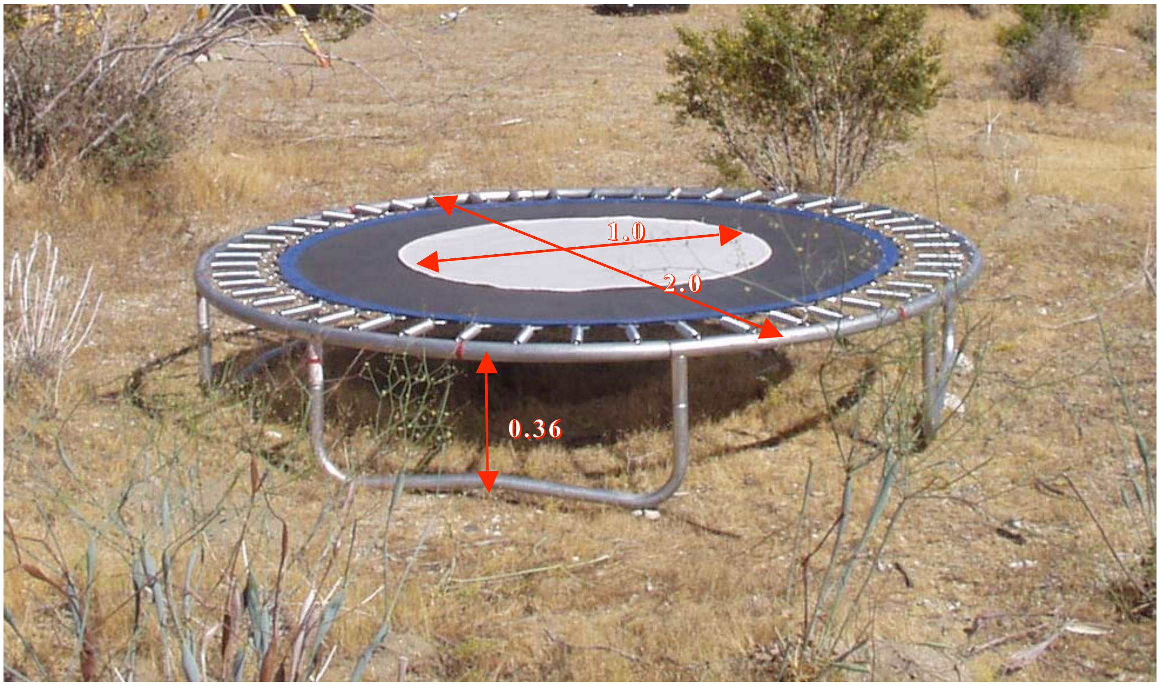
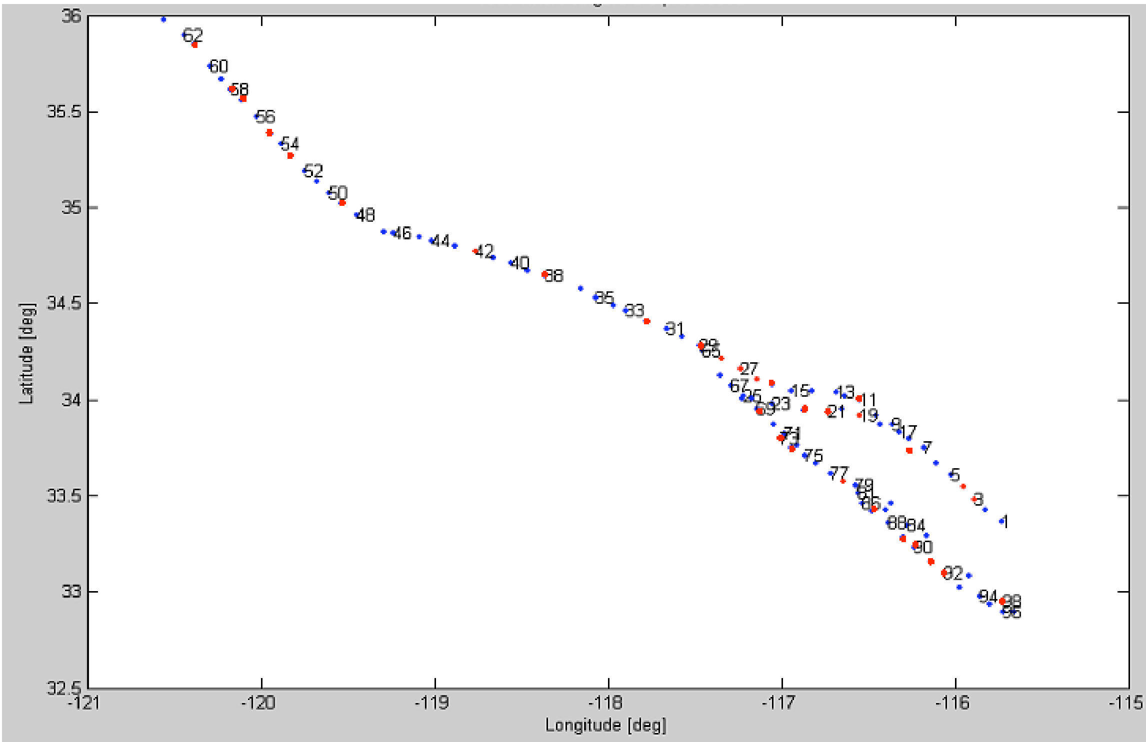
# Description of LiDAR Targets Used in the B4 Project

