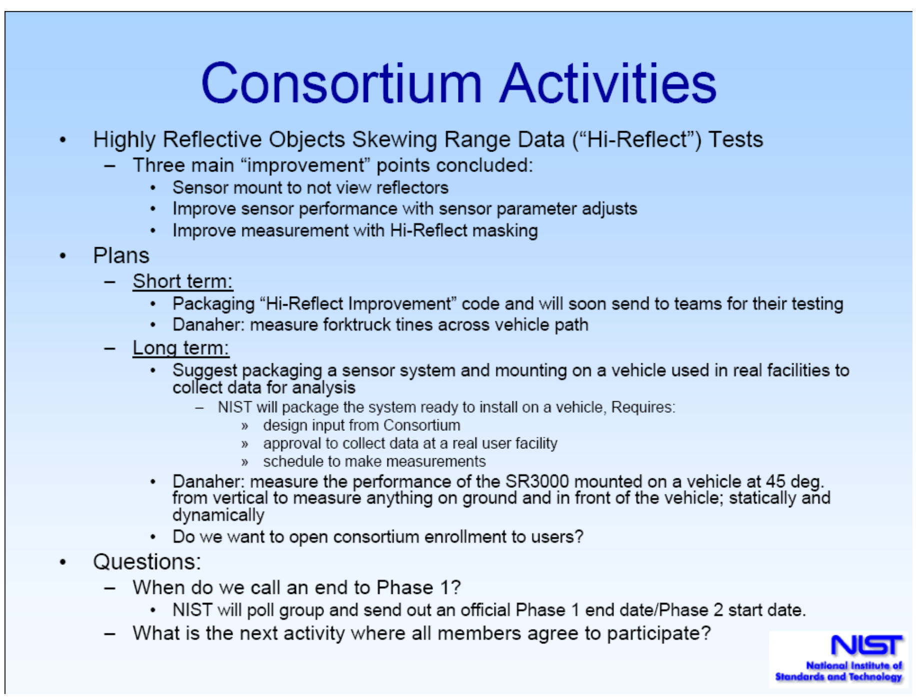
E: paul.sphikas@mesa-imaging.ch

6 APPENDICES

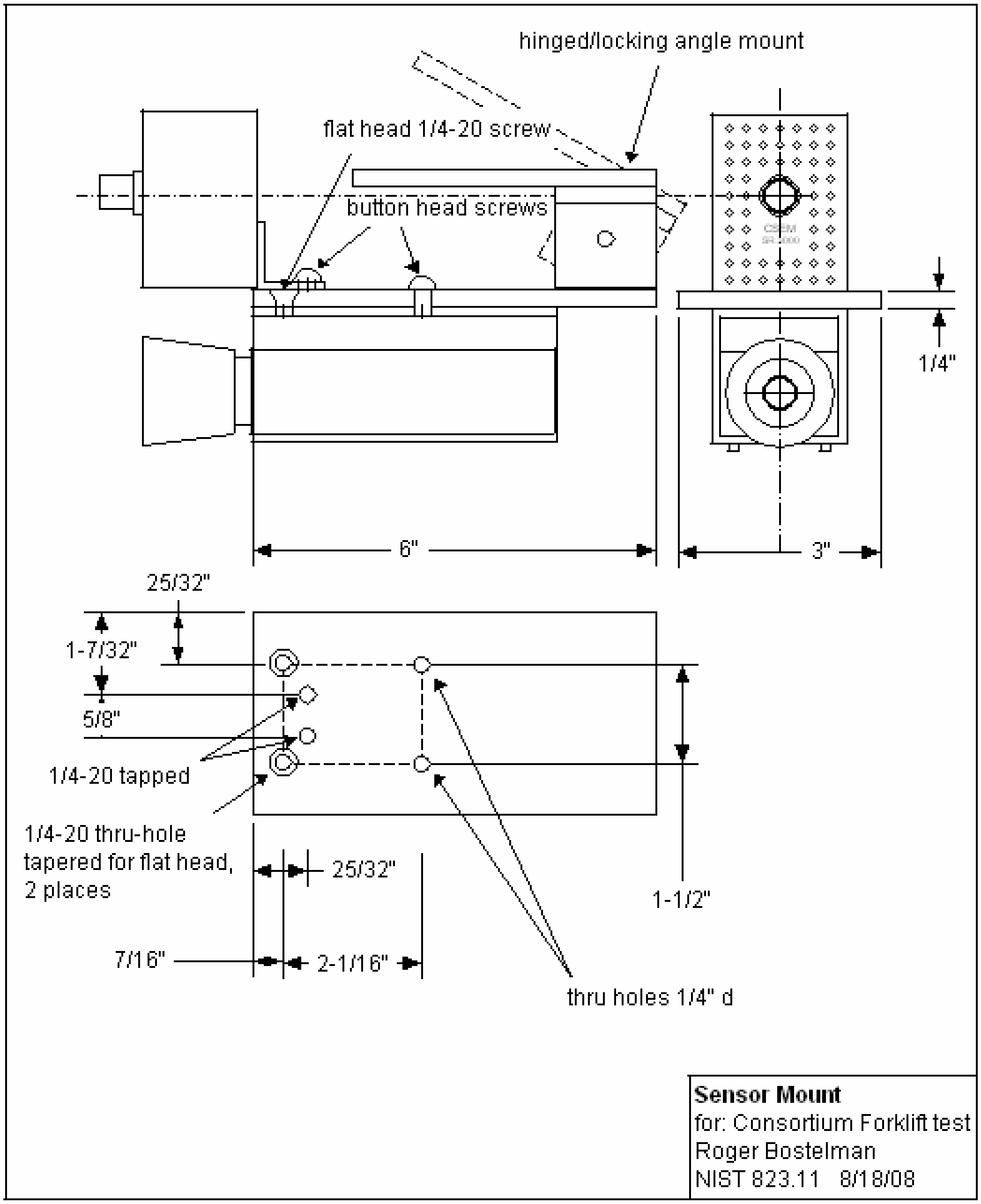
Appendix A. Presentation at NA2008

Roger Bostelmans' presentation to the FMC and Danaher Motion Consortium member representatives at the NA2008 Show in Cleveland, OH, April 24, 2008.





