Tilt Compensation for Laser Scanners

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1. Summary

Laser scanners from Leica Geosystems come equipped with a device called a tilt compensator. While using a laser scanner with a tilt compensator, the operator is required to approximately level the scanner using small screws in the mount. Although this process takes only a few seconds for someone used to leveling the instrument, one swiftly starts to question what a tilt compensator is, what is it doing, and most importantly, what possible benefit does such a device deliver to the operator. This paper strives to answer these questions for the operator who might be tempted to skip the step of leveling and would like to know when that is acceptable.

Figure 1: The Leica Scanstation P40, a survey grade laser scanner, with integrated tilt sensor, mounted on a surveying tribach. The tribach has three little wheels to allow fine leveling.

The benefit of the tilt compensator in a Leica scanner manifests in both the data collected from one position and when attempting to "register", or find the relative position and orientation, of data collected from two different positions. These benefits can only be realized if the accuracy of the tilt readings from the senor is well under the angular accuracy of the instrument in which it is a part, because the readings of the sensor are used to "compensate", that is, adjust, continuously the measurements from the instrument. Otherwise the compensation would make the data worse. The accuracy of the tilt sensor hence serves as a bell weather to the angular accuracy of the instrument as a whole, at least, in the estimation of the manufacturer.

2. Tilt Compensation

What is tilt compensation? Inside a Leica Scanstation, there is small glass bowl filled with a special oil, forming an artificial horizon. A light pattern is projected into the oil, bounced off the surface, and ultimate imaged on a camera. Images are taken continuously as the scanner is operated; these images are processed and the direction of gravity determined several times a second to a high level of accuracy. The direction of gravity is used to rotate the data measured by the scanner so that the upright axis is aligned with gravity. This rotation of the data is what is meant by the word "compensation", the "tilt" part is a colloquial reference to determining the direction of gravity.

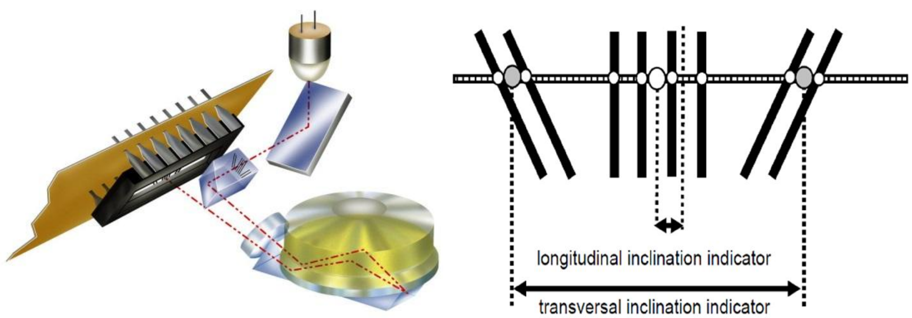


Figure 1: Leica tilt sensors are also based on using a small line camera, much like the angular encoders. Much like the angular encoders, their sensitivity is very high, less than 1 arc second.

The inclusion of tilt compensation is in fact the single distinguishing characteristic of a laser scanner with the Scanstation moniker. The first Leica laser scanner to bear this name was the "Leica Scanstation", released in 2006. The same unit without a tilt compensator is called the HDS3000, released in 2004. Tilt compensation is only practical with the use of highly accurate tilt sensors, which have long been a part of surveying instruments. As a consequence, instruments in the pre-Leica days, such as the Cyrax 2400 and the Cyrax 2500, did not have tilt compensation.

The fact that the tilt sensor, taken from Leica's highest accuracy surveying total stations, is the genesis of the entire Scanstation product line gives one a sense of how important it is considered internally, to Leica. As a feature, it suffers from what is known idiomatically in Switzerland as the "Cooking with Water" problem. No one explains why it is so important; everyone just knows that it is. The confused expression of someone being told about the tilt compensator likely is not even noticed. Outside of the surveying community, the terms "tilt compensation", or "dual axis compensation", lights up no light bulbs. Describing its performance, say, for the P-series, as being 1.5 arc seconds accurate, has the distinctive ring of technobabble, something spoken in a laboratory with little to no relevance in the field.

In fact, tilt compensation is important for practical reasons that happen only outside the laboratory. In the laboratory, you do not have to move the scanner around. In the laboratory, you can mount the scanner to specially constructed mounts which are so stable as to be considered fixed. In the real world, you have to put the instrument on a tripod on the ground to collect data. Then you have to move it. The tripod is not infinitely strong because a big, strong tripod is very inconvenient to move around. And it turns out, that putting targets up on tall things often a risky endeavor that is not always possible to do, because tall things might not be available or accessible. Even when "tall things" are available, tall things can be flimsy, and this is a problem. The tilt compensator is all about these practical realities of collecting data in field.

3. Single Position Benefits of Tilt Compensation

Why is a tilt compensator so important? You are out at a job site, it is -10 C, and the instrument wants you to twiddle some little knobs on the tribach to get it approximately leveled. A surveyor does this without a second thought. Personally, I have some thoughts, particularly about doing this kind of fine adjustment while I am wearing gloves, because at -10 or -20, I am wearing gloves, and thick ones at that. But I will adjust and activate the tilt compensator because I am out in the cold and mess because I need to get a measurement. Part of getting that measurement is controlling the uncertainty of this measurement. Let's consider the case of measuring the distance between two buildings.

