NIST Test Report
on
Highly Reflective Objects Near the SR3000 Sensor
Roger Bostelman, Will Shackleford
February 27, 2008

As indicated by Egemin's data they sent us, the SR3000 sensor has a measurement issue whereby highly reflective objects detected by the sensor skew the sensed obstacle detection ranges. When no reflective object is within the scene, the objects are not skewed. NIST has been studying this issue by contacting MESA and by performing our own performance measurements. This report shows the information (slide and email exchange) from Mesa and the follow on test and results that NIST determined. Several photos and screenshots of the experiments performed at NIST are shown displaying the skewed range phenomena and potential solutions for using the SR3000 and other flash LIDAR sensors around highly reflective objects. Conclusions end the report with our findings and recommendations followed by an Appendix with additional data screen shots.

MESA INFORMATION
Email Exchange with Peter Hunt and Roger Bostelman:

> From: Roger Bostelman [mailto:bostel@cme.nist.gov]
> Sent: Friday, February 01, 2008 9:45 AM
> To: Peter Hunt
> Subject: SR3000
>
> Peter,
> Question for you if you please. Our consortium members of AGV
companies
> is experiencing issues with high intensity reflectors "messing up" the
> range and scene data they are capturing. Has there been any
adjustment
> software been written, hardware fixes, or both done on the SR3000 that
> provides a solution for this issue?
>
> Thanks,
> Roger

Quoting Peter Hunt <Peter.Hunt@mesa-imaging.ch>:

> Hi Roger,
>
> Good to hear from you. I am assuming you are referring to a problem
we
> refer to as the dynamic range or stray light problem. Highly
reflective
> objects at closer range could be "flooding" or saturating the pixel,

> thereby not providing accurate data readings. Another possibility is
> stray light. Stray light is caused by the returned optical signal
being
> reflected off surface in the imaging lens or chip surfaces. This can
> result in light being imaged onto undesired pixels, therefore creating
> erroneous distance values.
>
> About 6 months ago we reduced this problem by adding an
anti-reflective
> window directly on top of our imaging chip. Although this improves
the
> performance it does not eliminate it.
>
> Our forthcoming new product (SR-4000), which is an industrialized
> version of the SR-3000 further reduces the problem. We have a
> re-designed imaging lens which will significantly reduce the stray
light
> problem. We plan to announce this product in early Q2.
>
> I hope this information is helpful. Please let me know if I'm missing
> the mark on the problem or if you have any further questions.
>
> Have a great weekend.
> Best regards,
>
> -Peter
> ___________________
> Peter Hunt
> MESA Imaging AG
> 53 Pleasant St, Concord, MA 01742
> www.mesa-imaging.ch/
> Tel: +1 978 771 0636
> phu@mesa-imaging.ch
> ____________________________________
>

-----Original Message-----
From: bostel@cme.nist.gov [mailto:bostel@cme.nist.gov]
Sent: Friday, February 01, 2008 3:24 PM
To: Peter Hunt
Subject: RE: SR3000

Peter,
I think you nailed the problem. Is there anything we can now do with
the SR3000 to resolve or reduce this problem?

Do you have a loaner SR4000 we can try out to show our consortium members how it differs in our test set-up? Or, what about one of the newest ones you plan to sell later in the year?

Have you heard of anyone augmenting the SRX000 with another sensor to get around the problem? e.g., a camera, stereo cameras, etc.?

Thanks,
Roger

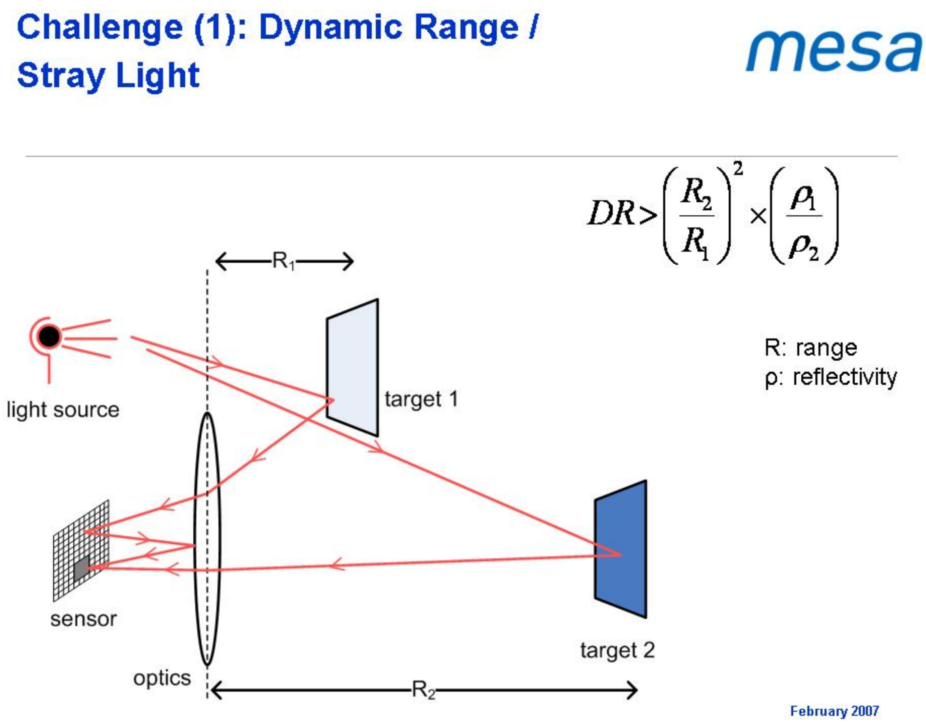
Subject: RE: SR3000
Date: Tue, 5 Feb 2008 23:14:44 +0100
From: "Peter Hunt" <Peter.Hunt@mesa-imaging.ch>
To: <bostel@cme.nist.gov>

Hi Roger
At the moment there is not much we can do to reduce the stray light effect you are witnessing. As I mentioned, the next generation of camera will help tremendously.

I may have confused you on the SR4000. The SR4000 is not available yet; we plan to announce it in Q2. This camera will have our latest pixel technology which should help reduce this issue. Alan Lytle is lined up to get one of the earlier shipments so if you're nice to him he might let you see it!!

I do not know of any other sensor technology which is used in conjunction with our camera to get around the problem. People are using other laser scanners or point sensors with our camera, but it does not address the problem.

Thanks,
-Peter



NIST EXPERIMENT

<u>Experimental Apparatus</u>

- MESA SR3000 Flash LIDAR with up to 7.5 m range and 20 degree field of view (FOV)
- PMDTech 200 Flash LIDAR
- 18” long x 2” diameter cylinder covered with Highly Reflective material (vehicle absolute positioning system reflective material)
- Laptop with:
  - SR3000 drivers and NIST-modified control for high-intensity thresholding program
  - and NIST-developed camera signal masking program
- Obstacles:
  - Chairs: one with overhanging seat from center post (blue material) and one wooden with four legs.
  - Checkerboard plastic board on an easel (tilted slightly back at it’s top).
- Metric tape measure on the floor

<u>Experiment and Results:</u>

Two experiments were completed: 1.) passing sensor test, and 2.) highly reflective object test. The SR3000 was fixed to the front edge of a small table on wheels at a height of approximately 36” above the floor. NIST asked Egemin at what height were their reflectors typically mounted above the floor. Their response was: “Typically we use 30" long reflectors. With the scanner laser beam at a typical height of 96", this puts the bottom of the reflector at 96"-15"=81"” NIST therefore chose a maximum “0” surface height on which to set the sensor at 80” above the floor. The reflector was set on surfaces measuring 80” (called 0 height), 60” (called -0.5 m height) and 37” (called -1m height) above the floor and at ranges of 7 m to 3.5 m from the SR3000. The bottom of the reflector cylinder was placed on these surface heights. Figure 1 shows a CAD drawing of the experimental layout. The following photos show the experimental set up.