Appendix B. Sensor mount

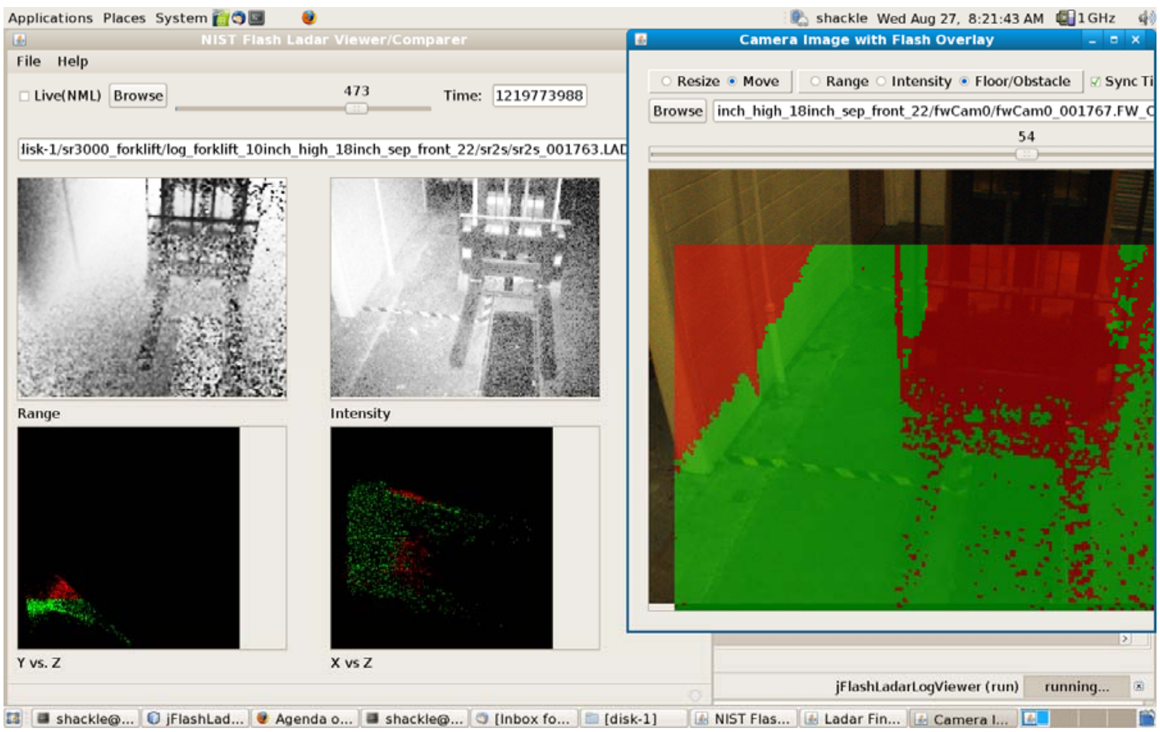


Appendix C. Test images from Experiment 2.1

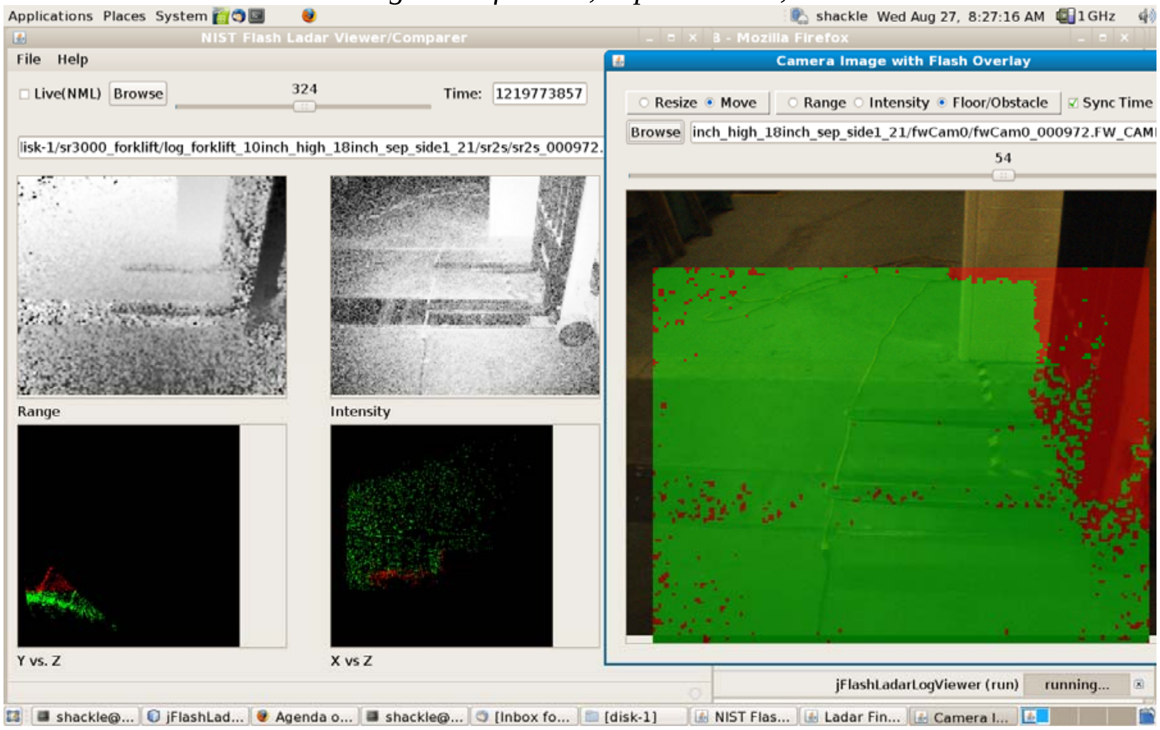
Legend of captions: (repeated from Experimental Results section)