The laser scanner would be placed somewhere near these two buildings and the scene would be scanned. In the office, one would either select points, accepting the random error due to range noise in the uncertainty, or perhaps solve for particular geometric features of the buildings such as walls or corners using many points, reducing the impact of range noise.

Let's compute the uncertainty in the case with extracted corners, using the systematic error bounds given in the P-series scanner data sheet. Given each corner is, say, 35 meters away from the scanner, then the lateral angular uncertainty for data produced by a Leica P-series scanner on each corner is 8 arc seconds * (4.85e-6 radians/arc second) * 35 meters = 1.4 millimeters, plus or minus. The range uncertainty is 35 meters * 10 ppm + 1.2 mm = 1.5 millimeters, about the same. This represents a plus or minus figure, so when comparing two measurements, one could have an error off to one side, the other measurement, on the complete opposite side. If we form a box with depth is 3 mm and whose sides are 2.8 mm vertically and horizontally, then we have a worst case error of the diagonal length through the box, given by $\text{sqrt}(2.8^2 + 2.8^2 + 3^2) = 5$ mm, between two measurements. That is about ¼ of an inch, not plus or minus, as I doubled sides.

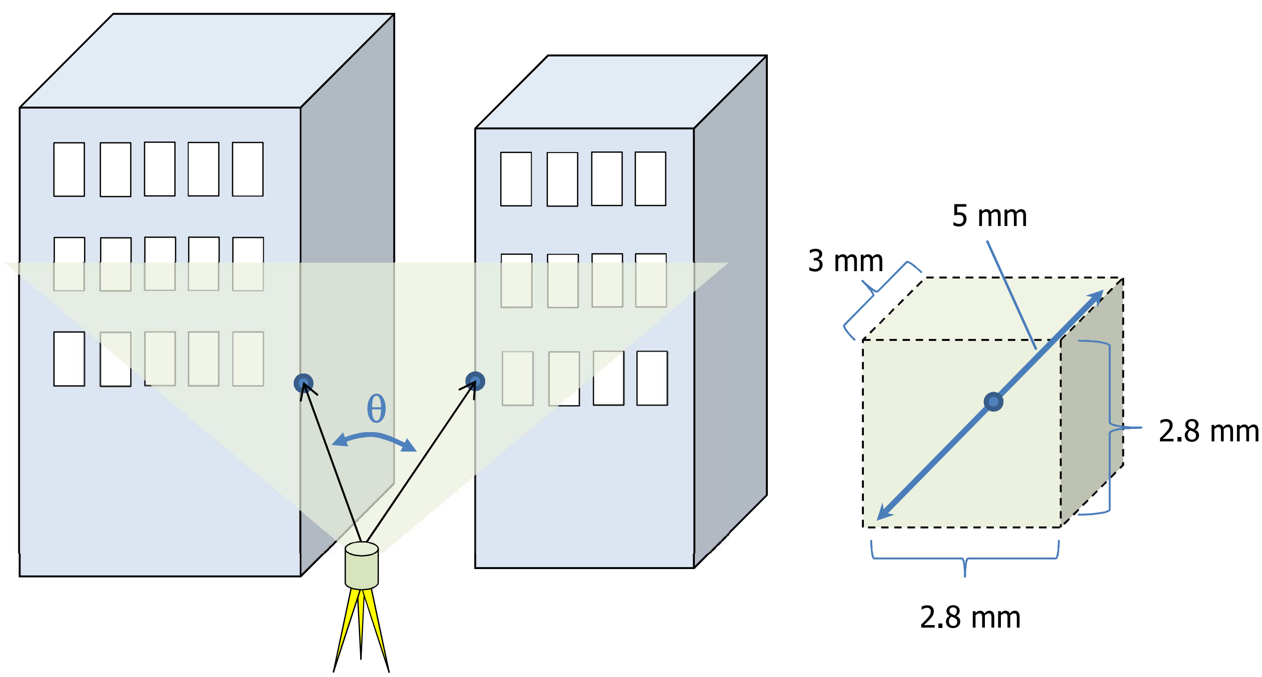


Figure 2: Measuring the space between two buildings. The diagonal worst case error is swiftly computed from the specifications and the measurement situation.

Nowhere in this calculation did the accuracy of the tilt compensator enter. The calculation assumes that the tilt compensator is active, so ignores the fact that the laser scanner takes some seconds perhaps minutes to collect the data displayed all at once in the office, after the fashion of a cooking show, where the baking and simmering takes no time at all. If you are the one having to be out in the -15 weather taking the data, you might not feel that way, blowing on your hands and hopefully NOT stamping your feet, but that is not the guy in the office's problem. You cannot even tell how long it took to collect the data when looking at the point cloud. That information is missing in the data set. If knowing when any particular point was collected is somehow important, you are in trouble because it is not available.

