Leica ScanStation:: Calibration and QA

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1. Summary

Leica Geosystems, in creating the Leica Scanstation family of products, has designed and conducted a number of steps to ensure the accuracy and performance specifications are met. This document summarizes some of the steps taken in service and in manufacturing in order to ensure accuracy specifications are met, using the Leica Scanstation C10 as an example. Similar steps have been applied to the creation of the Scanstation, the Scanstation 2, and the HDS3000. Leica is in the business of selling survey instruments and the quality of the data produced by these instruments is central to the value the company delivers to the customers.

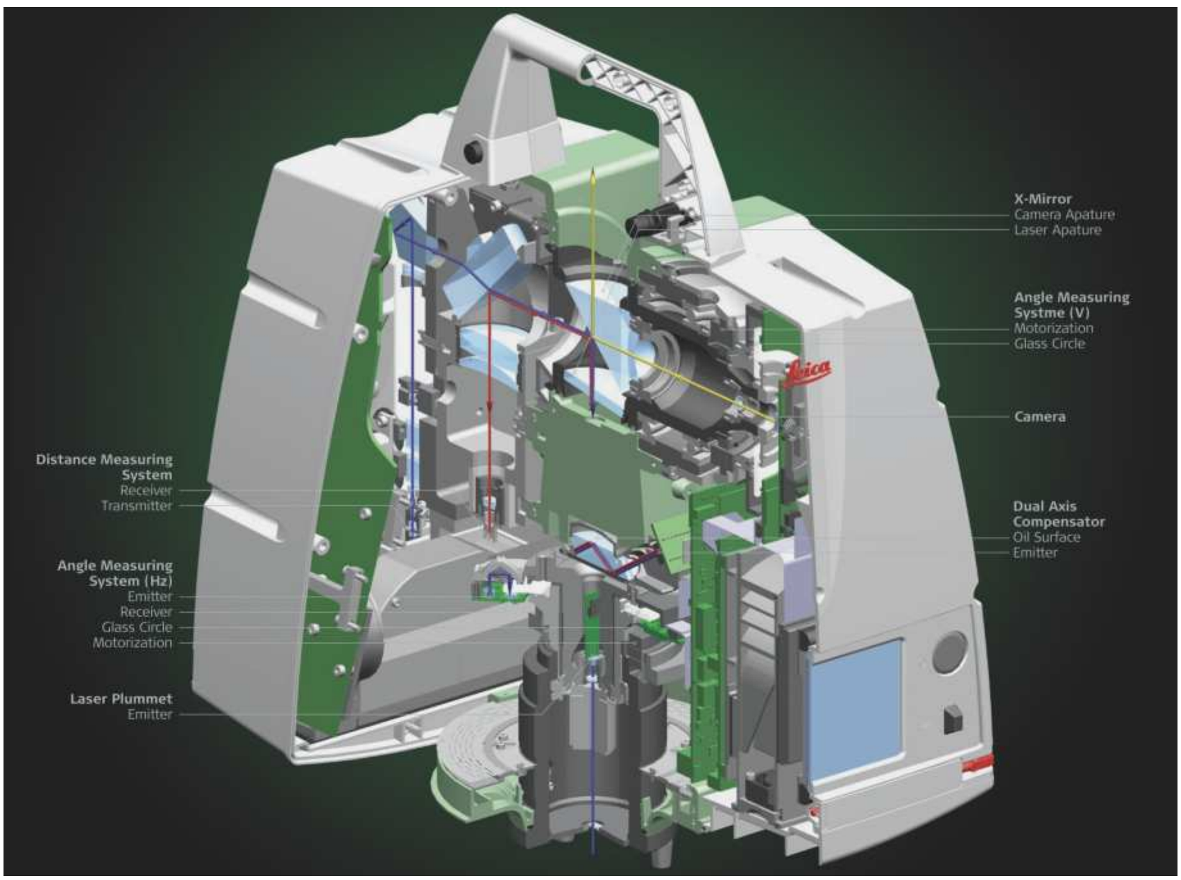

Figure 1: A cut away view of the Leica ScanStation C10, showing major components.

Every Scanstation produced and serviced by Leica Geosystems goes through the key steps described in this document, with records archived at each step. We will briefly discuss system preparation, calibration, quality assurance, and discuss some of the design validation testing performed on the C10.