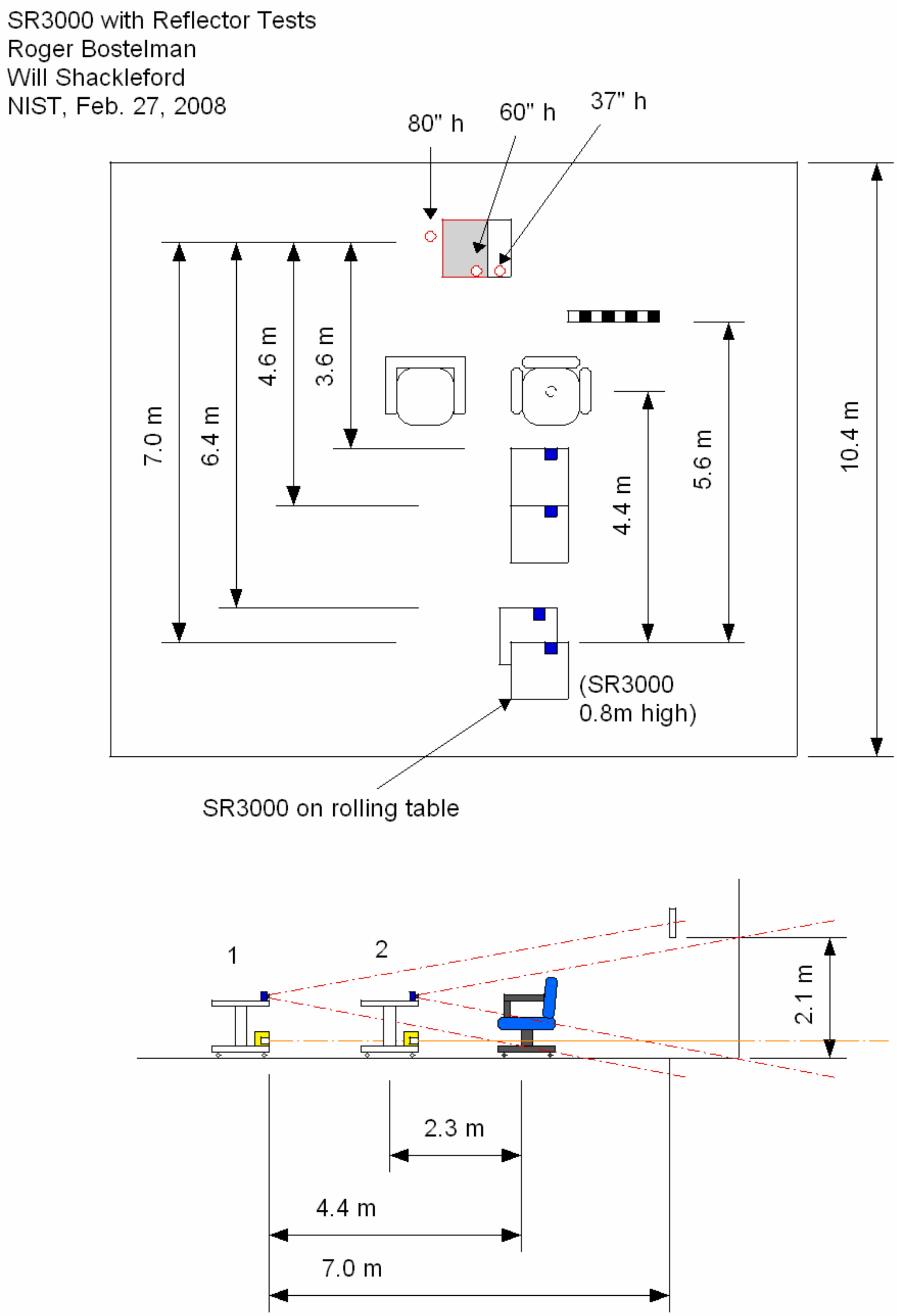


Figure 1. Experimental Layout. Top shows the top view of the experiment with the roller table with SR3000 sensor moved to a series of locations. Bottom shows the side view of the SR3000 sensor on the table and the table at two different range locations. Also, as an indicator of a potential mounting configuration, a Safety Sick sensor is shown on the bottom of the table. The Safety Sick was not a part of the experiment.

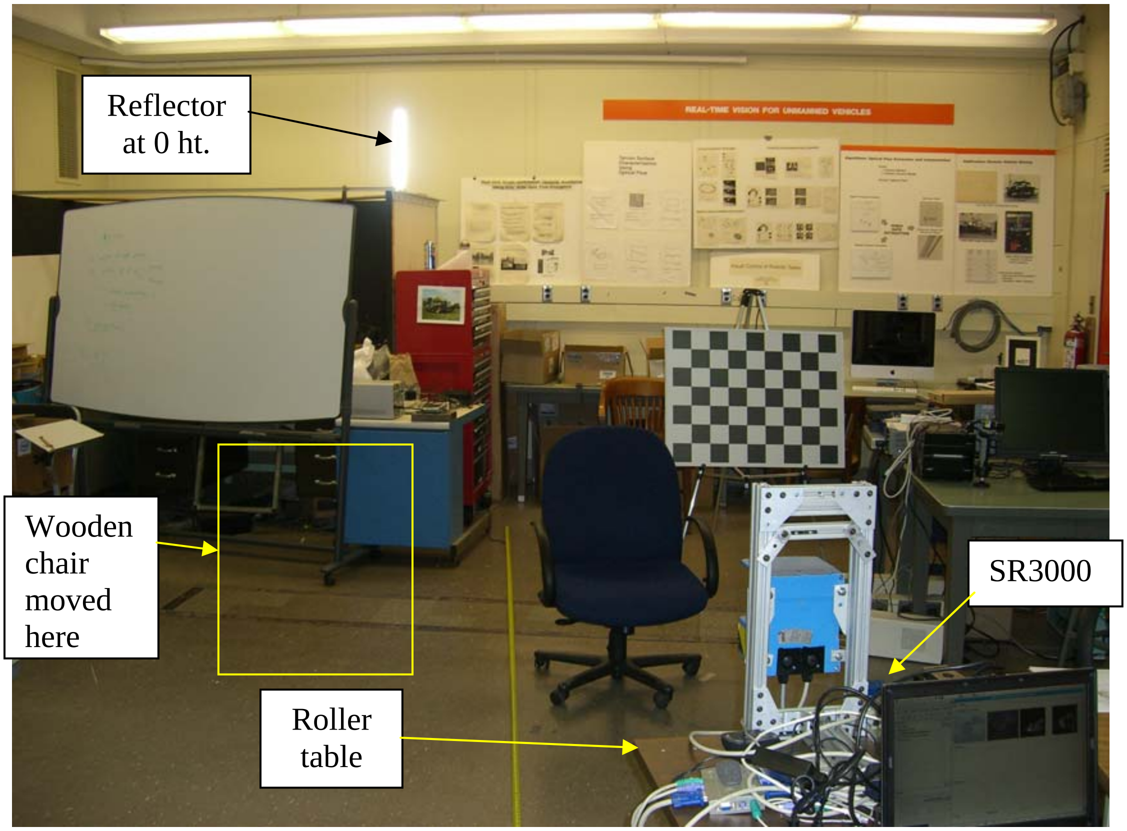


Figure 2. Photo of the experimental set-up in the lab. The roller table is at approximately 6.4 m from the reflector. For most tests, a second wooden chair (back of photo) was placed beside the blue, material chair as an obstacle.

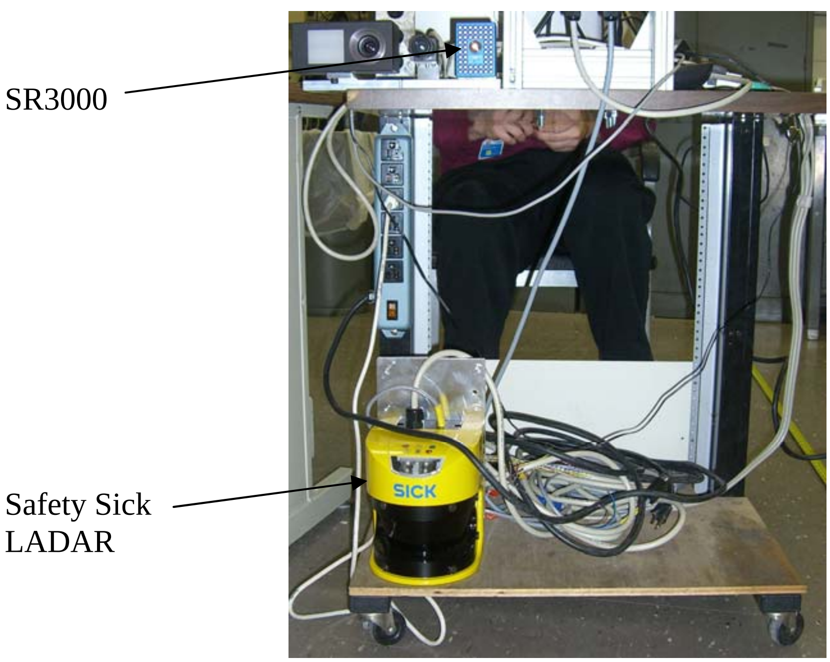


Figure 3. Photo of the SR3000 sensor and Safety Sick (not used) on the roller table and taken from the reflector end of the room.

Figure 4. Photo of the experimental set-up with the reflector, illuminated from the camera flash, set at the -1m height and showing the computer laptop data capture system. At this location, the roller table is 3.5 m from the reflector.

1.) As an aside to this reflector experiment, it was brought up in previous discussions regarding these sensors whether or not interference from passing vehicles also equipped with these sensors caused range measurement issues from either passing vehicle sensors' light source. A PMDTech 200 flash LIDAR was powered so that it's LED light source, similar to the SR3000 was illuminated. Once powered, the 200 sensor was brought near the SR3000 detecting range to obstacles. The 200 was moved at the same height as the SR3000 and at an approximated passing vehicle distance or closer (< 3') to the SR3000. Results showed that the SR3000 demonstrated no visually detectable change in range measurements. A more thorough test using two SR3000 sensors performing the same experiment could be done to ensure no-interference issues should the Consortium deem this as a necessary test.

2.) The SR3000 was moved to a variety of distances as shown in Figure 1 and at each distance from the reflector, the reflector was moved to three different heights. Since we captured so many SR3000 images, they are shown in the Appendix section at the end of this report.

Results show that when the SR3000 is mounted low so as to not capture highly reflective absolute positioning reflector returns, the received data is not distorted. When detected within the scene, the image is slightly distorted in that region. In this case, two options are possible that we tested: 1) SR3000 threshold adjust and 2) post process intensity removal tool developed at NIST.

1) The SR3000 can be adjusted to remove high intensity data directly from the received camera data. We simply added a simple “adjuster” tool for simplicity. This can be run as a constant image adjuster in real time.
2) We developed a high intensity return data removal tool which worked fairly well and can be used along with 1 above. Both of these points are shown data captures below. This can also be run as a constant image adjuster in real time.

Another phenomenon:
When at the 3.5 m distance to the reflector and with the reflector even partially within the sensor FOV, the screen image background (behind the reflector) flickered from green (near) to red (out of range). It was thought that the sensor was overpowering the scene with LED light at the upper scene portion where the reflector was located during tests at the -0.5 m and -1 m heights. A piece of black tape covered the top two rows of sensor LED’s. The tape alone did not change the scene. Additionally, a flat-black painted board facing the sensor and separated from it by about ½” or less was used to block the top LED rows and reflected light. This technique did remove the flicker previously seen. The photos below show the set up and collected range images.