Figure 3: Leica surveying tripods are carefully engineered, but are not infinitely stiff. Neither is the ground on which they are placed, in the real world. Notice the color is bright, which makes it easy to spot but also more subtly reflects instead of absorbs sunlight, instead of, say, black, and also notice the little foot pads at each tripod foot – you step on those to firmly set the tripod. No stomping your feet.

The unfortunate reality is that the points that comprise the derived location of the corner on the left was taken at a different times, separated by perhaps many seconds, perhaps minutes, than the corner on the building on the right. Because the observations were made at different times, the scanner was not necessarily at exactly the same position and orientation between these different times. But wait, you would naturally object, the scanner was just sitting on the tripod the entire time. No one touched it.

With a reasonable tripod one could argue that the center of the scanner did not move any significant amount, significant being judged by the desired accuracy (say, ¼", or 6 mm). If it moved even a fraction of this the operator has a chance of noticing and re-taking the data. We should qualify the world fraction to mean a good fraction. Motions of less than a millimeter over the course of a minute are not so easy to discern in the freezing cold, clutching your coffee and NOT stomping your feet. The scanner center did not move significantly, and this propagates exactly as is to the error of the building corners. As long as the operator is reasonably careful you can reasonably conclude that you do not have to worry about the center of the scanner moving.

Notice, however, the calculation on the uncertainty bound also contained the angular accuracy of the measurement, and it was described in this enormously tiny unit called an arc second. At first glance the unit of arc second seems completely out of proportion to the interesting accuracy levels of some fraction of an inch, or some few millimeters. But then you can see that angular error is multiplied by range, which is fine if the range is just a few yards. But of course, it is not a few yards or a few meters. We do not pick these things; the human-scaled spaces involve tens if not hundreds of meters. This distance forms a cruel lever which amplifies even the smallest errors at the fulcrum, that is, at the scanner.

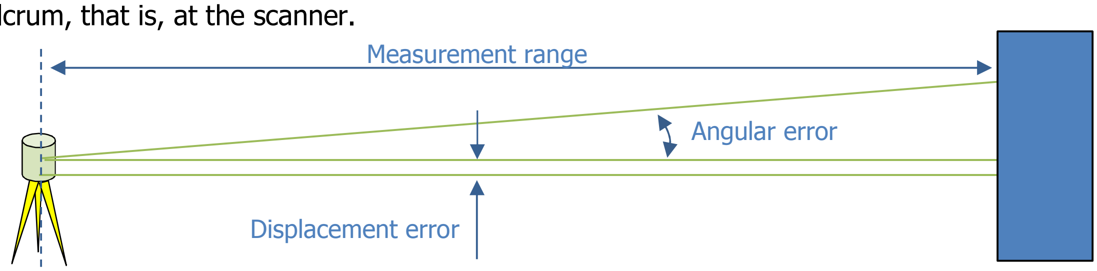


Figure 4: Bounding the accuracy of a point at a range of more than a few meters forces a brutal limit on the angular error of a point through the cruel lever of range, unlike displacement error.

If you start to calculate how much the tripod has to move to cause a significant angular error, the word "microns" starts to enter your vocabulary. Microns are small units, used to describe things like the diameter of human hairs (50 to 150, depending on how fine your hair is). Microns are a bad thing to be concerned about when scanning a couple of buildings in the cold and mess; they are not on a human scale and unaided the scanner operator has no chance to detect that the scanner is perhaps slowly sinking into the frozen ground, because the tripod foot is not freezing, having just come out of the trunk of the car. Perhaps the idea of waiting at the job site for a few hours before collecting data to let everything thermally stabilize did not occur to the operator.

The basic problem is that angular stability requirements needed to take useful measurements over basically normal ranges are so tight that it is not practical for the operator to be responsible for them by somehow rooting a kind of super strong and stiff tripod to the ground. Fortunately, in our story, the operator activated the tilt compensator. The measurements taken at the end of the scan as compared to the beginning of the scan are compensated with respect to gravity to an accuracy of 1.5", which is so small that there is no reason to keep track of this error in the computation of uncertainty. The bound on the error is then 1.5*4.85e-6*35 meters = 0.25 millimeters. The error is perhaps a couple of (thick and coarse) hairs wide at 35 meters. The error has been reduced by the instrument to the point where you do not need to pay attention.

The accuracy of the tilt sensor is well inside the accuracy of the P40 because the readings form the tilt sensors are used to modify the scanner measurements while they are being made. Modifying the scan data with tilt measurements made at the same time is the only hope you have of correcting for real world tripods; a measurement before or after the scan data is collected temporally separated and can only provide a guess about what the tilt was at a different times.

We do not guess at Leica. Since the tilt sensor is used to compensate the scan data continuously, it is part of the angular error budget. This means accuracy of the data simply cannot be better than the tilt sensor, in fact, as it is only part of the error budget, the error better be a factor smaller than the brutal angular requirement. This is why literally decades of effort has gone into making tilt sensors with accuracy levels that seem unbelievably tight. The P40 tilt compensator can locate the direction of gravity to 1.5 arc seconds, which is 1.5 * 4.85e-6 radians = 7.275e-6 radians. What does that possibly mean? You can think of an angle as the size of something at a distance. For example, a US dime is 17.91 mm in diameter. There are 1609.34 meters in a mile. For the dime to subtend 1.5 arc seconds, it would have to be placed more than 1.5 miles away.