2. Calibration

When a laser scanner of any sort is assembled, care has to be taken about the order in which the parts are applied, the adhesives used, and the torque of each screw. The C10 has each of these specified and technicians use specially calibrated torque wrenches during assembly. The fine parameters of the scanner after assembly, such as the tilt of the elevation axis relative to the azimuth (standing) axis, are not known. In addition, residual stresses will exist between parts and must be relieved.

For this reason, each scanner after assembly is environmentally stressed, visiting the specified temperature ranges and beyond, over a period of several days in environmental chambers. In addition, the scanner is operated inside an environmental chamber before calibration over the operating range to verify operation.

Angular and Range Calibration

Once the scanner is prepared for calibration, it is placed inside a calibration chamber as shown in Figure 2. The door is sealed and the calibration process starts. The chamber itself has a variety of optical quality double paned windows through which the scanner can observe laser tracker targets and scanner targets.

Figure 2: Inside view of Leica Geosystems Calibration chamber. From the front window the laser tracker reference system can be seen. The laser scanner mounts into the hard mount pedestal and the door of the chamber is sealed.

Figure 3: View of the calibration floor in Widnau, Switzerland. Three calibration chambers are visible in the photograph, as is the reference laser tracker. Three calibration chambers are also installed in San Ramon, California, USA.

Figure 4: Operator view of the calibration chambers in Widnau. Thermal control units are connected via insulated air ducts to each scanner calibration chamber, allowing each chamber to be set at independent temperatures.

The scanner is then calibration at various temperatures, by either heating or cooling the scanner calibration temperature, letting the unit settle, and then by running the appropriate calibration procedure.

At each temperature, the scanner laser parameters are determined as follows. The scanner measures the angular location of a large series of tracker balls, which are in turn measured by the Leica laser tracker.

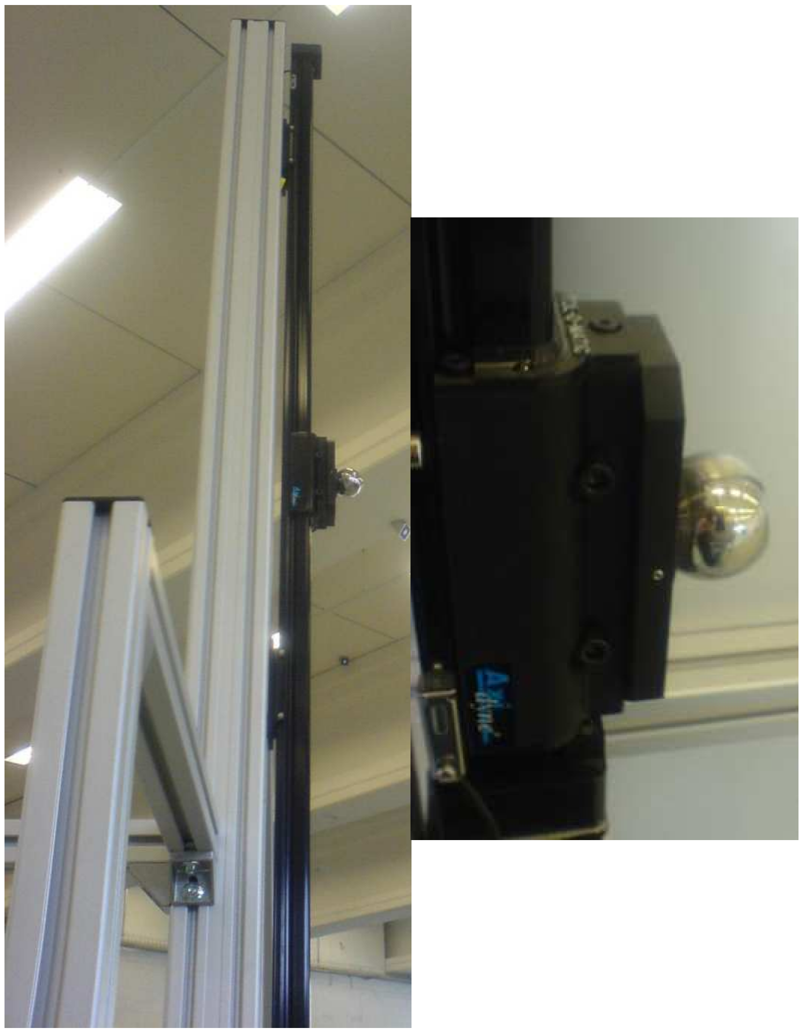

Figure 5: Motorized stage (left) with Leica tracker ball attached to magnetic mount (right, close up). The motorized stage allows the tracker ball to be moved and the target used many times in one calibration. With each scanner measurement, the position of the tracker ball is measured by the laser tracker to a high accuracy; the tracker measures the tracker ball's internal corner reflector. The scanner measures the outside surface.