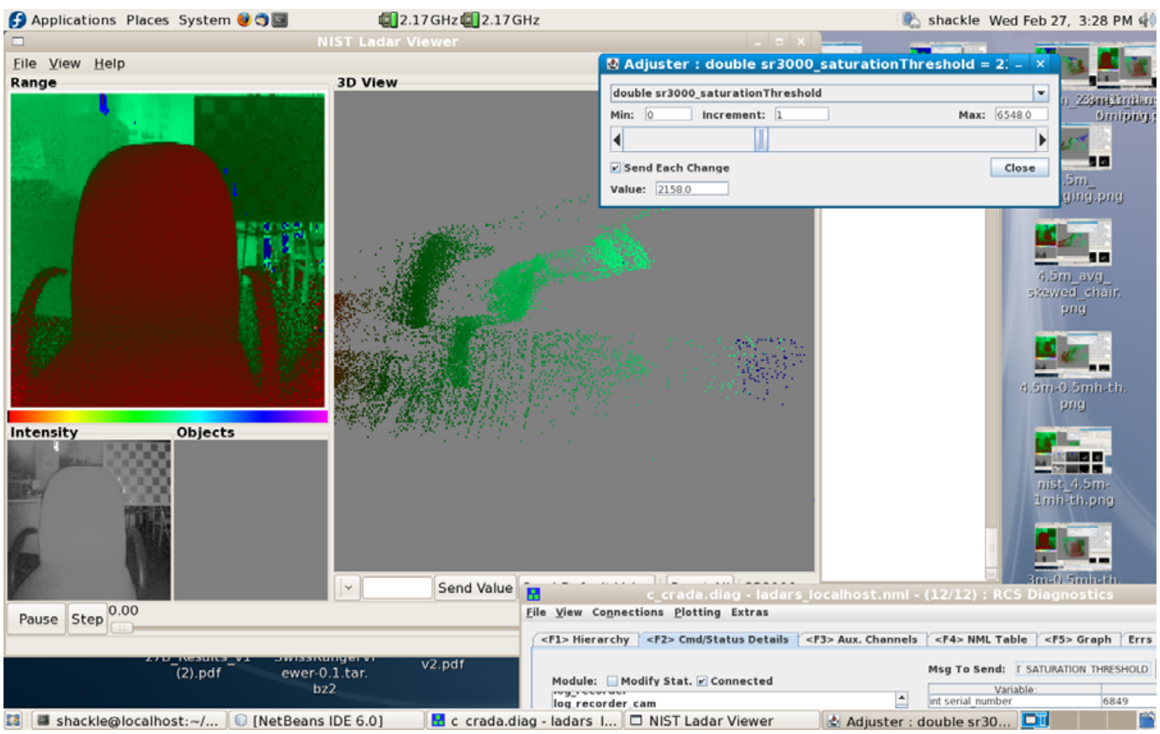


Figure 5. Range image with reflector at -0.5m height and distance to reflector of 3.5 m. The camera was thresholded to limit high intensity objects as shown in the adjuster window with the sliding bar.

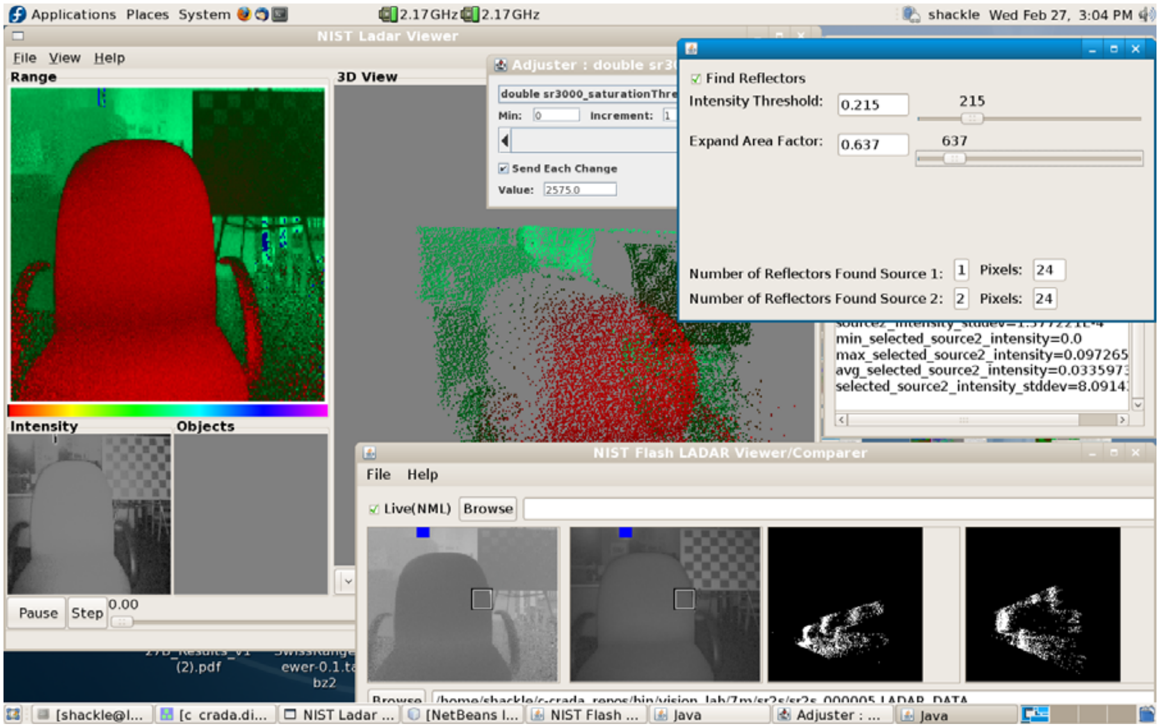


Figure 6. Image Data: 3.5 m distance to reflector with reflector at -0.5 m. In addition to the sensor threshold adjustment, the NIST camera windowing was used to block high intensity objects as shown in the above data, bottom two images with blue squares blocking the reflector. This had a positive effect on the range data, object skewing results.

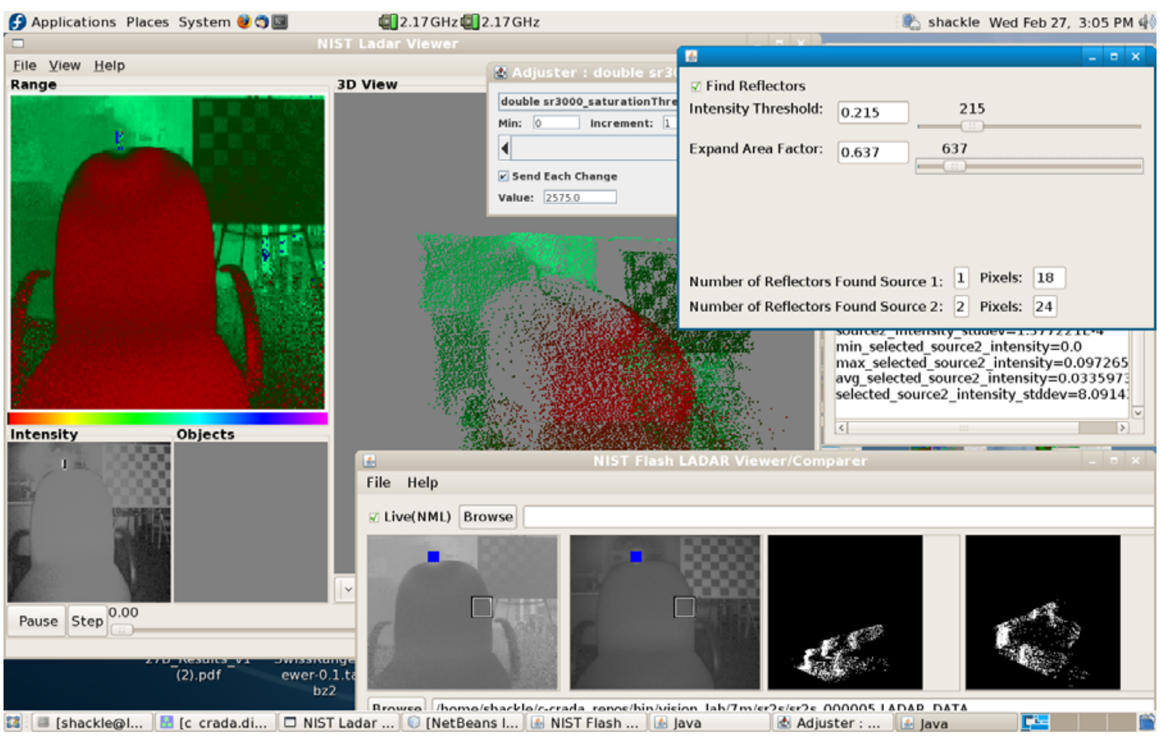


Figure 7. Image Data: 3.5 m distance to reflector with reflector at -1.0 m. In addition to the sensor threshold adjustment, the NIST camera windowing was used to block high intensity objects as shown in the above data, bottom two images with blue squares blocking the reflector. This had a positive effect on the range data, object skewing results.