The picture below shows the target implementation used for the project, together with the target size parameters.




B4 LiDAR target implementation

The following figure shows the base station locations along the fault line (blue marks). LiDAR control targets were typically placed close to base stations during the survey, the base stations where targets were placed are shown in red. Typically a cluster of 3-4 targets was placed at each location with some separation between them to provide even coverage, normally within 100 m distance of the base station. Due to rugged terrain and fast operation requirements the targets were not leveled for this survey.



Base stations along fault line and LiDAR target locations.

**GSP-surveying of the targets**

Since the targets were not leveled for this survey, to determine the target position, 6 points around the target perimeter were GPS surveyed with 1 Hz frequency. The first point was surveyed for approximately 8 minutes, then the following 5 points for 5 minutes each.

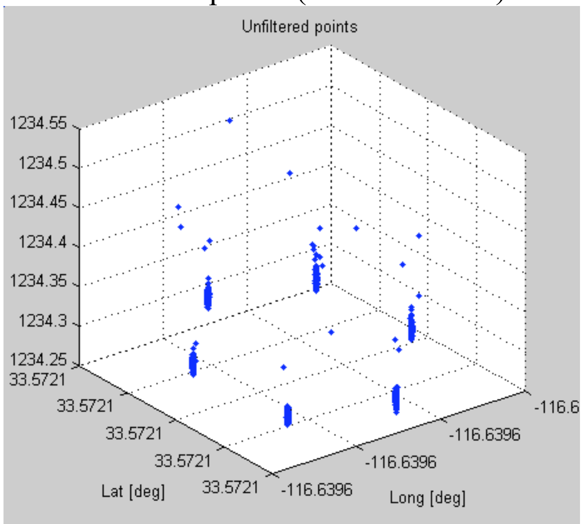
The GPS data was processed by the KARS software (Mader, 1992) in kinematic mode. Since the targets were always placed at most a few hundred meters from a base station, the baselines for the targets were usually very small, and therefore L1 phase solution was calculated, which typically resulted in less than 1 cm RMS values.

After the kinematic GPS processing, the following steps were performed to determine the target center coordinates:

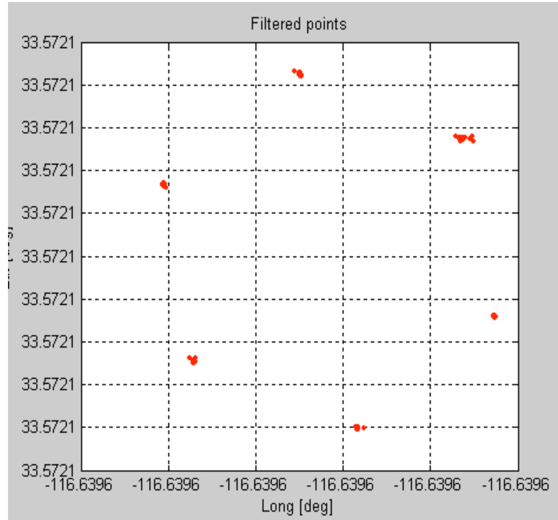
1) Epochs of GPS solution when GPS antenna was moved from one location on the target circle to the other, and outlier points are filtered from the points and six clusters are determined.
2) Six points are determined by averaging the points in each cluster separately.
3) Final target center coordinates are determined by averaging the six determined positions around the target perimeter.