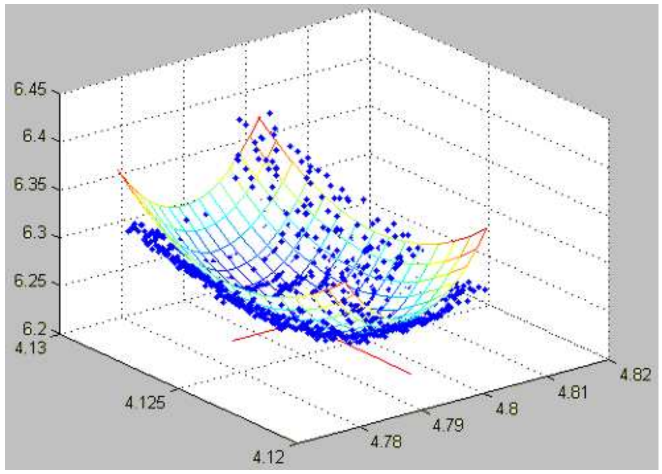

Figure 6: Example fit of a laser scanner scan of a tracker ball. Plot is generated by MATLAB and algorithm is by the author. Calibration process is run by a MATLAB script.

Both the pose of the scanner and the scanner parameters are inferred by performing a bundle adjustment on the measurement set, again, algorithm by the author. Targets failing to fit inside an acceptable tolerance band require operator intervention and generally have to be re-shot by the technicians. In addition, the behavior of the tilt sensor, the range scale and range offset are measured by comparing the scanner measurements against both the laser tracker and a calibrated Leica total station.

At each temperature the scanner parameters are measured. These parameters are loaded to scanner and so when the scanner is run, the run time parameters are derived from these single temperature observations. Typically parameters change as much a 1" per degree C, though some have much greater stability.

Tilt Calibration

The tilt sensor mounted in the Leica C10 is the same unit used in standard Leica total stations. The mounting is extremely stable but the mounting position is unknown and the sensor itself has gain and cross behaviors which must be identified.

A separate calibration stand exists for the tilt sensor, shown in Figure 7. The tilt sensor room temperature behavior is identified on the this tilt calibration stand. The scanner is placed in the stand and the laser beam pointed at a specially modified reference unit, shown to the left of the scanner in the figure. The reference unit is mounted with a camera able to view the laser beam; this allows the software to tie the two coordinate systems (scanner, and reference) together. The tilt table can then perform a series of motions and compare the two sensors outputs and in a straight forward way determine the adjustment parameters of the Scan Station C10. In addition, if any tilt sensor is out of specifications, it will be rejected on this stand. Temperature behavior of the tilt sensor is determined in the environmental chamber and again, units with out of specified behavior are identified and removed.

Figure 7: Tilt calibration station for the Leica ScanStation C10.

Camera Calibration

The third calibration fixture is for calibrating the internal camera. The internal camera can take pictures over the entire field of view of the scanner, and these images are assembled into mosaics which are then applied to the point clouds. Hence the objective of the camera calibration is to ensure a good match between measured LIDAR points and pixels on the camera. For this reason, the camera calibration is performed after LIDAR calibration.

A special set of targets (see Figure 8) has been created to calibrate the camera. These targets are white disks on a black background, and are automatically located by the scanner and by the camera. The camera will take photographs of these targets from many different positions, both from the front and from the back. The calibration control software, again in MATLAB and C++, identifies the target centers both in the scans and in the images, and solves for the matching correspondences, as shown in Figure 9. Once a large set of corresponding matches is assembled, a bundle adjustment again is run to solve for the camera parameters. Parameters include the mounting of the camera inside the scanner as well as the distortion to the image caused by the lenses. All fitting, estimation, and data collection algorithms developed by the author.

Figure 8: A view of the camera calibration stand. Two sets of targets are placed in front of the scanner and are both imaged and scanned.