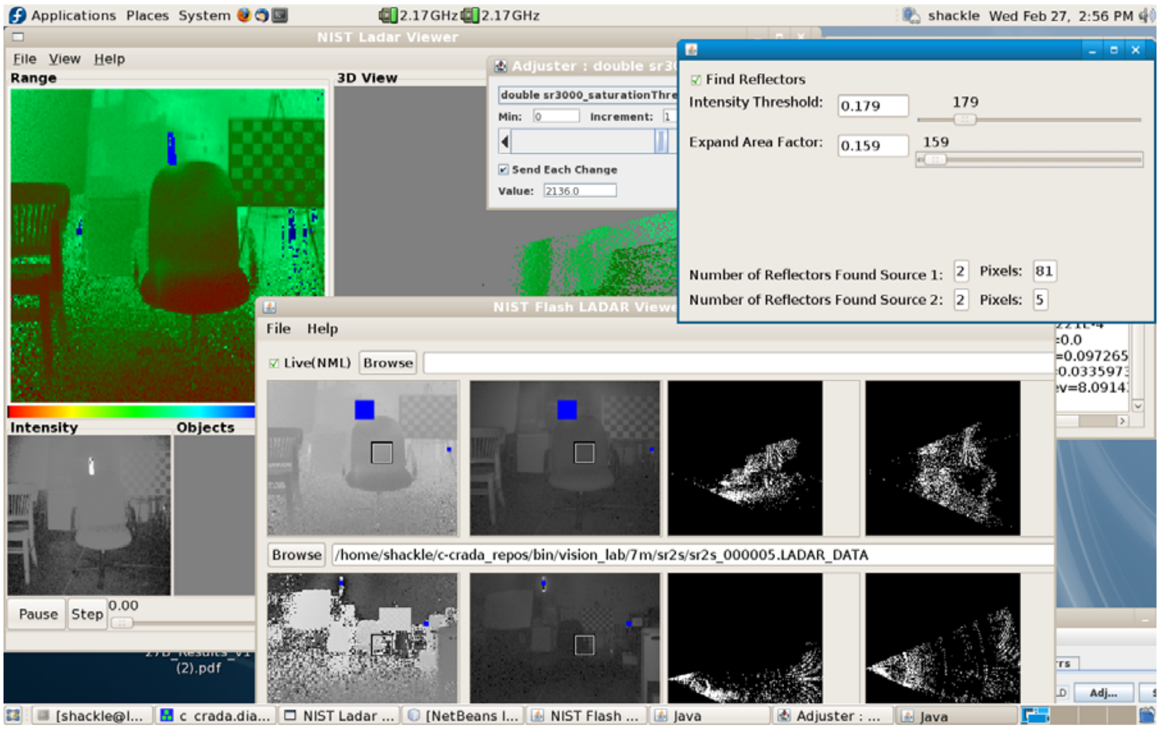


Figure 8. Image Data: 4.4 m distance to reflector with reflector at -1.0 m and using the NIST camera windowing to block high intensity objects. Note the second high intensity object detected on the checkerboard tripod leg.

Another mounting method for the SR3000 to the vehicle could be to allow the upper portion of the field of view to be parallel with the floor at the highest vehicle structure location and facing down towards the ground as shown in Figure 9. The floor could be software masked such that the sensor does not detect it as an obstacle, especially knowing the approximate fixed sensor height. Above the sensor would be the absolute positioning system sensor that, unfortunately, would not be protected by the SR3000 sensor.

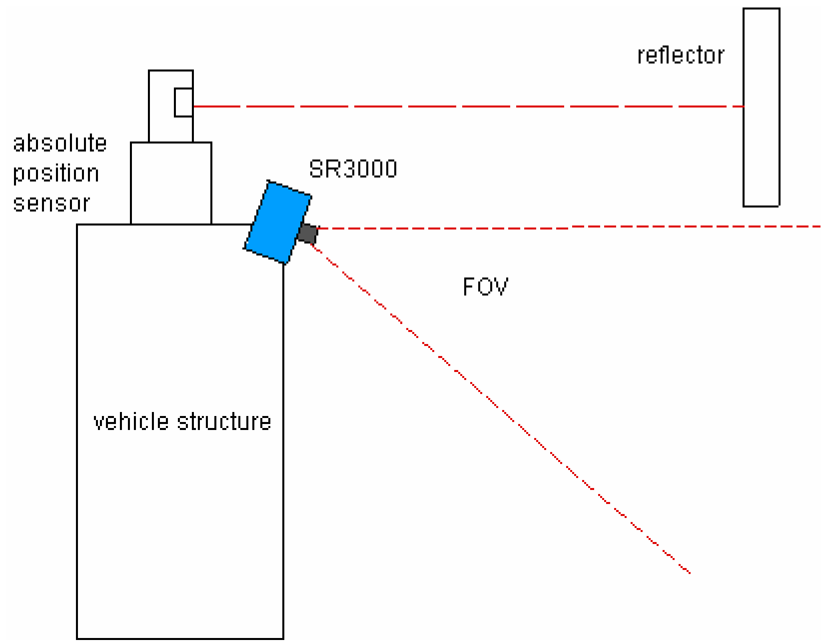


Figure 9. SR3000 possible mounting scheme to not detect high intensity reflectors.

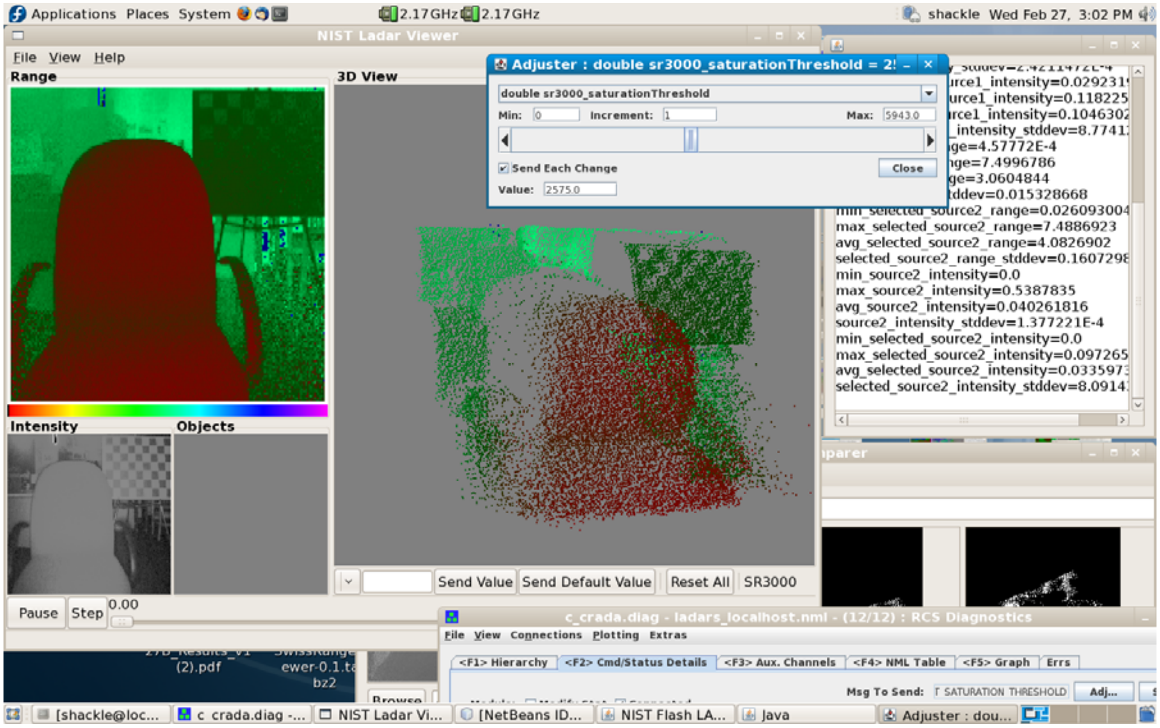
Conclusion

- The SR3000 demonstrated no visually detectable change in range measurements when an LED array light source from a similar sensor passed by.
- Mounting the SR3000 specifically to detect obstacles well below (i.e., all data captured) or just below (i.e., figure 9) the reflector heights could eliminate or greatly reduce position sensor reflector interference with the SR3000.
- Using SR3000 software drivers programmed to automatically threshold out highly reflective objects could improve range skew issues.
- Masking the upper LED's removed some image distortion. Better is to use a non-reflective surface just above the camera lens to block the upper LED's. And perhaps even better is to not use the data through a software algorithm that detects the flickered background data from one distance to another since it is only the background information.

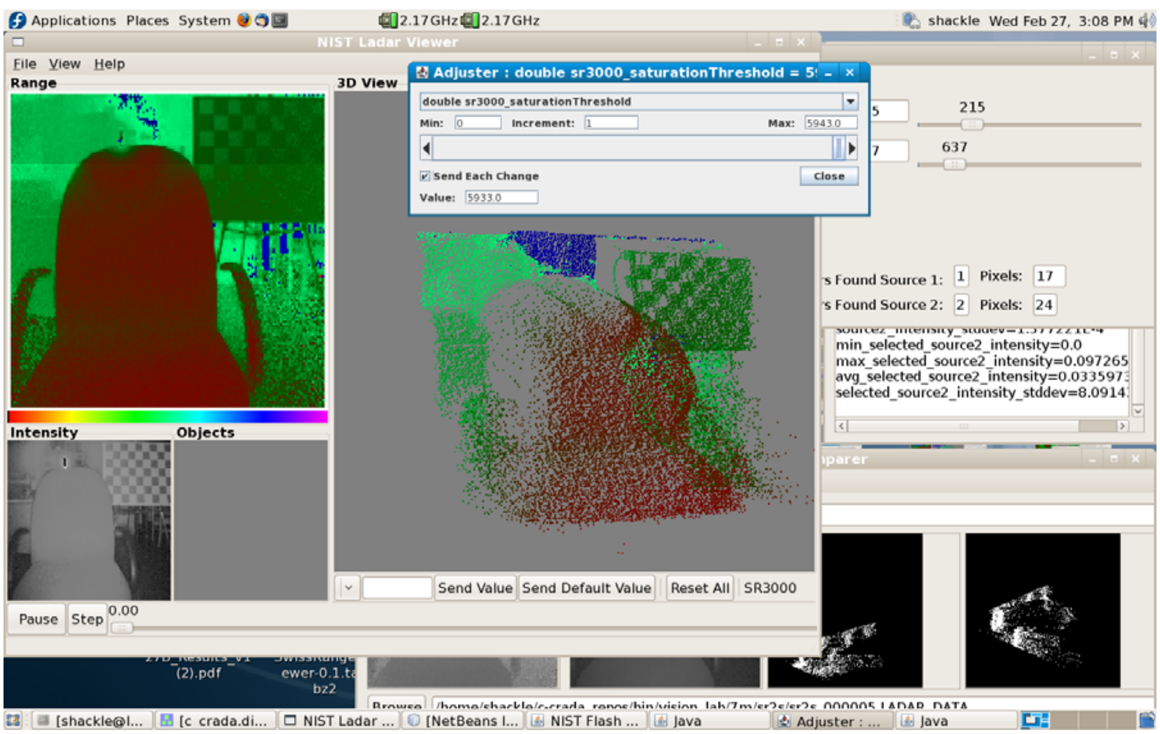
It was seen that the SR3000 sensor demonstrates modulation issues whereby obstacles just outside the 7.5 m spec'ed range by the manufacturer will appear within the nearest 0-7.5 m ranges as obstacles. Possible solutions are that the manufacturer change the modulation frequency every other cycle to change the range to obstacles to allow software masking of obstacles beyond the specified detectable range. Another possible method is to use other sensors and algorithms to intelligently classify that obstacles beyond the 7.5 m max range are not close obstacles to the sensor.