Far = ~ 7.3 m (12 ft) separation between camera and tines
Close = ~ 1.2 m (4 ft) separation between camera and tines
0.25 or 0.5 m (10 in or 20 in) = the tines height above the floor
Front or side = view of tines (i.e., front view or side view of tines)
Side 1 – vehicle left (as seen from forklift driver)
Side 2 – vehicle right (as seen from forklift driver)

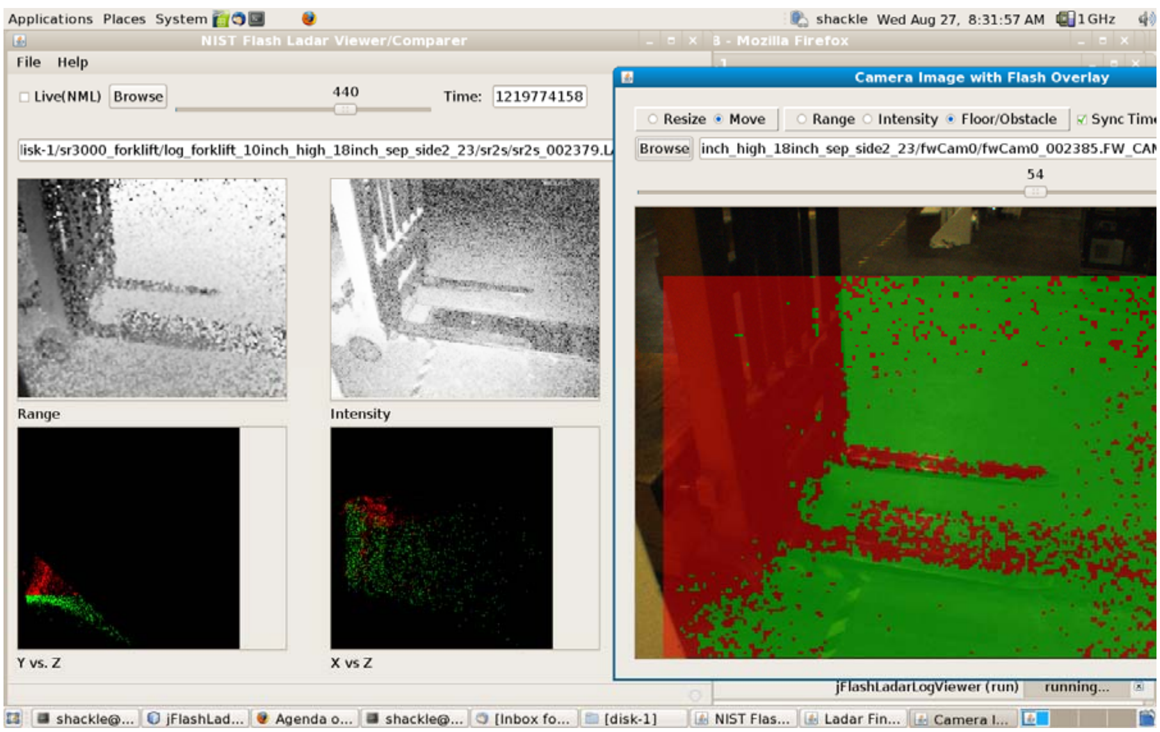
The left four images show range (upper left), The left, four images show range (upper left), intensity (upper right) and data from the color camera including: Y vs. Z plot of camera data (lower left) and X vs. Z plot of camera data (lower right). The right image is an overlaid image of the obstacle detection using only range data from the SR3000 overlaid onto the color camera image.