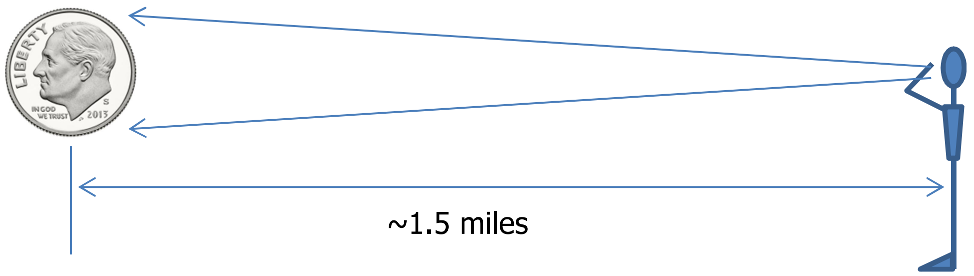


Figure 9: A dime placed 1.5 miles away subtends approximately 1.5 arc seconds. The requirements for angular accuracy are brutal. They are ultra-brutal for tilt compensation.

This notion of tilt compensation does not generally play out in the laboratory setting. Consider the National Institute of Standards and Technology (NIST) paper, "Laser Scanner Two Face Errors on Spherical Targets", which details a set of careful measurements of scanner accuracy that can be inferred from the measurement data without the need of specially calibrated reference targets. The tilt sensor does not enter into the analysis, because the first assumption is the scanner base is perfectly fixed. This is a fine assumption in the laboratory, because you can set the scanner up on an extremely strong and rigid mount.

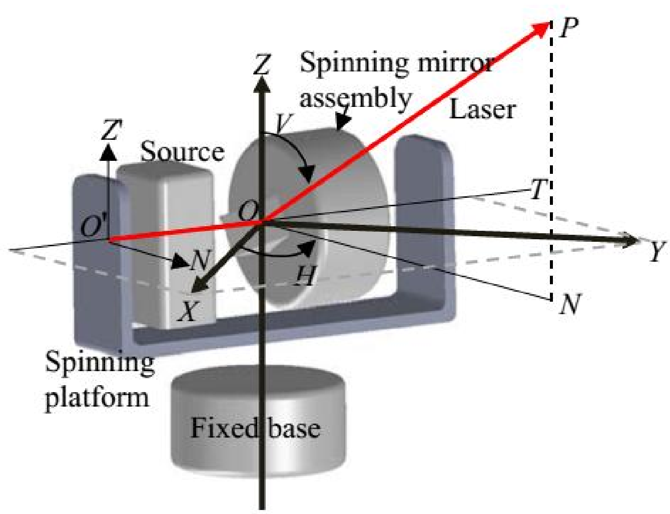


Figure 10: Figure underlying the mathematical model used in the NIST paper, borrowed from the paper. Notice the base of the scanner is labeled "Fixed".

The work from NIST is a scientific examination of the laser scanner accuracy; it is very important to limit or control the different factors that can influence the results. The P-series has this NIST test built into the scanner – it is called "Check and Adjust", and will determine the calibration errors (and correct for them) as shown in the paper albeit described in different terms. If you ever have the chance to visit Leica in Switzerland, you will find yourself tripping over similar very strong mounts all throughout the research and development facilities. In Switzerland, the preference is to instantiate these mounts as concrete pillars.

Figure 11: Conveniently placed Concrete pillars dot the landscape in the Rheintal of Switzerland. Similar structures can be found littering the basements of the development offices.

Short concrete pillars do not move very much. If you happen to have one to mount the scanner to, then continuous tilt compensation is not as important but as it turns out, still very useful as detailed in the next section. Out of the laboratory, there might be a shortage of pillars in just the right places for collecting the scan data. A firmly planted tripod will have to suffice.

By activating the tilt compensator, you are effectively transforming the tripod into a concrete pillar. This alone would be sufficient reason to use the tilt compensator, but there is more.

Figure 12: Here is a typical job site, bereft of conveniently placed concrete pillars to mount the scanner on. Time for a good tripod and a tilt compensator.

4. Registration Benefits of Tilt Compensation

The greatest benefit of tilt compensation comes with registration – that is, the process of finding the relative position and orientation between two or more scanner positions. Registration is an unavoidable process in all but the most simple of jobs, because as it turns out, the world is 3d and laser scanners cannot see through objects. That means if you want a water tight model of any object, meaning points all over the surface, at some point something has to move, and likely you are going to move the scanner. And if you have to move the scanner, you will have at least two data sets taken from different positions. How *well* you put together the point clouds together is one of those details that matters when using surveying laser scanners.