A suggested follow on to this report is to allow NIST to attach an independent test system to an AGV in a real distribution or production facility to collect data using the SR3000, cameras and/or other sensors and including self-power and computer collection hardware and software. Findings can remain within the Consortium and be used mainly for testing and developing sensor mounts and software algorithms.

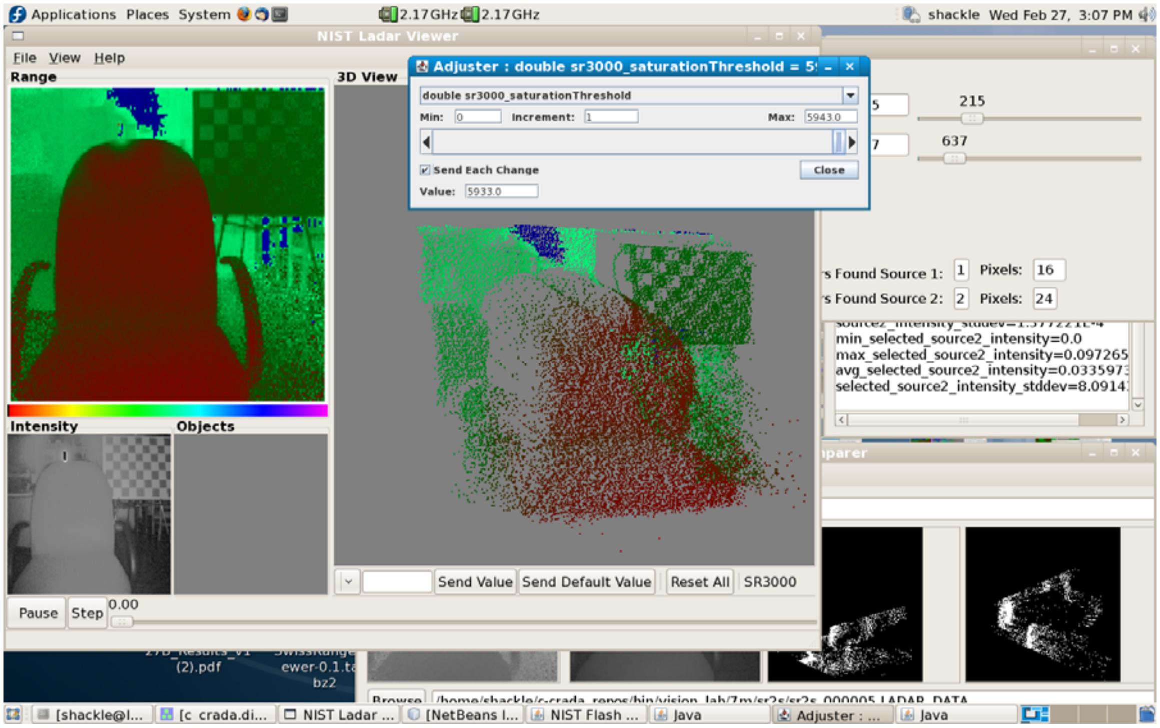
Appendix: Additional images and collected data from the test.



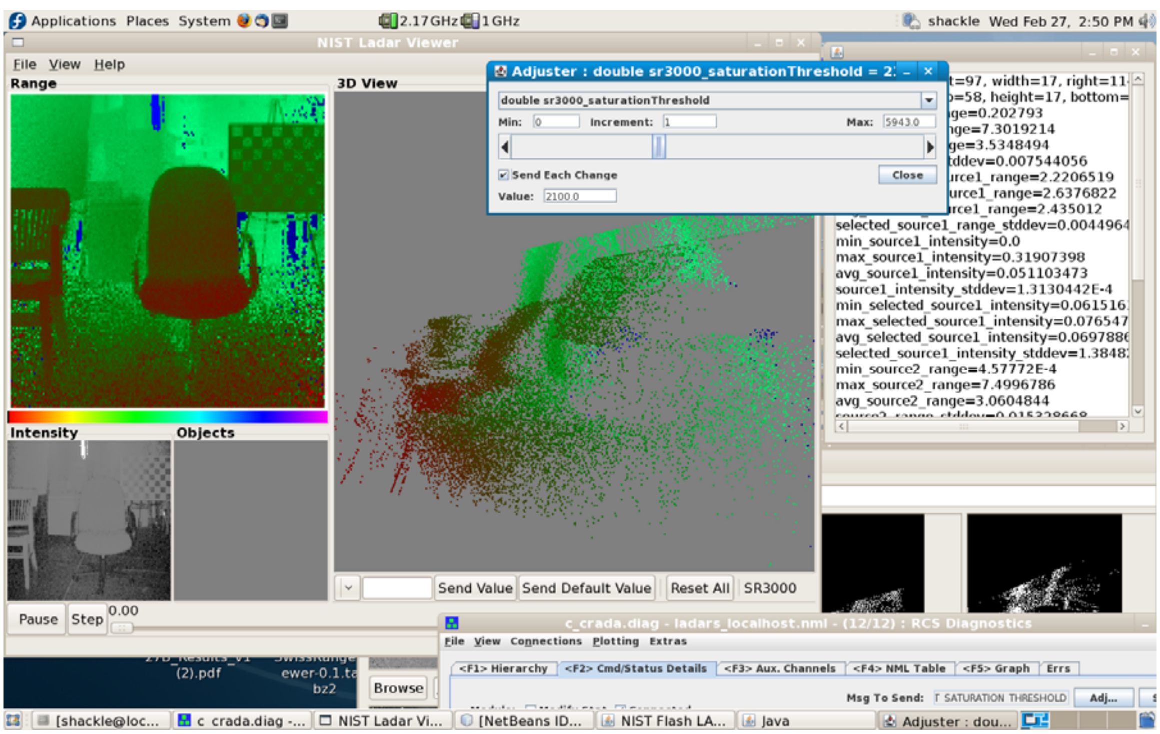
3.5 m to reflector; sensor threshold used, reflector at -0.5m height.



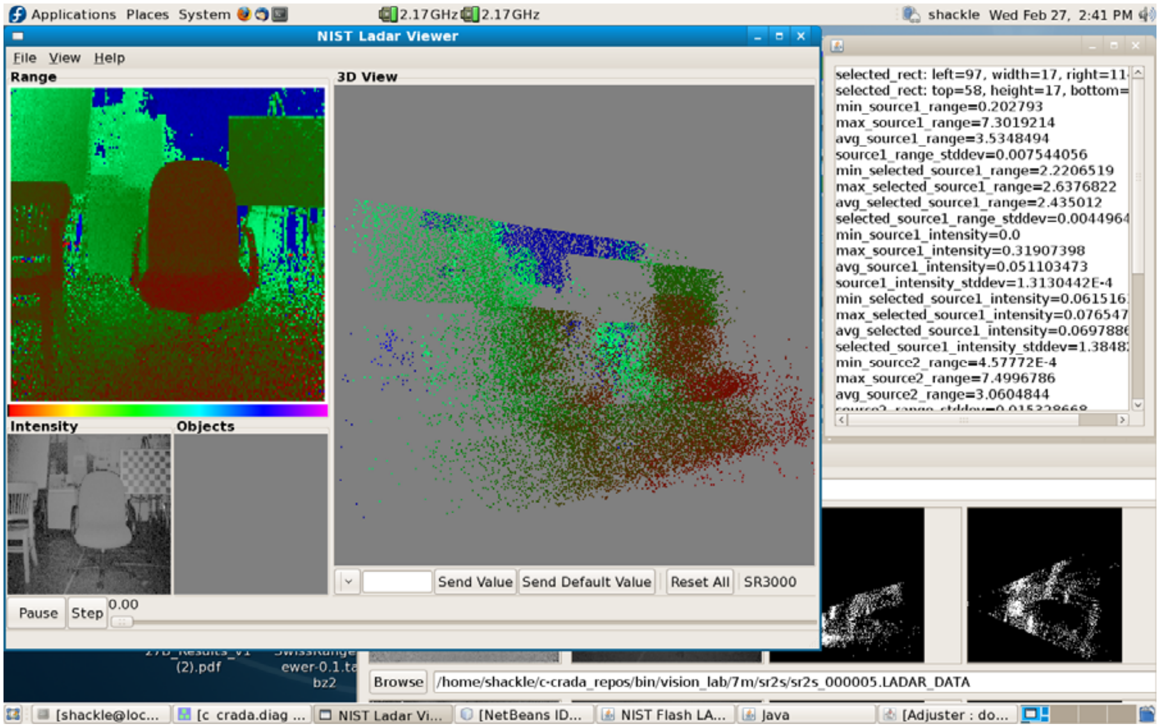
3.5 m to reflector; no threshold used; reflector at -1.0m height.