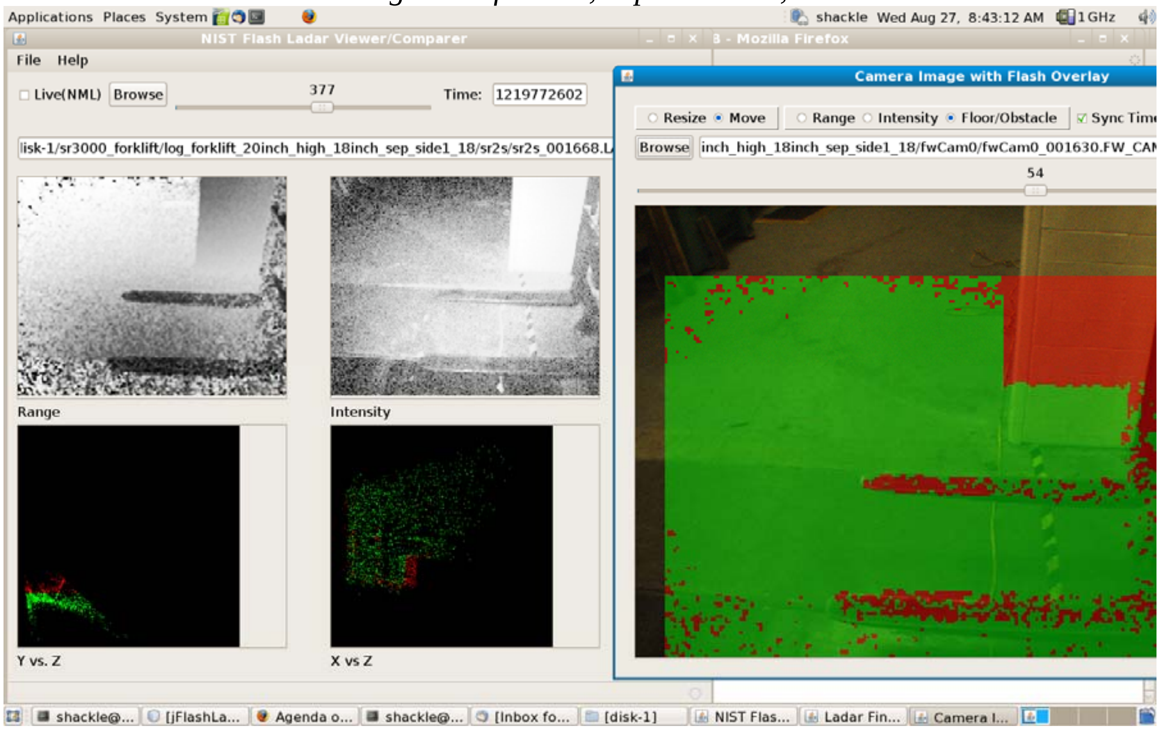
Front 10" front close



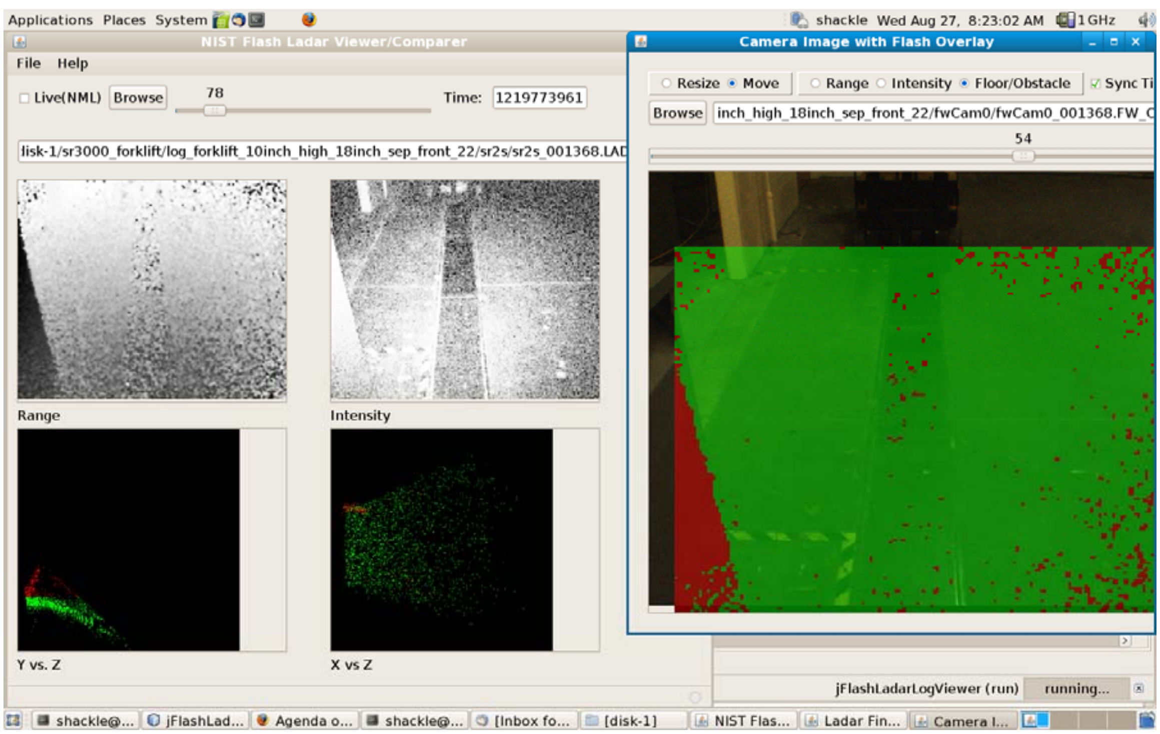
10” side 1 close



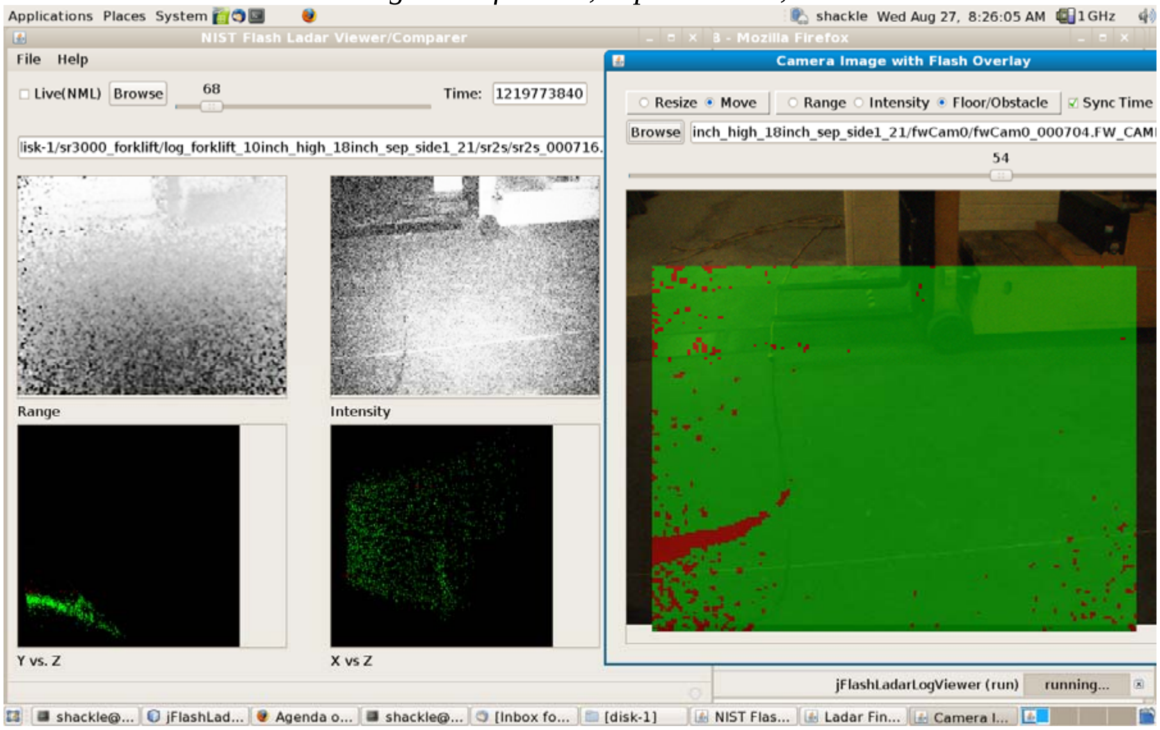
10” side 2 close



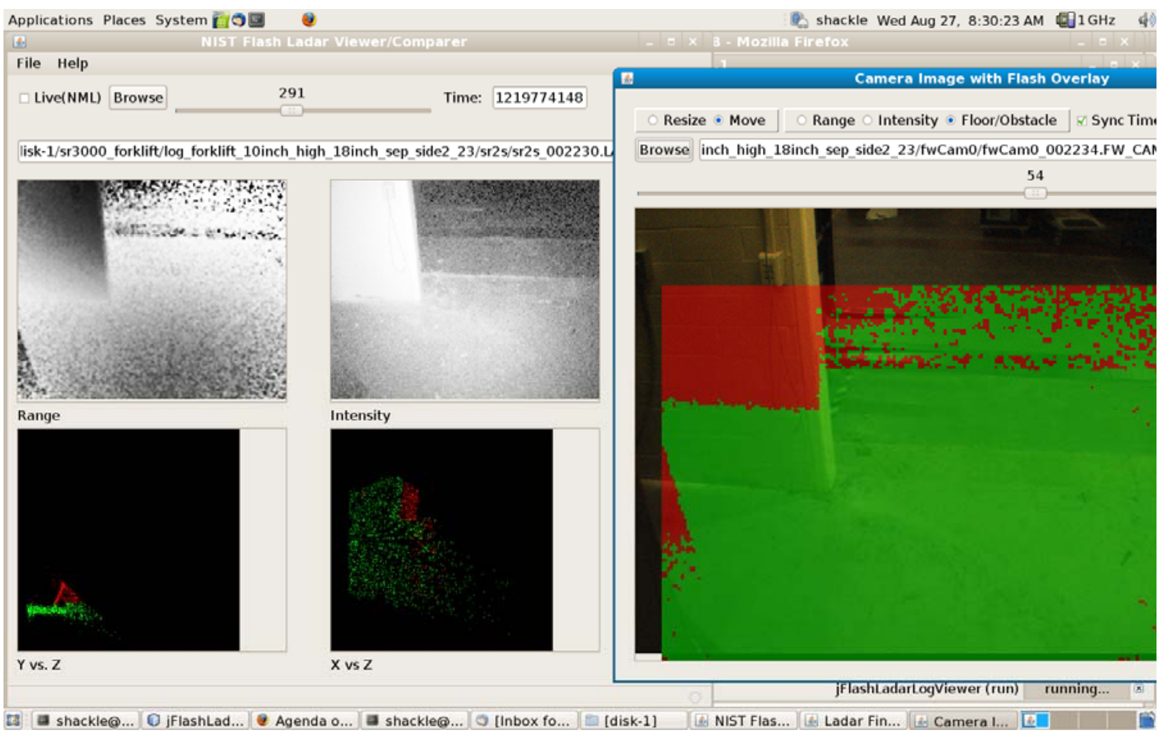
20” side 1 close



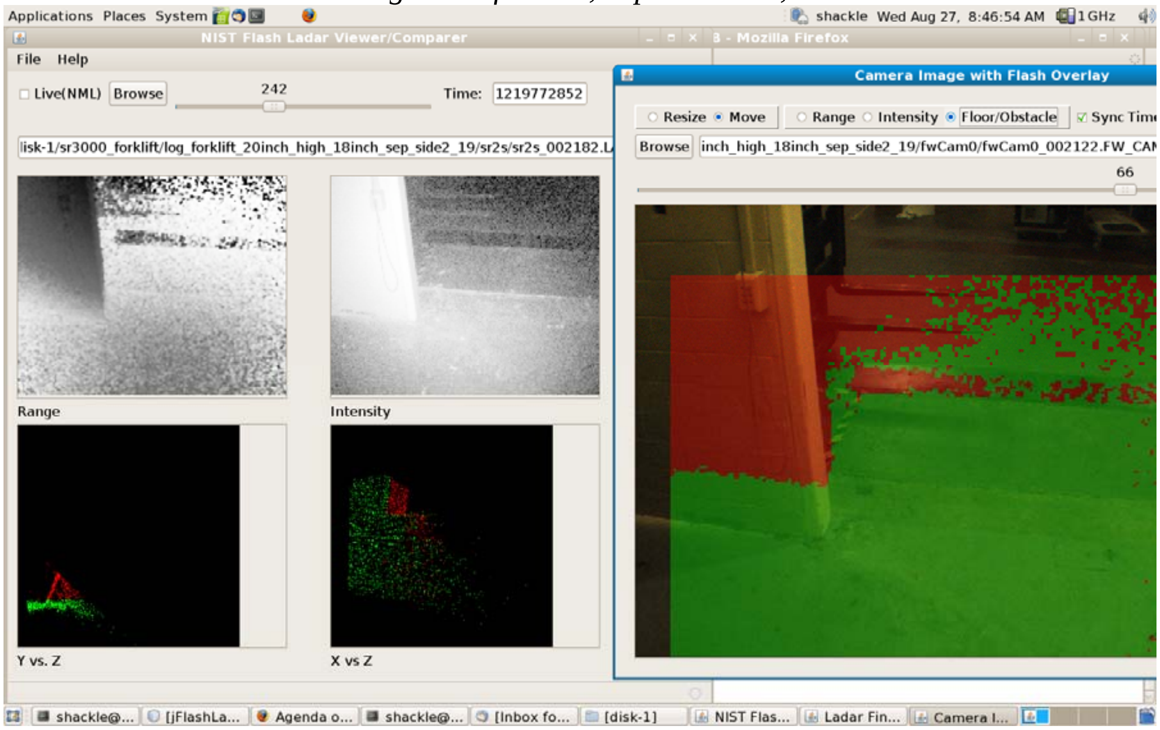
10” front far



10” side 1 far



10” side 2 far


Applications Places System
shackle Wed Aug 27, 8:46:54 AM
1GHz
NIST Flash Ladar Viewer/Comparer
File Help
Live(NML) Browse
242
Time: 1219772852
lisk-1/sr3000_forklift/log_forklift_20inch_high_18inch_sep_side2_19/sr2s/sr2s_002182.L
Range
Intensity
Y vs. Z
X vs Z
Camera Image with Flash Overlay
Resize Move
Range Intensity Floor/Obstacle
Sync Time
Browse
inch_high_18inch_sep_side2_19/fwCam0/fwCam0_002122.FW_CAM
66

20” side 2 far

Appendix D. SR4000 Data Sheet

(courtesy MESA Imaging AG)

SR4000 Data Sheet

MESA IMAGING

DESCRIPTION

The SR4000 is an optical imaging system which provides real time distance data at video frame rates.

Based on the time-of-flight (TOF) principle, the camera employs an integrated light source. The emitted light is reflected by objects in the scene and travels back to the camera, where the precise time of arrival is measured independently by each pixel of the image sensor, producing a per-pixel distance measurement.