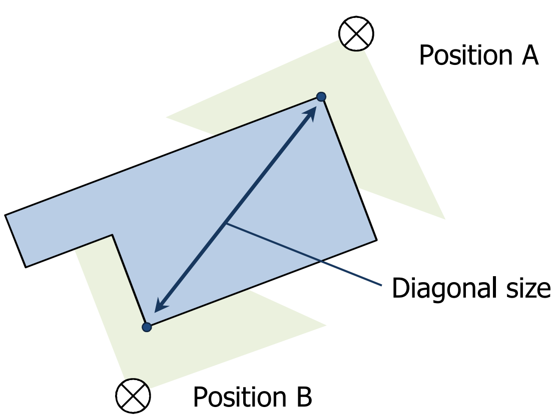
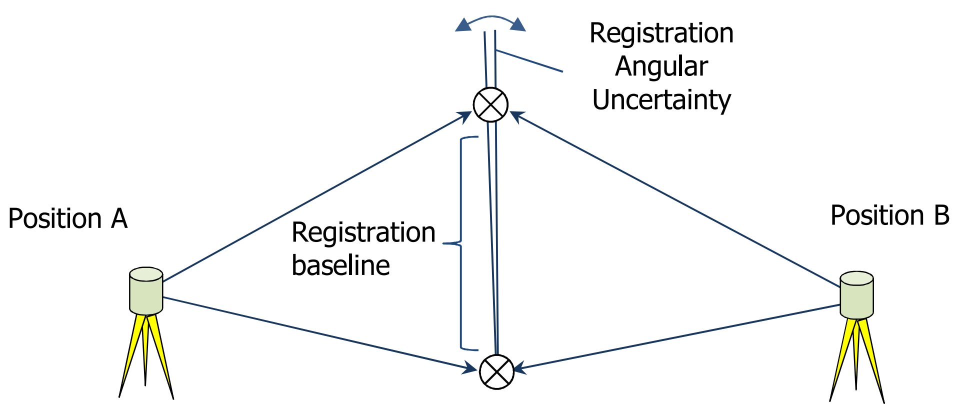


Figure 13: Measuring the diagonal size of a building footprint using data from two different scan positions, labeled A and B. Neither position can see the other corner, and while you might be able to place the scanner so it can see both corners, or at least, their edges, the scanner will not be

able to see both walls for both corners at the same time, which is needed to find the corner precisely.   Time to register.

The reason that registration, or scan assembly, is important is no different than the reasons that angular accuracy, for example, matters for laser scanners when making measurements, even though at first glance one does not see the connection because what you want are distances, as a general rule. The problem arises in exactly the same basic, everyday question: suppose I want to measure the distance between two points in my (now merged) point cloud? If these points happen to come from different scan positions, you will find yourself with a collection of questions that need to be answered about how the point clouds were put together. These assembly processes can sophisticated, automatic, simple, or manual. None of that matters. What matters is what confidence you can assign to the result.

When we calculate the uncertainty of the diagonal measurement, a new term appears which is due to the uncertainty of the registration. The angular uncertainty of the registration, **multiplied** by the range, which is now NOT so trivially small, and the positional uncertainty simply add in, for **every** registration involved in the chain to get from Position A to Position B. Like the embarrassing cousin in the family, no one likes to talk about this factor but you are well advised to pay close attention to it. Surveyors are very familiar with this issue and their vocabulary bear marks of this concern, yielding discussions around topics such as loop closure and baseline.



<u>Figure 14:</u> Registration involves comparing collections of points from one position to collections of points of a second position. The relative error is minimized under the presumption that the shared object from which the points are measured has not moved between the data collection events. The residual registration error tends to be smallest where registration algorithm checks, so the geometry of the patches used matter.

Laser scans are assembled by looking at scan points of common or shared objects in one form or another. The data from the scanner is accurate to some millimeters, and no other data source is within an order of magnitude of this kind of accuracy, at least for now. So there might be GPS or photogrammetry involved at some step, but these technologies can only be, at this time, handmaidens in the process of finding the registration and if not removed from the process before the end, will dominate the residual registration uncertainty. So other while methods can lead the registration close to the correct answer, at some point, a collection of points from one position must be compared to a collection of points from another position, and the differences noted and used to correct the relative position and orientation of the two scanner positions.

So the scans are aligned as close as possible by one method or another, and the error is made very small where ever the comparisons are made. The position uncertainty is something like the residual errors of this process on the patches used, the angular uncertainty is simply the uncertainty at the patches added together divided by the distance between them, which for lack of a better term am calling the registration baseline, as shown in Figure 14. The angular uncertainty is important because while registration can make the parts of point clouds that overlap have a small error, the measurement you want rarely is in the overlap area. Remember, the reason you move a laser scanner is because you see different things from different positions.

Some conclusions can be quickly reached. First, having a small angular error from a registration is needed to control the uncertainty in the measurements made on point clouds. Second, having a really long registration baseline results in small angular error, particularly if you have a small displacement error at these long ranges, which, by the way, goes a long way to explain the prevalence of the use of scanner targets placed at range, as long a range as possible. On a Scanstation, you can pick these specially made objects on the video stream and take a high density scan right on the target, locating the spatial position to a high degree of repeatability. It is the detail (many points) at range that makes possible those long baselines. And third, perhaps not quickly reached, a long vertical registration baseline is really difficult to get in most practical circumstances.