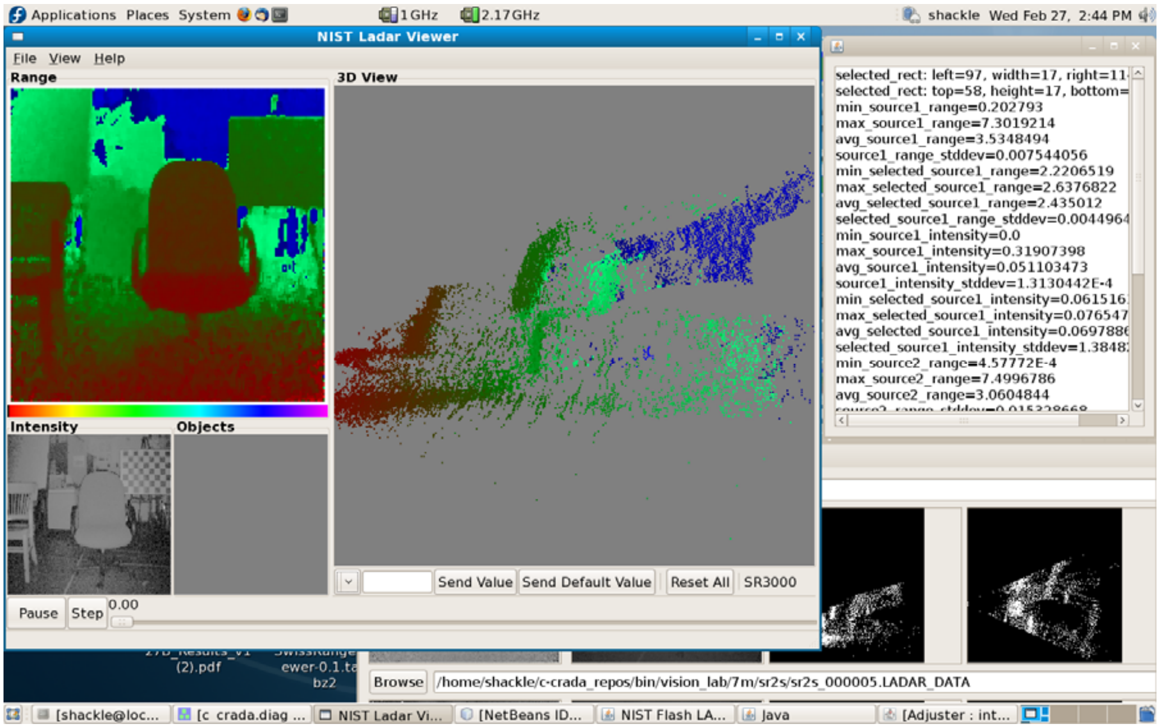
3.5 m to reflector; no threshold used reflector at -1.0m height. Flickered background data.



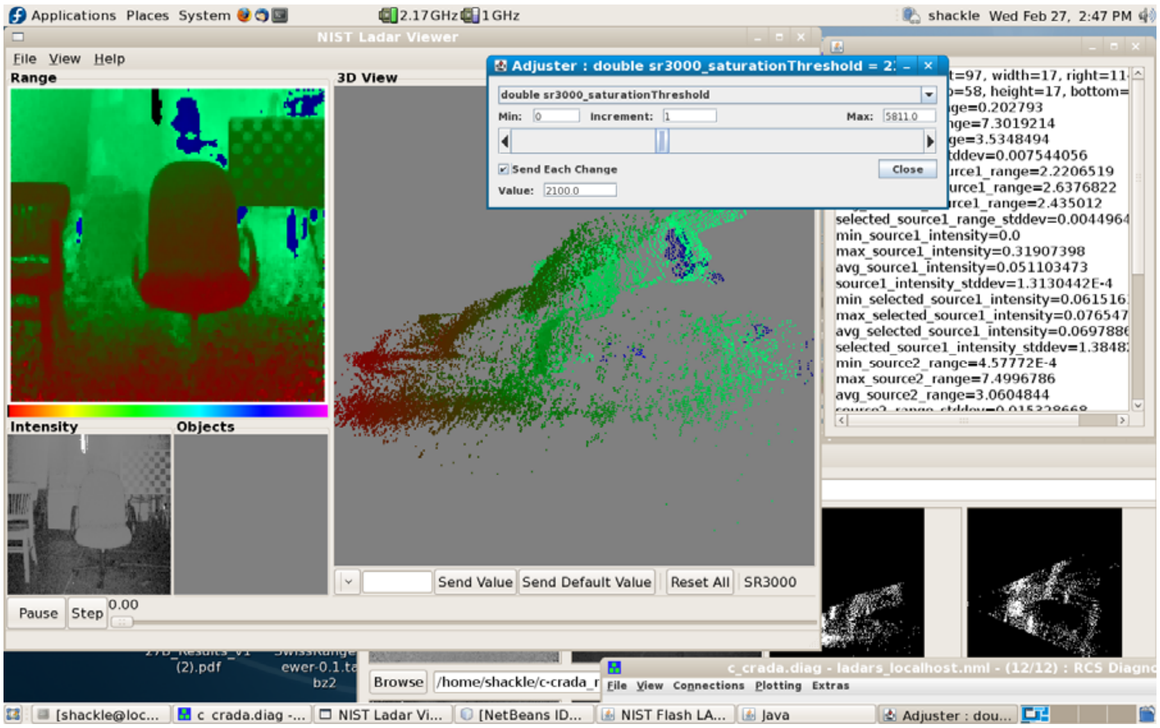
4.4 m to reflector; sensor threshold used; reflector at -0.5m height. Note skewed chair back and checkerboard leaning towards reflector. Chair front appears good.



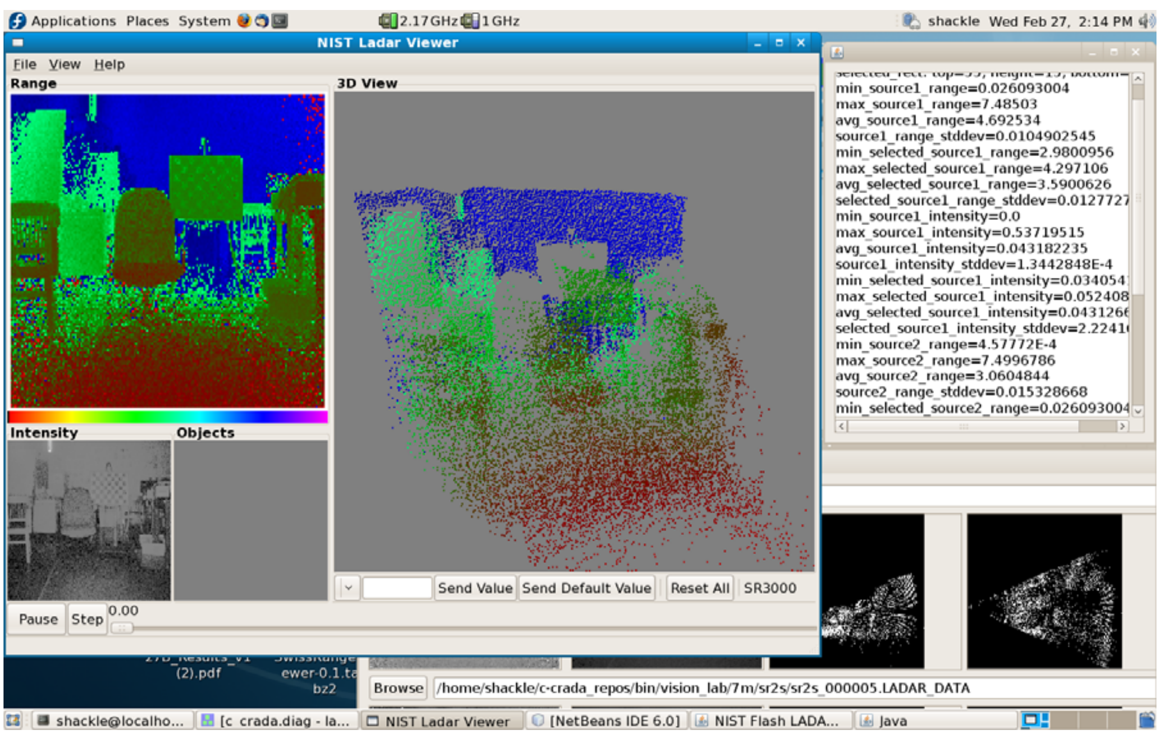
4.4 m to reflector; no sensor threshold used.