Designed for indoor operation, the SR4000 is easily connected to a computer or network via the USB2.0 or Ethernet interface, enabling creation of real-time depth maps.

Representing the 4th generation of time-of-flight cameras designed by MESA, the SR4000 provides stable distance information in a robust, reliable hardware package measuring 65 x 65 x 68mm (USB version).

The SR4000 is delivered with drivers and a software interface that enables a wide range of user defined applications.

FEATURES

- Captures complete 3D scenes at video frame rates
- Self calibrating optical design yields stable measurement results
- Solid-state design
- 176 x 144 pixel array (QCIF)
- In-pixel background light suppression
- USB 2.0 or Ethernet interface
- Continuous or external trigger acquisition modes
- Multi-camera operation using Coded Binary Sequence (CBS) modulation
- Eye-safe LED illumination
- Robust industrial grade housing
- User selectable parameters, including focus, frame rate (exposure time), and continuous vs. trigger mode operation

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Page 1

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August 2008

SR4000 Data Sheet

MESA IMAGING

APPLICATIONS

Factory Automation

- AGV Navigation
- Dimensional weight measurement
- Forklift / pallet space sensing
- Container level monitoring for solids (full/empty)
- Multi-variant object sorting, pick-and-place
- Object position and orientation measurement

Media / Retail

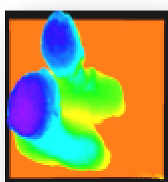
- Interactive advertising
- Scene capture for 3D Displays
- Interactive museum and artistic exhibitions

Consumer

- Interactive video game development platform
- Controller hardware-free arcade game input device
- Gesture-based computer input control

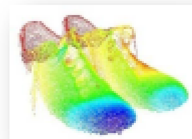
Security / Surveillance

- Access Control
- Person counting and queue measurement
- Facial recognition



Health / Fitness

- Biomechanical analysis
- Foot scanning for custom orthotic inserts
- Exercise and fitness equipment
- Movement sensing during medical diagnostics, such as X-Ray, MRI
- Rehabilitation systems



Agriculture

- Farm animal monitoring
- Automatic milking system sensor
- Plant type identification and growth measurement

Mobile Robotics

- Autonomous navigation and obstacle avoidance
- Search and rescue sensor
- Human – Machine Interface development

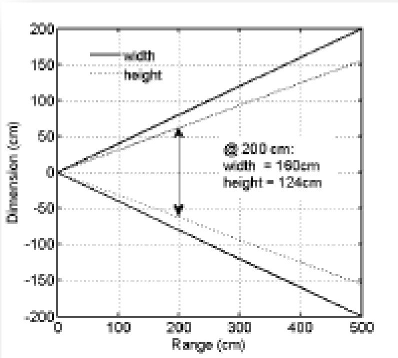
SR4000 Data Sheet

MESA IMAGING

PERFORMANCE

Field-of-View

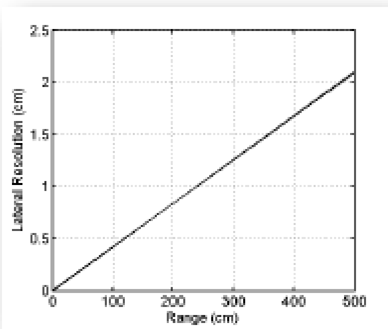
The size of the area illuminated and measured by the SR4000 is a function of the distance from the camera.