Why is a long, vertical registration baseline so difficult to get? Generally this has nothing to do with the scanner, unless the one you are using an instrument that cannot scan upwards. The population of objects at high elevation angles that can be scanned from two positions and used to establish that very stable (low angular error) vertical registration can be very limited in many normal situations. Stable objects tend to be near the ground in the real world – think of those concrete pillars – if they exist at all. And if you are inclined to use scanner targets, you will have to place them where ever you want to tie the registration together. Perhaps unsurprisingly one tends to find these targets sprinkled around the horizon of the scanner. A long, horizontal baseline is not practical to find in most real situations from the scan data.

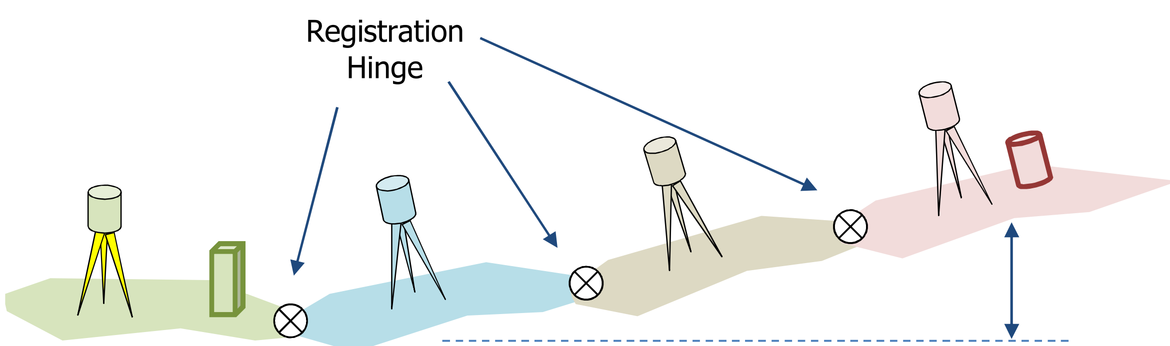


Figure 15: When the objects being scanned are all low, one might imagine that a long vertical baseline is unimportant. After all, nothing that is being measured is at any kind of height. Unfortunately, this is untrue. Registration errors can be very large even in flat land.

Consider the scanning traverse – think of this as a serial chain of registrations – shown in Figure 15. These positions could be taken along a corridor in a building or along a roadway. Between each of the scan positions is a registration with a very small residual error in the cloud to cloud matches. Perhaps even targets where used. However, the overlap area is only between the positions and is largely confined to the ground, because there are no tall objects shared between these positions. As a consequence, the relative vertical angle between each scan position is not very known. One might be tempted to use the word ill conditioned, but the simple fact is you just cannot observe the relative vertical angle between scan positions because there is no data available that provides a long, vertical registration baseline.

Figure 16: Uncertainty is all about what you do not know. That is why we measure.
Obviously the road or corridor does not curl up into space like is shown in Figure 15. Unless, of course, it is curled up like that. The data is not clear on the matter. And while we are at it, let me note that buildings are vertical (see Figure 16), corners are perpendicular and that tall pole is not moving when trucks pass and neither is that damn with all the water behind it. Unless, it turns out they are not like that. The point of taking a measurement is to find out. Using a prior assumption about the world to modify the data is not measurement.

The registration hinges shown in Figure 15 are completely eliminated by the tilt compensator. Why? The tilt compensator provides an extra target not visible in the diagram with an extremely good, vertical baseline, about 6300 km. It is called the "center of the earth", and it just happens to be the case that every single scan position can see the same shared target. Not only that, each scan position has this target to a really good accuracy – recall that dime placed 1.5 miles away? When you are tempted to skip leveling the scanner and deactivating the tilt compensator just keep in mind the curled registration traverse.