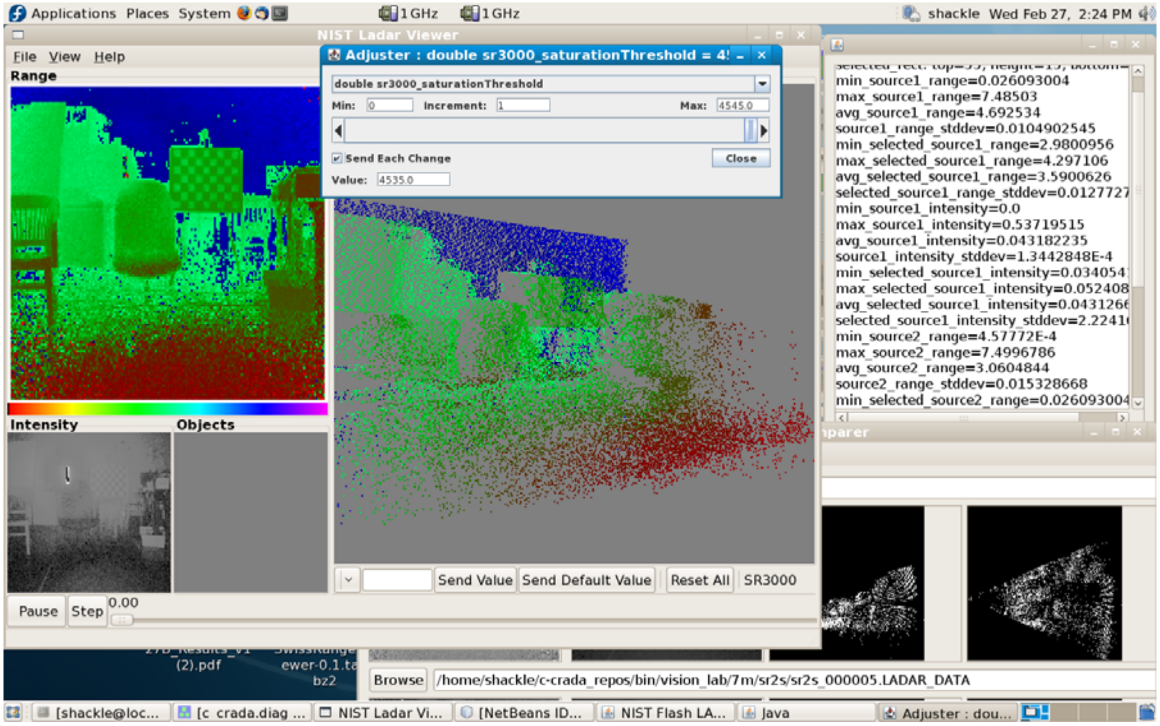
4.4 m to reflector; no sensor threshold used. Sensor averaging function used to smooth data. Could be used to better predict where are the floor or objects.



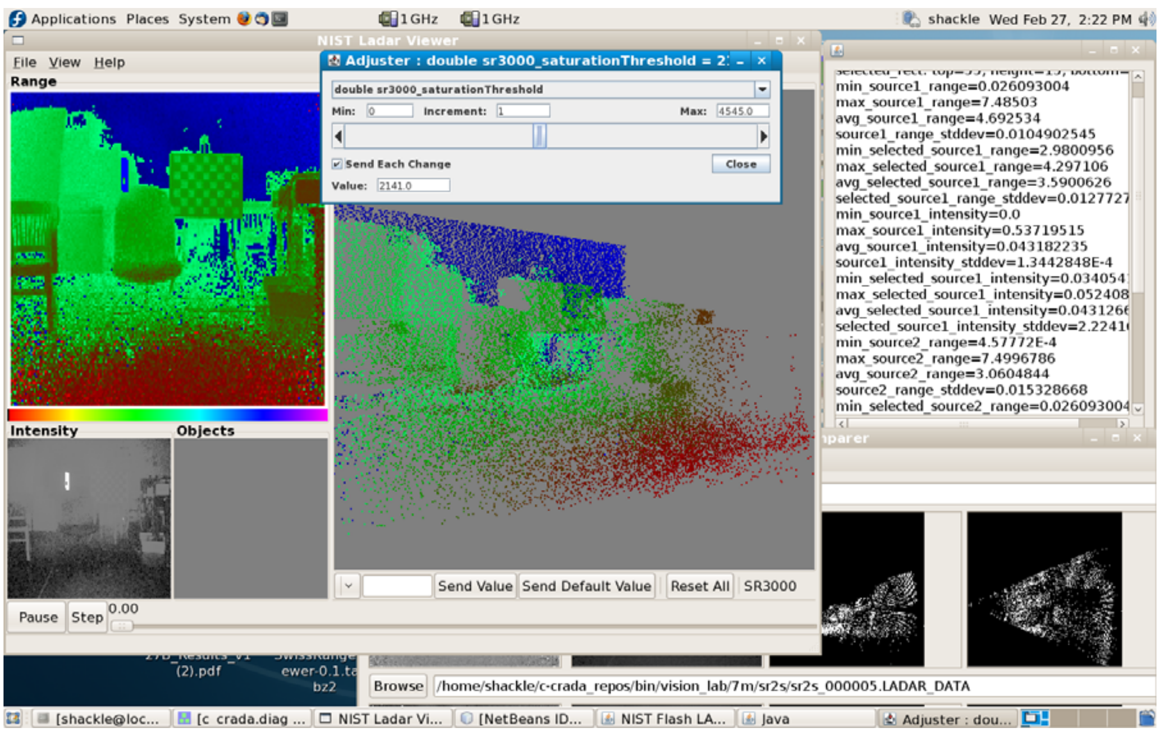
4.4 m to reflector; sensor threshold used. Sensor averaging turned on.



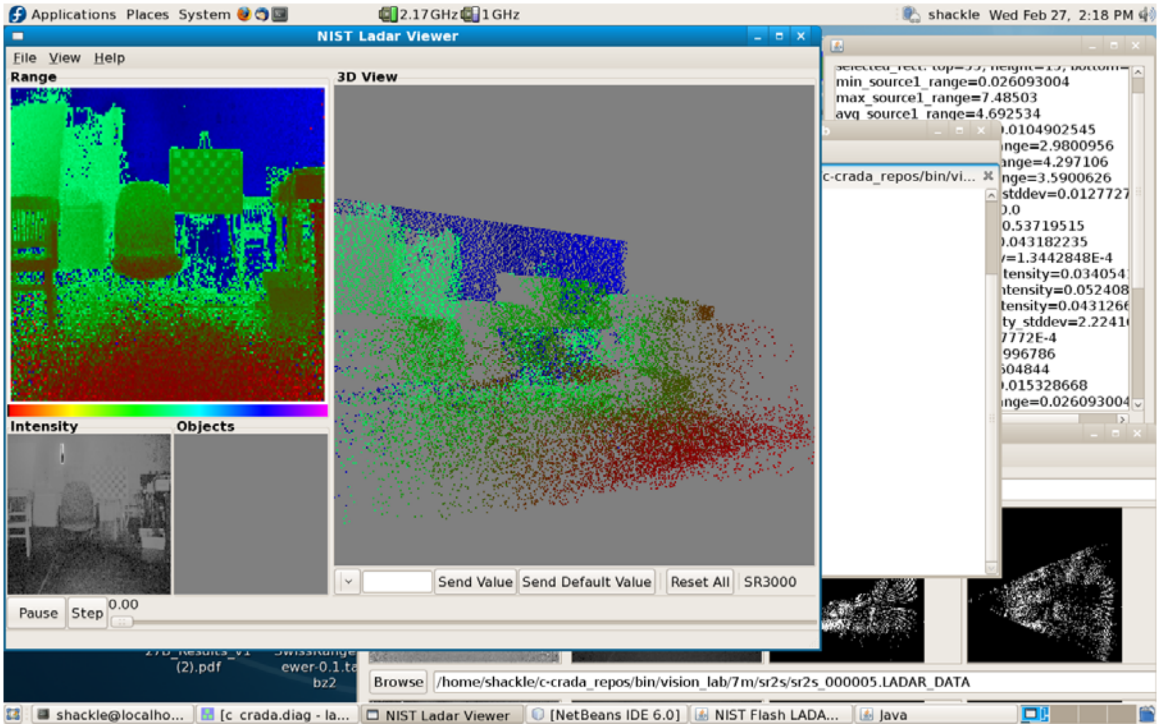
5.5 m to reflector; no sensor threshold used, reflector at 0m height.



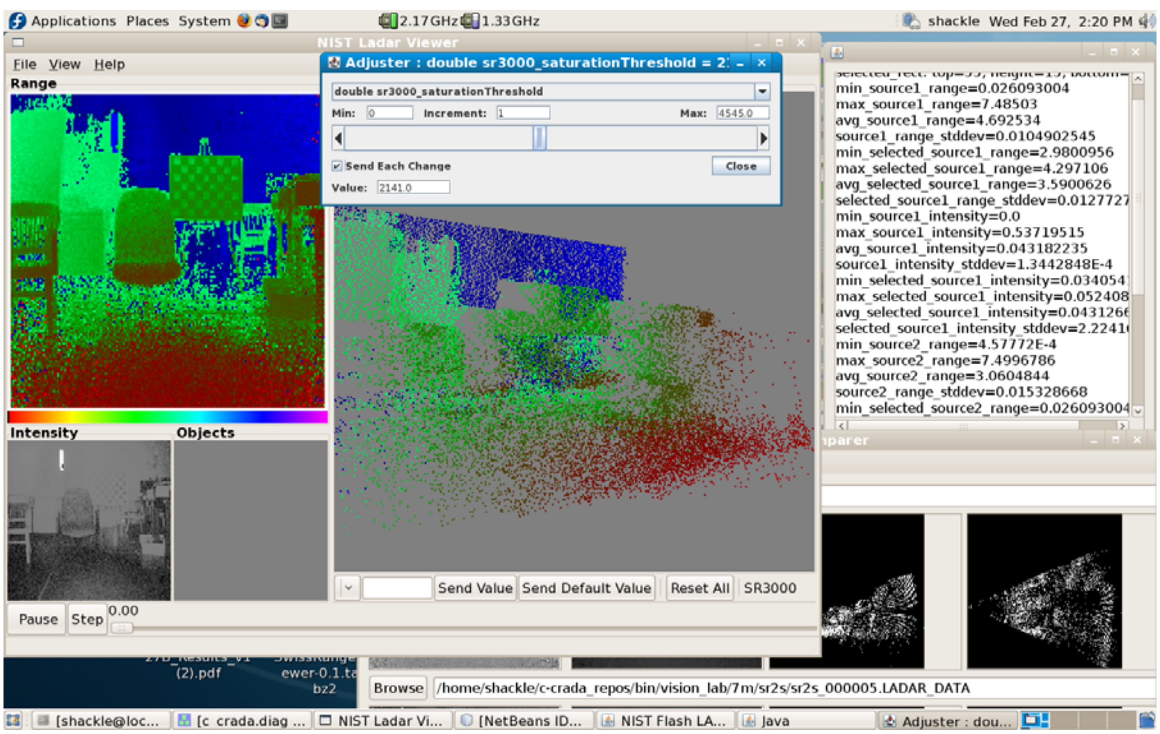
5.5 m to reflector; no sensor threshold used, reflector at -1.0m height.