An example of the processing steps is shown in the figures below.

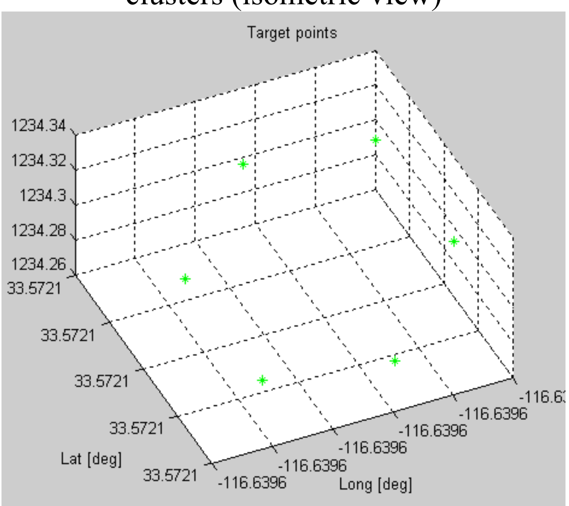
Result of kinematic GPS processing – unfiltered points (isometric view)



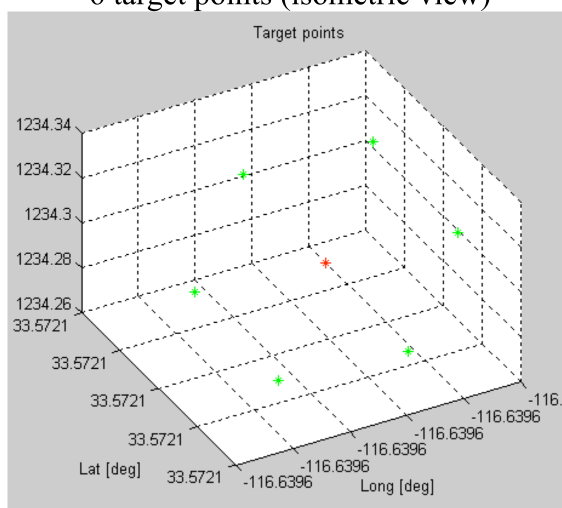

Filtered points, 6 clusters (top view)




6 determined target points after averaging clusters (isometric view)




Final target center position after averaging 6 target points (isometric view)




The surveyed target control coordinates are listed in the document: *control_metadata_febr_2007.xls*. The coordinates are in geographical coordinate system in WGS84.

**Target identification in LiDAR data**

The actual LiDAR point density was about 1.5-2.0 pts/$m^2$ in the B4 project, which provided for excellent vertical component analysis, while the horizontal accuracy could be checked only at a rather coarse level (the B4 targets were designed for a 4 pts/$m^2$ density). Despite of the smaller number of LiDAR points per target, in many cases the 2-

concentric-circle design of the target provided strong constraint on the possible horizontal position of the target, and in those cases the 3D position of the target was determined.

At the target position determination in LiDAR data, the following rules were applied:

3D target position was determined in the following cases:

- at least 3 points were found on the target and the scan line distance was not too large
- at least 3 points were found on the target and the scan line distance was large, but at least 1 point was an inner circle point
- at least 3 points were found on the target and the scan line distance was large, but all the points were inner circle points

Only elevation of the target was determined in the following cases:

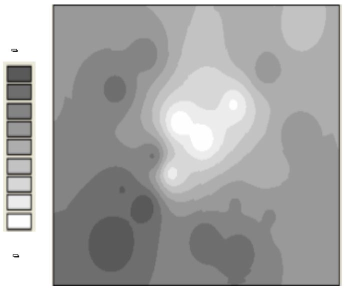
- two points were found on the target
- only one point was found on the target, but its elevation was about 30 cm higher than the ground points (30 cm is the target height)
- three or more points were found on the target, but the scan line distance was large and no inner circle points were found on the target

Target position was not determined in the following cases:

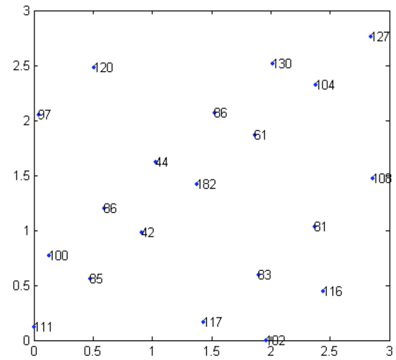
- No points in the 3m by 3m window around the GPS surveyed target position were found higher than the ground
- A few points in the window were found higher than the ground, however the elevation difference was significantly different from the 30 cm target height

An example for the target position determination in LiDAR data for a case when 3D position is determined is shown below. The left figures show a 3-by-3 m area containing the target in both elevation and intensity data. Both figures are interpolated only for illustration purposes; for the target identification in LiDAR data, the original LiDAR points were used without interpolation. The figures in the middle show the LiDAR points with their intensity values and the identified target points (5 points shown in green that fell on the outside black target ring and 1 point shown in red that fell in the white inner circle). The figure on the right shows the final identified target position – as a results of the Hough transform-based algorithm -with light blue color. The yellow patch – as the result of the target identification algorithm - shows all the possible locations of the target circle center, and the corresponding circle positions are shown in dark blue. More details about the target identification algorithm used can be found in (Csanyi and Toth, 2007).

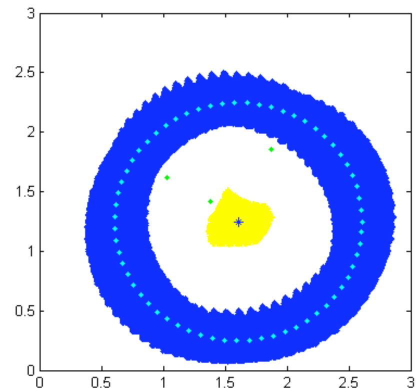
The accuracy of the determined target positions in LiDAR data largely depend on the LiDAR point density and point distribution and is provided by the target identification algorithm. At the point density and distribution of the B4 project, the typically achieved horizontal accuracy (when horizontal position could be determined) was about 10-20 cm (1 sigma standard deviation) and about 4 cm vertical standard deviation.



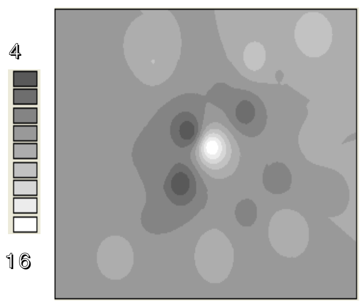
target in elevation data



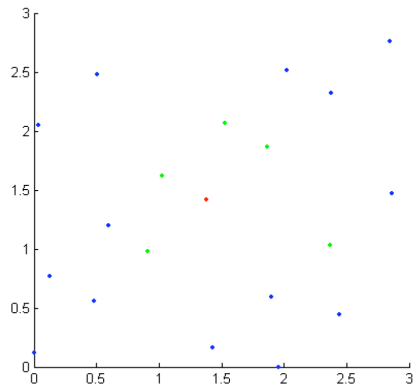
LiDAR points with intensity values



identified target position




target in intensity data



LiDAR points on target

**Comparative analysis of the GPS-surveyed and LiDAR-determined target positions**

The table below (can also be found in *control_summary_febr_2007.xls*) shows different statistics computed from the found errors at the target locations for each 50 km fault segment. The errors were computed by deducting the GPS-surveyed target coordinates from the LiDAR determined target coordinates. The table shows the mean error, the RMSE (root mean square error), and the maximum error in the North, East UTM coordinates and height, as calculated from all targets measured at each fault segment. The table also lists the number of targets for which 3-dimensional position was determined in the LiDAR data, and the number of targets where height was determined.