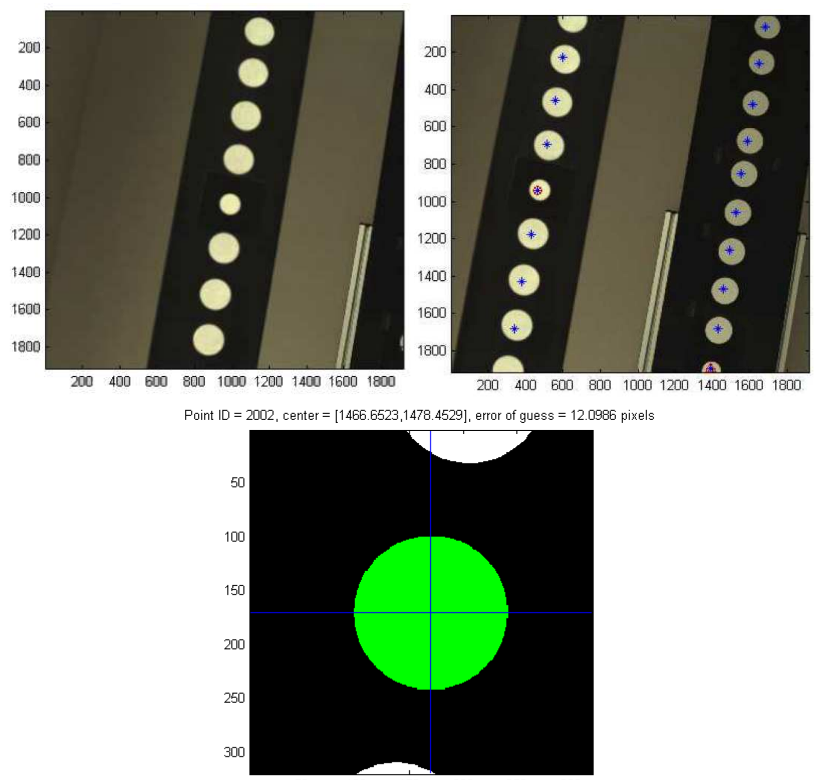

Figure 9: Images from a Leica C10 scanner as viewed in MATLAB. MATLAB has drawn on the image guess locations of the target centers using an approximate camera model. These

guess locations are used to solve the target correspondence problem, and are generally off by a gross amount such as 15 or 20 pixels. This is close enough to prepare the matches.