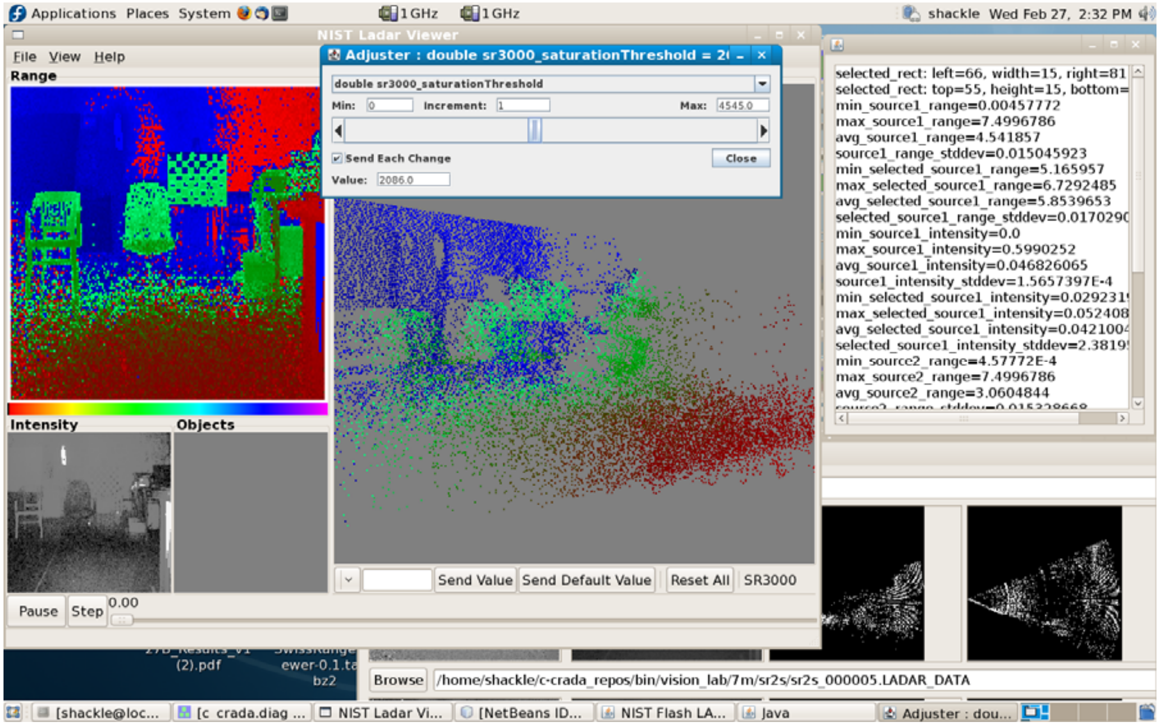
5.5 m to reflector; with sensor threshold used, reflector at -1.0m height.



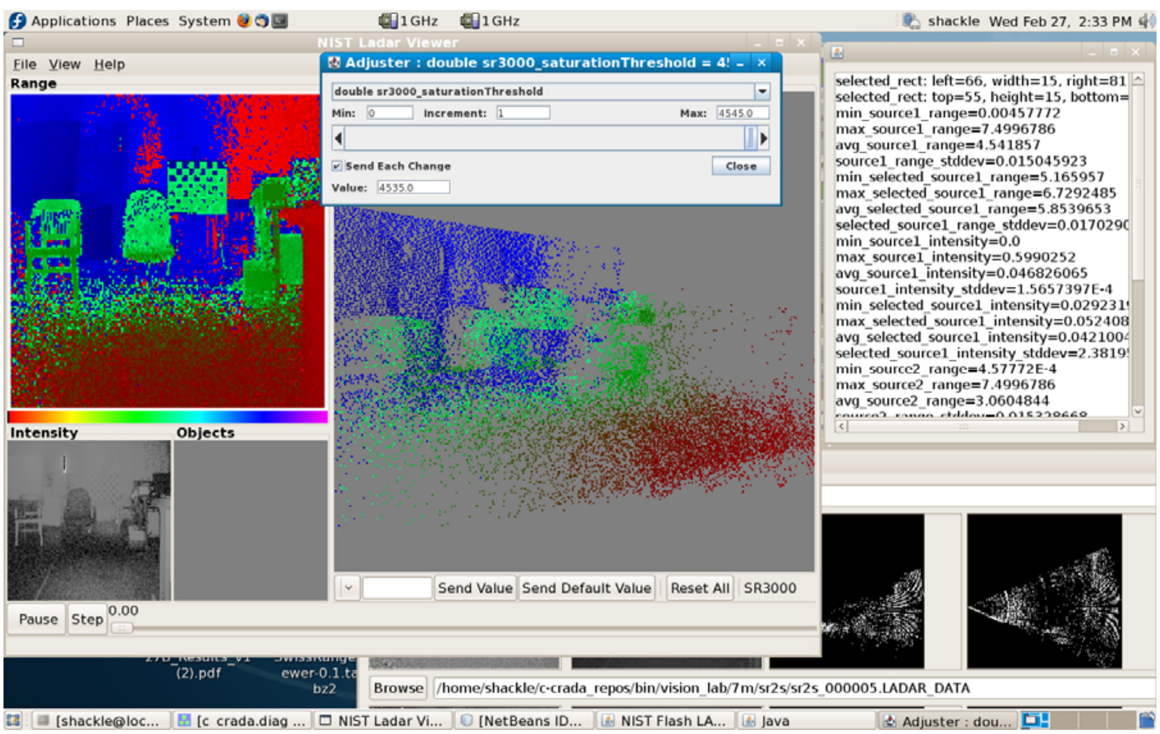
5.5 m to reflector; no sensor threshold used, reflector at -0.5m height.



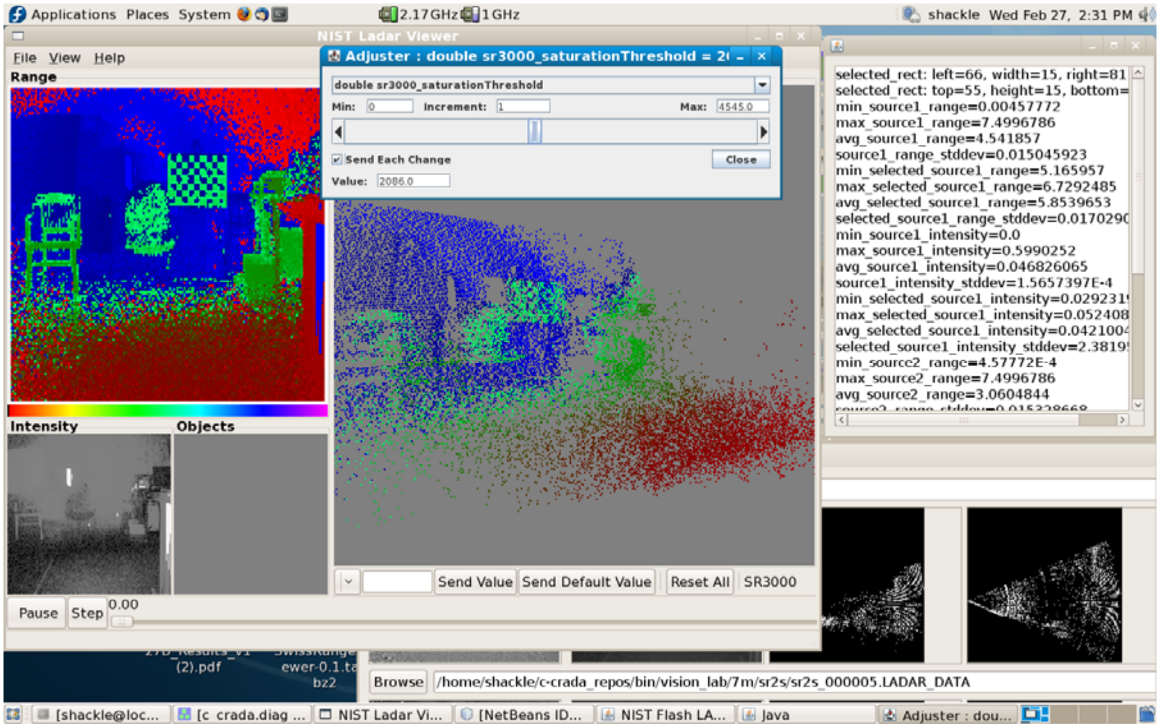
5.5 m to reflector; with sensor threshold used, reflector at -0.5m height.



6.4 m to reflector; no sensor threshold used, reflector at -0.5m height.



6.4 m to reflector; with sensor threshold used, reflector at -0.5m height.



6.4 m to reflector; with sensor threshold used, reflector at -0.5m height.