| | Mean error [m] | | | RMSE [m] | | | Max error [m] | | | No. of targets | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Segment** | **E** | **N** | **height** | **E** | **N** | **height** | **E** | **N** | **height** | **XYZ** | **Z** |
| **SAF11** | 0.05 | -0.13 | 0.04 | 0.16 | 0.15 | 0.05 | 0.29 | 0.2 | 0.08 | 4 | 8 |
| **SAF10** | -0.14 | -0.4 | 0.01 | 0.14 | 0.40 | 0.03 | 0.14 | 0.4 | 0.05 | 1 | 5 |
| **SAF09** | -0.14 | -0.43 | -0.01 | 0.14 | 0.43 | 0.03 | 0.14 | 0.43 | 0.05 | 1 | 3 |
| **SAF08** | | | 0.01 | | | 0.01 | | | 0.01 | | 1 |
| **SAF07** | -0.01 | -0.17 | 0.00 | 0.01 | 0.17 | 0.02 | 0.01 | 0.17 | 0.04 | 1 | 3 |
| **SAF06** | 0.06 | -0.25 | -0.01 | 0.06 | 0.25 | 0.00 | 0.06 | 0.25 | 0.00 | 1 | 2 |
| **SAF05** | 0.09 | -0.2 | 0.12 | 0.17 | 0.22 | 0.13 | 0.24 | 0.30 | 0.18 | 3 | 4 |
| **SAF04** | -0.06 | -0.27 | -0.03 | 0.07 | 0.32 | 0.04 | 0.10 | 0.45 | 0.06 | 2 | 3 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **SAF03** | -0.08 | -0.05 | 0.17 | 0.08 | 0.08 | 0.18 | 0.11 | 0.11 | 0.26 | 2 | 5 |
| **SAF02** | | | | | | | | | | | |
| **SAF01** | 0.15 | -0.17 | 0.00 | 0.16 | 0.18 | 0.03 | 0.21 | 0.23 | 0.04 | 3 | 6 |
| **SJF01** | 0.05 | -0.26 | 0.16 | 0.07 | 0.28 | 0.16 | 0.10 | 0.36 | 0.19 | 2 | 4 |
| **SJF02** | -0.04 | -0.31 | -0.02 | 0.09 | 0.34 | 0.06 | 0.14 | 0.50 | 0.09 | 3 | 5 |
| **SJF03** | | | | | | | | | | | |
| **SJF04** | | | | | | | | | | | |
| **SJF05** | -0.08 | -0.22 | -0.02 | 0.11 | 0.31 | 0.06 | 0.16 | 0.46 | 0.12 | 9 | 12 |
| **SJF06** | -0.05 | -0.14 | -0.01 | 0.13 | 0.17 | 0.03 | 0.21 | 0.27 | 0.06 | 4 | 5 |
| **SJF07** | | | | | | | | | | | |
| **Banning1** | 0.17 | -0.05 | -0.08 | 0.17 | 0.05 | 0.09 | 0.17 | 0.05 | 0.13 | 1 | 4 |
| **Ban. 2,3,4** | -0.01 | -0.23 | 0.00 | 0.13 | 0.39 | 0.11 | 0.2 | 0.62 | 0.18 | 9 | 12 |
| **Mean** | **0.00** | **-0.22** | **0.02** | **0.11** | **0.25** | **0.06** | **0.29** | **0.46** | **0.26** | **46** | **83** |

As the table shows, 83 targets were successfully identified in the LiDAR data, and despite of the lower LiDAR point density than originally planned the two-concentric-circle target design facilitated the determination of the 3-dimensional target positions for 46, more than half of the targets.

As the table illustrates, the overall accuracy of the measured LiDAR strips was found to meet the requirements. The accuracy analysis was performed according to the American Society for Photogrammetry and Remote Sensing (ASPRS) LiDAR Guidelines 2004 (Maune, 2007). The assessed vertical accuracy of the LiDAR dataset at a 95% confidence level is: Accuracy$_z$ = 0.152 m. More details can be found in the final report at <ref>.

## References

Csanyi, N. and C. Toth (2007). Improvement of LiDAR Data Accuracy Using LiDAR-Specific Ground Targets, Photogrammetric Engineering & Remote Sensing, Vol. 73, No. 5.

Mader, G.L., 1(992). Rapid Static and Kinematic Global Positioning System Solutions Using the Ambiguity Function Technique, Journal of Geophysical Research, 97, 3271-3283.

Maune, D. (2007). Digital Elevation Model Technologies and Applications: The DEM Users Manual, The American Society for Photogrammetry and Remote Sensing.

Toth, C., D. Brzezinska, N. Csanyi, E. Paska, N. Yastikli, 2007. LiDAR Mapping Supporting Earthquake Research of the San Andreas Fault, ASPRS Annual Conference, Tampa, FL, May 7-11, CD-ROM.

Web pointers:
control_metadata_febr_2007.xls
control_summary_febr_2007.xls
NSF Final Report