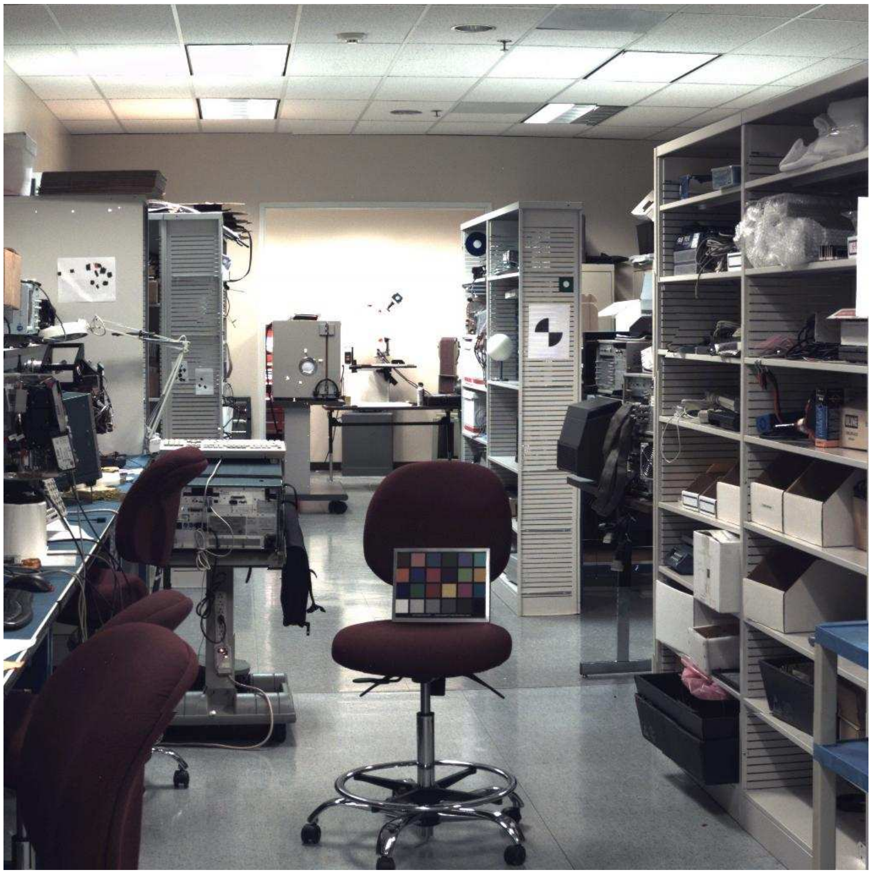

Figure 10: An image mosaic from a Leica C10 scanner showing the hardware development laboratory in San Ramon, California. The image is a mosaic of 16 difference C10 images; the boundaries are hexagon shaped tiles but are difficult to see.

The calibration procedures are designed to ensure and do ensure that each Leica ScanStation product produces reliable and accurate results within acceptable ranges of reliability and within design parameters.

3. Quality Assurance

The process of calibration determines the internal parameters of the scanner and collects enough redundant data to perform an initial assessment of the quality of the calibration. In addition, Leica performs a series of quality checks on each ScanStation C10. Two of those steps, an accuracy test and a camera fitting test, are described in this section. There are other tests testing other parameters of the scanner as well.

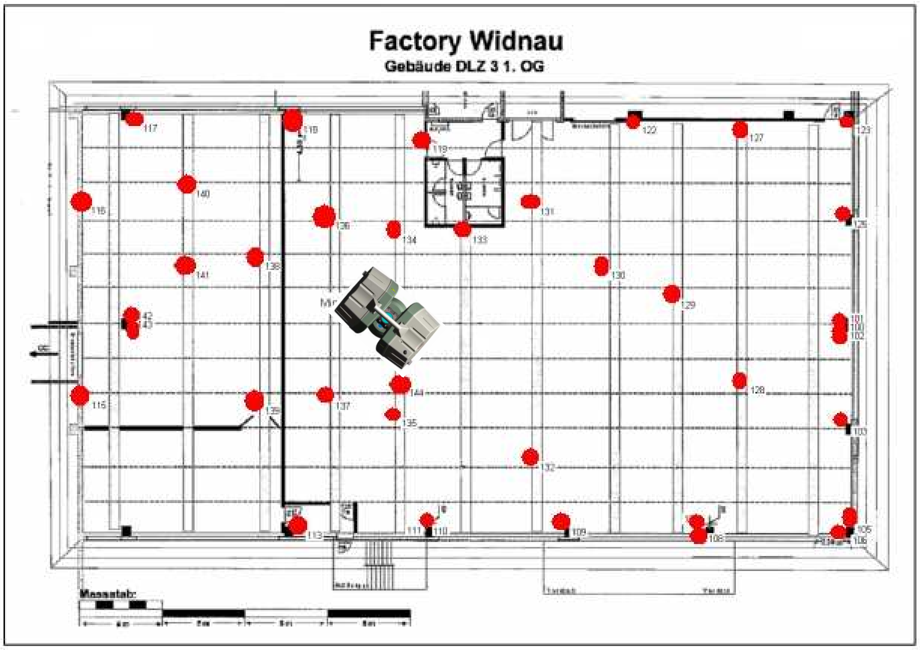

Figure 11: The distribution of targets shown in this figure. The targets themselves are up to 30 meters away from the scanner, so the position of the scanner is not shown to scale. Targets are HDS laser scanner targets and are surveyed by total station.

For the angle and range QA, the scanner is placed on a pedestal and automatically acquires approximately 46 targets, in both faces. These target locations are checked against survey and against each other.