At a typical operating range of 2 meters, the 43.6° x 34.6° FOV corresponds to a target area of 1.6 x 1.24 meters.

Lateral Resolution

The lateral resolution of the camera is determined by its

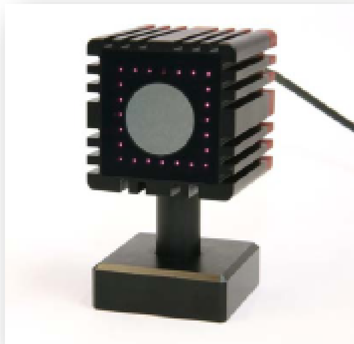


(fixed) FOV in combination with the number of pixels in the sensor array. Each of the 176 (horizontal) and 144 (vertical) pixels corresponds to approximately 0.23° of angular resolution. The graph shows the lateral resolution in cm vs. the distance (range) from the camera.

Distance Accuracy

The accuracy of TOF cameras varies with individual camera settings, object reflectivity, and ambient lighting conditions.

Each pixel provides a nominal accuracy equivalent to 1% of the distance to an object, or +/- 1 cm, whichever is greater.



Distance measurements can be optimized by the user via various filtering and averaging techniques. These include median filtering, detail-preserving ANF (Adaptive Neighbor Filtering), time averaging multiple samples, and continuous adjustment of exposure times.

SR4000 Data Sheet

MESA IMAGING

SR4000 SPECIFICATIONS

	Performance Specifications	
Pixel Array Size	176 (h) x 144 (v)	QCIF
Field of View	43.6° x 34.6°	Lens: F# 1.0, f=10mm
Pixel Pitch	40 µm	Horizontal and vertical
Angular Resolution	0.23°	Center pixel
Illumination Wavelength	850nm	Central wavelength
Modulation Frequency	30 MHz	Default setting
Modulation Format	Sinusoidal or CBS	CBS available in 4Q2008 release
Operating Range	0.3 to 5.0 meters	With standard settings
Distance Accuracy	+/- 1 cm	z-direction, single pixel
Repeatability	< 5mm at range up to 2 meters	Single pixel (1σ); 50% reflective object
Frame Rate	Up to 54 FPS	Camera setting dependent
Communication Interfaces	USB 2.0	
	Fast Ethernet (100 Mb/s)	
Operating System	Windows XP, Vista; Linux, MacOS	
Electrical Power Consumption	0.8 A @ 12 V	
	Mechanical / Environmental	
Operating Temperature	+10 °C to +50 °C	Ambient, with adequate heat sinking
Storage Temperature	-20 °C to +70 °C	
Dimensions	65 x 65 x 68 mm	USB2.0 version
	65 x 65 x 90 mm	Ethernet version (includes connector)
IP Code	IP-54	USB version, excluding connector
	IP-54	Ethernet version, with rated connector
EMI Rating	Class A	
Case Material	Anodized Aluminum	
Window Material	Polycarbonate	Illumination cover
	Coated Borafloat glass	Objective cover
Mounting Holes	4 x M4; 2 x 4H7; 1 x 1/4"	

Notes:

1. The SR4000 is designed for operation in indoor environments.
2. Camera should be properly attached to a heat sink during operation.
3. Beta release; final industrial ratings upon completion of qualification.
4. All specifications are subject to change.

Rear view (USB version)

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Page 4

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August 2008

SR4000 Data Sheet

MESA IMAGING

ORDERING AND AVAILABILITY

Product	Model	Order P/N	Availability	Notes
Cameras				
SR4000	USB2.0, CW	00400001	Sept 2008	Sinusoidal modulation
	USB2.0, CBS	00400003	Dec 2008	CBS modulation
	Ethernet, CW	00400002	Dec 2008	Sinusoidal modulation
	Ethernet, CBS	00400004	Dec 2008	CBS modulation
Cables				
USB Cable	1.8 meters	00200006	Sept 2008	USB2.0 Type A - 5pin Mini
Ethernet Cable	1 meter	00200008	Dec 2008	RJ-45 connectors
Trigger Cable	2 meters	00200007	Sept 2008	Lumberg M8 Female 4-pin
Power Supplies and Cords				
Power Supply	Power Supply 12V/2A	00200001	Sept 2008	Lumberg M8 Female 3-pin
Cord	Germany / France	00200003	Sept 2008	Schuko type – IEC C13
Cord	Switzerland	00200004	Sept 2008	SEV 10/11 – IEC C13
Cord	US / Japan	00200005	Sept 2008	NEMA 5/15 – IEC C13
Cord	UK	00200009	Sept 2008	BS 1363 – IEC C13

Notes

1. 2008 products are beta releases. Formal qualification planned for 1Q2009.
2. Camera, cable(s), and power supply should be ordered as separate line items.
3. See *www.mesa-imaging.ch* for commercial Terms and Conditions, and product updates and notices.
4. Each camera shipment includes CD with manuals, visualization software, API, and software drivers.