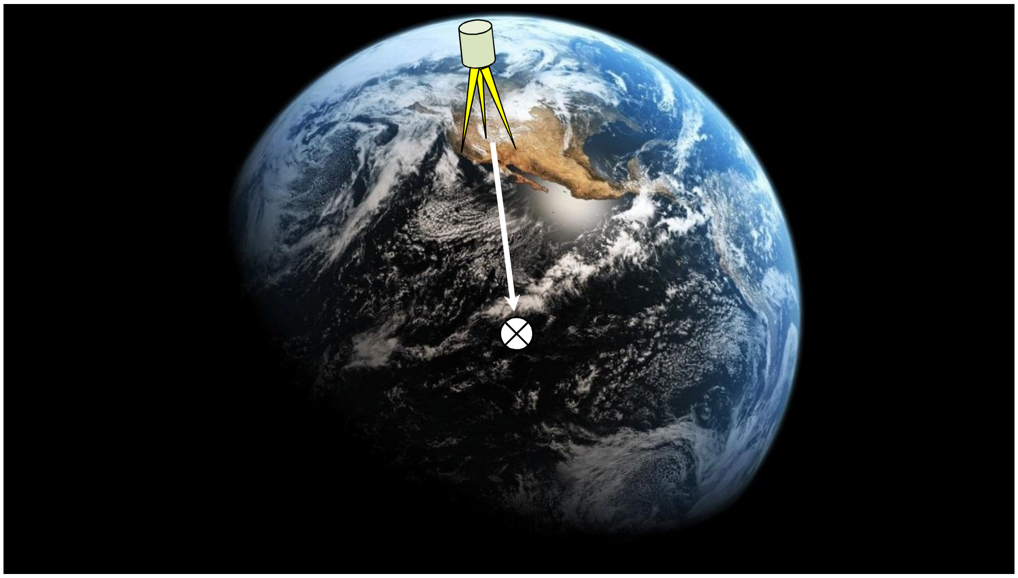


Figure 17: The center of the earth makes for a fairly stable registration target, and the baseline is hard to beat, since it is longer than the scanner can see by a good margin. Not only that, the center of the earth can be seen from every scan position that you are likely to take.

Figure 18: Sometimes the places to mount targets up high are just not available. You can certainly scan a road without a tilt compensator, but getting useful results is very challenging. Cloud to cloud registration here? Forget about it. You would get an answer and it would certainly look right and the residuals would be very small. It might even be right sometimes.

5. Scanning without Tilt Compensation

In some situations, the scanner simply cannot be placed in an approximately level position, and some scanners do not have tilt compensation at all – they may have other devices, referred to as inclination and tilt sensors, which may or not be absolutely referenced to the direction of gravity and are not used to adjust the data continuously, the hallmark of a tilt compensation. The accuracy of these other devices might not be known or characterized over the operating temperature envelope of the device. They have uses, of course – such devices can play the role in the registration process by leading the algorithm to an alignment in the neighborhood of the final answer, but unless they are very high accuracy and measured concurrently with the scanning measurements, such readings cannot provide the final registration.

If forced to take data without tilt compensation active, some precautions are in order. First, selecting a good tripod and being mindful of how it is planted at each scan position is always a good idea, but it far more critical when scanning without tilt compensation. Second, spending as little time as possible on each scan position collecting data reduces the chance that something happens while the scan is being taken. Third, remember that you will be depending on scan overlap to create the registration baseline. Keeping the scanning positions close to each other will control the registration error, particularly if you do not take any targets. Fourth, it is a good idea to discard data with range greater than a few meters, if at all possible, in order reduce the length of the cruel lever of the angular accuracy specification. And finally, make sure you inspect the data sets collected at each position particularly at the point where the front and back scans meet – this is the seam in the scan where points on one side are collected when the scan starts and the points on the other, just next door, are collected when the scan is finished.

Just a few words on tripods, because for many reasons tripods very similar to ones engineered for cameras are gaining popularity. They are very light, and with engineered materials used on the legs such as carbon fiber composites, are very strong if not stiff. They are almost invariably colored black and often have little wobbly bits like threaded screw adjustments on their feet. The price and weight make them very attractive. Now a camera tends to take all of its data simultaneously – you do not take column after column of pixels, they are taken all together in one array. Simply put, as long as the camera shutter time is short enough, you do not need a stable tripod. You can even just hold the camera in your hand. There are even throw-able ball cameras, for taking panoramas at height – there is no tripod and not even held. Laser scanners do not take all of the data at the same time, the data is taken sequentially, or "scanned". Looking at a point cloud, which shows the data all together as if it were collected at the same instant in time, it is easy to forget that this was not the case. You are dependent on the scanner being stably mounted during the entire scanning process. Survey tripods do not have wobbly threaded plastic bits at the feet. You will find spikes and foot pads to firmly set those spikes.

Figure 19: A camera tripod is also (usually) carefully engineered, for cameras. Use surveying tripods when taking measurements, with or without a tilt compensator active.

Without the tilt compensation, registration will depend solely on the registration baseline found in the overlapping parts of the scan. It is not just a matter of having a lot of points – recall, having a lot of points helps reduce random error – it is having the proper geometry to the overlapping parts. This is why using scanning targets is very helpful, because with a scanning target, you can place a large number of points (detail) at range without having to collect that level of data everywhere. The range at which a scanner can reliably pick out a scanning target becomes synonymous with the registration distance and ultimately the quality of the final result and hence a critical specification. Even with scanning targets, the upright orientation of the scan is difficult to determine because most of these targets are going to be placed along the horizon. For these reasons, without tilt compensation, you simple will need to place the scan positions closer together to get the overlap needed.