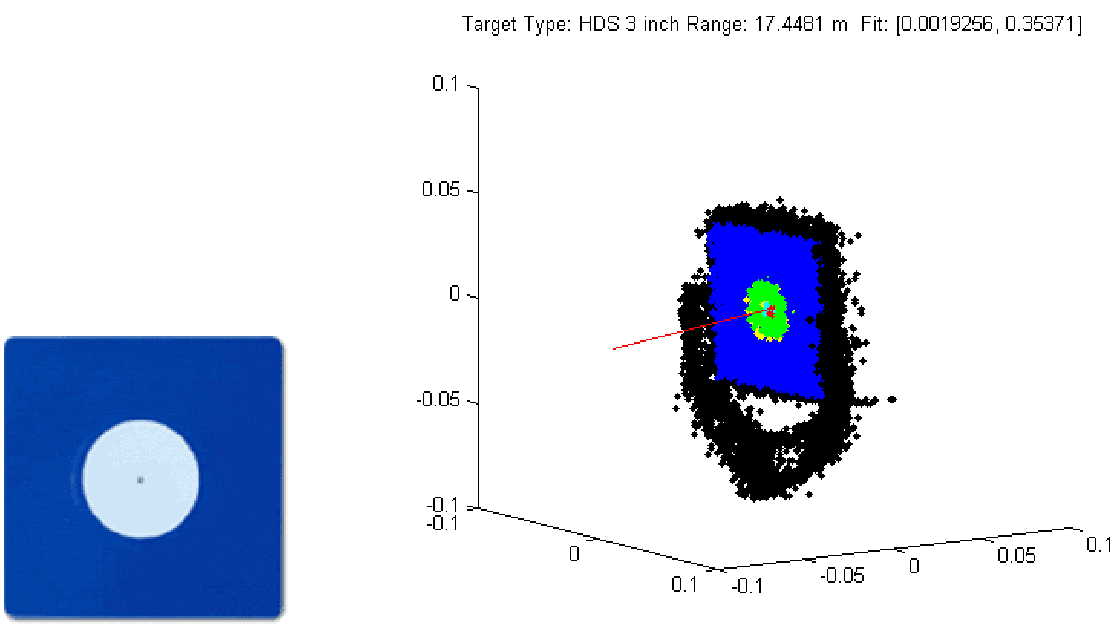

Figure 12: HDS targets as seen by the camera and by the author's fitting algorithm, used by the service and production floors as well as by the scanner.

The targets are surveyed by total station to better than 1 mm (generally 0.5 mm) accuracy. The scanner has a similar ability to locate the HDS targets. The accuracy specifications are estimated and compared against specifications. Scanners are not allowed in customer hands until it meets or exceeds the accuracy specifications. Clearly after the extensive temperature calibration of the scanner previously described, the yield in this process step is high.

The camera is also checked by scanning and taking pictures of the same targets. The image centers and the scanning centers are then compared. Again, this quality verification process has a very high yield but serves to ensure Leica equipment is accurate. Figure 13 shows a resulting match image for a target.

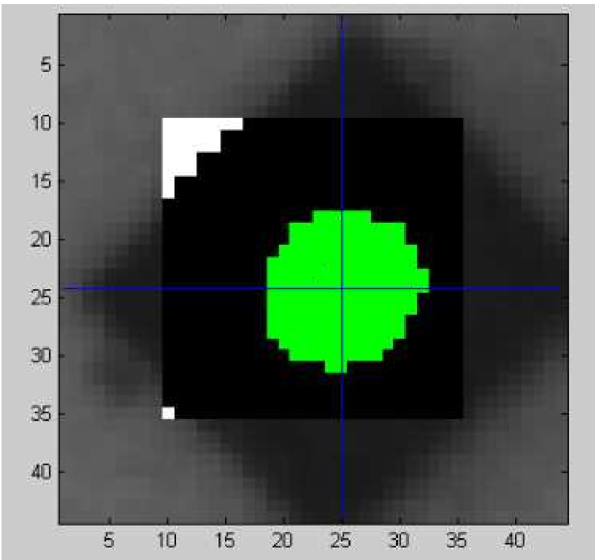

Figure 13: A match between an image center and a LIDAR determined center. The scanner locates the target, and then the camera image is taken. The image is turned into a black and white image, and put through a center extraction algorithm to determine the center. Pixels which belong to the white disk at the target center are colored green by the algorithm, and the estimated image center is marked by the cross hairs.

These QA procedures are designed to ensure and do ensure that each Leica ScanStation product produces reliable and accurate results within acceptable ranges of reliability and within design parameters

4. Conclusion

Leica Geosystems is in the business of selling measuring tools and takes great care to ensure that every product that is shipped meets or exceeds our specifications. Over the last decade, Leica Geosystems has shipped hundreds and hundreds of laser scanners following the processes described in this document. Scanners are accurately observed over temperature using traceable reference instruments. The results are checked for self consistency, and if acceptable, are double checked against standard survey equipment in a set of quality assurance tests. Scanners in service receive the same treatment. In short, Leica: when it has to be right.