QUOTATIONS

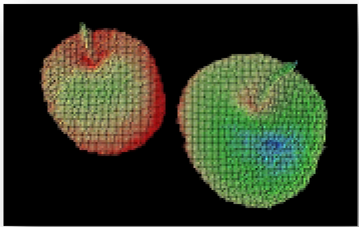
For quotations, pricing and delivery information, please contact:

sales@mesa-imaging.ch

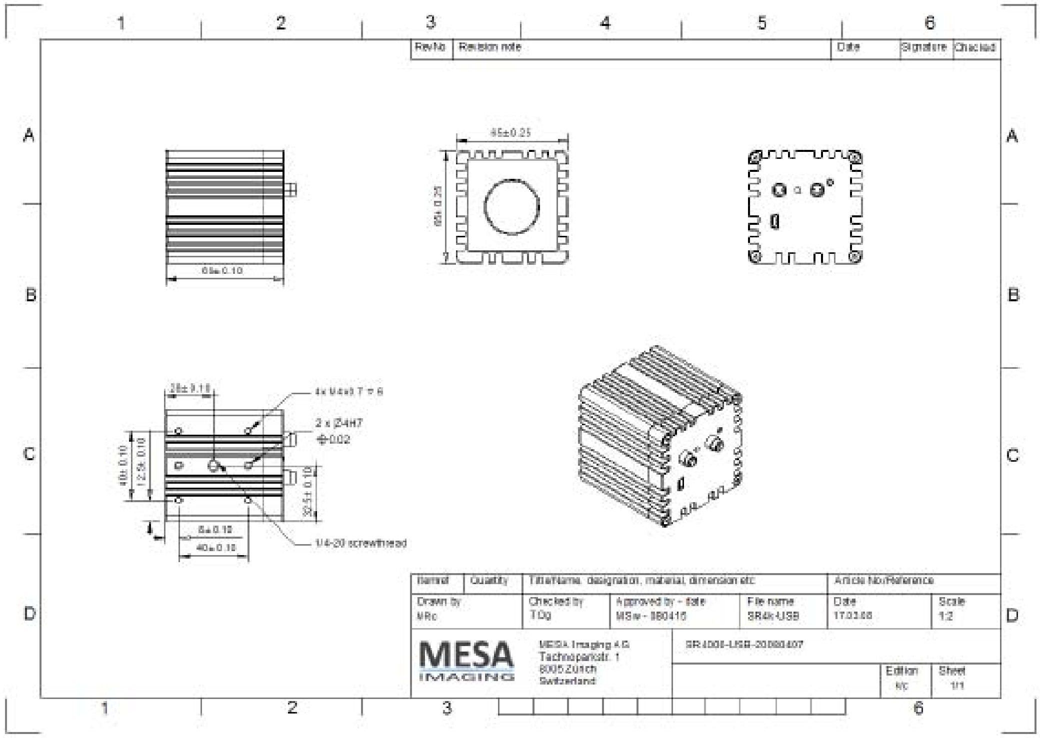
+41 (0) 44 508 1824

+41 (0) 44 508 1801 (fax)

www.mesa-imaging.ch



SR4000 MECHANICAL DRAWINGS (USB)



Appendix E. Comparison of SR3000 to the SR4000

(courtesy MESA Imaging AG)

SR4000 vs. SR3000 Comparison

MESA IMAGING

	SR4000	SR3000
Distance Measurement Stability	SR4000 is a self-calibrating camera that corrects for environmental fluctuations, component ageing, and camera settings - resulting in a major improvement in measurement stability.	Distance measurement fluctuate depending on ambient temperature and camera settings (such as integration time).
Imager Type	4th Generation (Silo) pixel offers lower-noise measurements and is capable of up to 100MHz modulation (for future product release).	Uses proven 3rd Generation BIGTOF pixel. Limited to 35MHz demodulation speeds.
Object Reflectance Sensitivity	SR4000 is less susceptible to variations in object surface reflectivity, yielding improved uniformity of distance measurements for multi-colored objects.	Overly sensitive to color and reflectivity variations in an object.
Confidence Map Output	A 16-bit output is provided that enables an application to qualify the relevance of each pixel's distance data and assign a corresponding level of confidence that such data should be used.	No confidence map function.
Pixel Array Size	176 x 144 (QCIF). Same as SR3000.	176 x 144 (QCIF).
Embedded capability	In-camera DSP allows future applications to be embedded into the camera, enabling stand-alone (PC-free) operation.	No embedded DSP.
Software Compatibility	Users that previously developed applications based on the SR3000 will require minor modifications (see website for details).	New drivers developed for the SR4000 work with the SR3000.
Communication Interfaces	USB and Ethernet products are part of the standard offering (interface must be specified when ordering).	USB only
Trigger Mode	An external trigger capability is standard on all cameras.	No standard trigger mode.
Frame Rate	Improved frame rate capability (up to 54 FPS) resulting from higher imager (pixel) performance.	Typical applications usually limited to 15-20 FPS.
Background Light Suppression	Improved background light suppression available on production release version (Jan 2009). Indoor only camera.	Indoor only camera.
Modulation Scheme	Sinusoidal and CBS (Coded Binary Sequence) modulation options; the latter providing for interference-free multi-camera operation.	Sinusoidal modulation only.
Optics & Field of View	43.6° x 34.6° is similar to the SR3000, but the lens collects 2X the light (F# 1.0). Optics are optimized for 850nm operation.	47.5 x 39.6° FOV but with less capable (slower, F# 1.4) lens; not optically optimized (AR) for 850nm.
Power Consumption	With only 22 LED devices (illumination is the main consumer of power), electrical power consumption is approximately one-half that of the SR3000 under normal operation.	The 54 LED devices consume a majority of the power required for camera operation.
Temperature Control	Fully enclosed housing contains no fan, improving reliability and allowing operation in more hostile environments. Camera is silent during operation.	Use of a somewhat noisy fan and the corresponding housing openings allowed dust and moisture to enter camera.
Reliability and Qualification	Camera is undergoing full qualification to allow use in industrial environments requiring long product lifetimes and 24/7 operation.	Prototype class (laboratory use) only.
Pricing	For low volumes, the SR4000 price is 20% higher than the SR3000.	The SR3000 is not offered in high volumes.
Availability	The SR4000 beta is available immediately. Series production of the qualified design in 1Q2009.	The SR3000 is available but will be discontinued in July 2009 (approximate date, not yet finalized).

September 2008