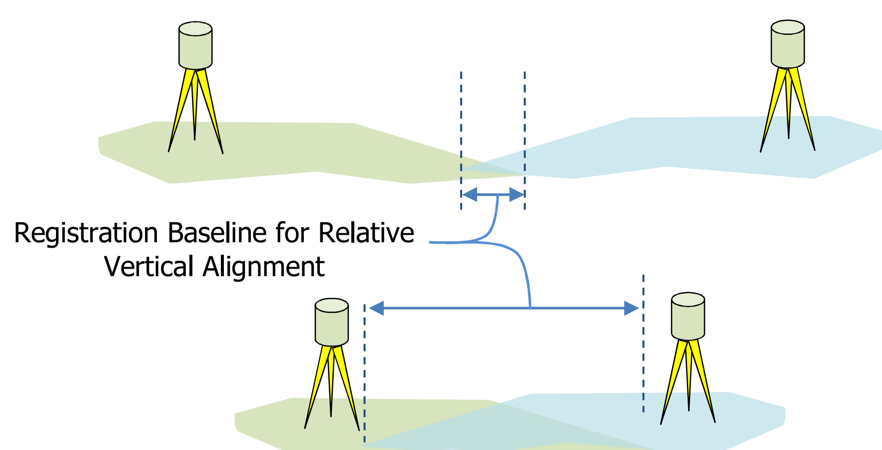


Figure 20: Without tilt compensation, the vertical relative alignment can only be determined in the overlap between relative scan positions. Lacking vertical geometry, say, inside a building or

along a roadway, this means using essentially the ground or ceiling. The registration baseline for the vertical alignment is consequently determined by how far apart the scan positions are. The further apart, the smaller the registration baseline becomes and the more uncertain the vertical alignment of the registration becomes.

When scanning without a tilt compensator, also avoid, if possible, long traverses. Recall that the overall uncertainty of a measurement between two points includes the cumulative sum of the uncertainties from each intervening registration. The entire chain is included in the calculation. Even if you overlap a great deal, the uncertainty is cumulative because the scan from the beginning of the chain, or traverse, does not include a points or references from the end of the chain. With a tilt compensator, the direction of gravity is used as a common reference, the center earth being a common point, shared by these two distant scan clouds. This is what people mean when they say the tilt compensator stabilizes the entire registration – the tilt compensator helps control the accumulation of error that builds through a traverse or chain of registrations. Some scanning scenarios, such as roads (Figure 18), are extremely difficult to accurately scan without a tilt compensator because the only way to collect the data is to take a long traverse.

Finally, when scanning without tilt compensation, inspecting the data from each scan position in the office before attempting registration, particularly cloud to cloud registration, is recommended. Checking at the seam where points from what is known as the "front" face of the scan to the "back" face of the scan, that is, points right next to each other but temporally separated by the maximum amount, is a good way to check if something happened over the scanning period. If there is no gap, then you are in the clear. If there is a gap, then cloud to cloud will struggle to match the gap to other scans because it does not exist in reality, and so (hopefully) will not appear in the other scan position data.

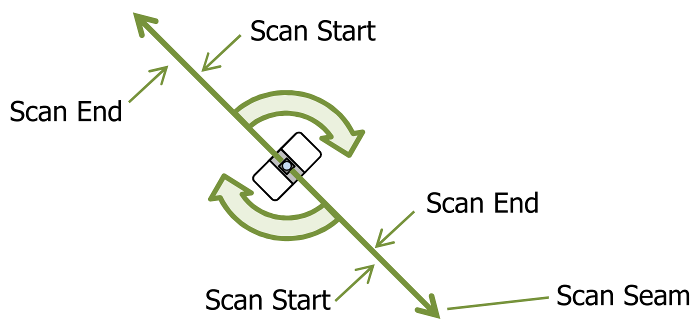


Figure 21: A close inspection of the scanning seam shows a deviation between the front face and the back face of the scan, and is colloquially known as a "scanning corkscrew".

If inspection reveals a gap, there is a good chance someone decided not to activate their tilt compensator! In such a case, the cloud to cloud registration will have a really hard time trying to match a gap that does not exist in the scans from other positions, or in the real world.

6. Summary

Laser scanners provide measurements of human scaled spaces, that is, spaces that span tens if not hundreds of meters, but the accuracy of these measurements needs to be controlled to some millimeters. This is already very challenging for the range measurement uncertainty bounds, but for the angular uncertainty, this challenge is brutal because the range acts like a lever, amplifying small errors. Leica uses the units of arc-seconds to describe the needed angular accuracies because millimeters over reasonable ranges lands in the scale of arc seconds. Of course, one could use degrees or some more everyday unit, but the number of zeros required would be confusing and easy to get wrong – eight arc seconds is easy to keep straight, as is 1.5 arc seconds. A collection of leading zeros only adds confusion to an already difficult topic.

The ideal conditions of the laboratory are not found in the field. The tilt compensator stabilizes the measurements from a single position as if the tripod you carried out was transformed into a concrete pillar. The tilt compensator stabilizes the registration as if you had placed a target that every station could see with a hefty baseline of thousands of kilometers. The only time the tilt compensator adds to the time required to collect the data is the few seconds needed to approximately level the instrument, and it is watching and compensating continuously to an almost unbelievable accuracy.

The tilt compensator inside the Leica Scanstation is the signature element which makes a laser scanner into a Scanstation. The device is the culmination of decades of effort from a company with nearly one hundred years of creating the most accurate survey instruments in the world. And the best part is you, the operator, do not have to pay any attention to the tilt compensator other than activating it. The quality is built in: just cooking with water in the Rheintal. So if you find yourself tempted to skip leveling the scanner, don't. Grab a cup of coffee to warm your hands and do not stomp your feet.