By Gavin Schrock, PLS

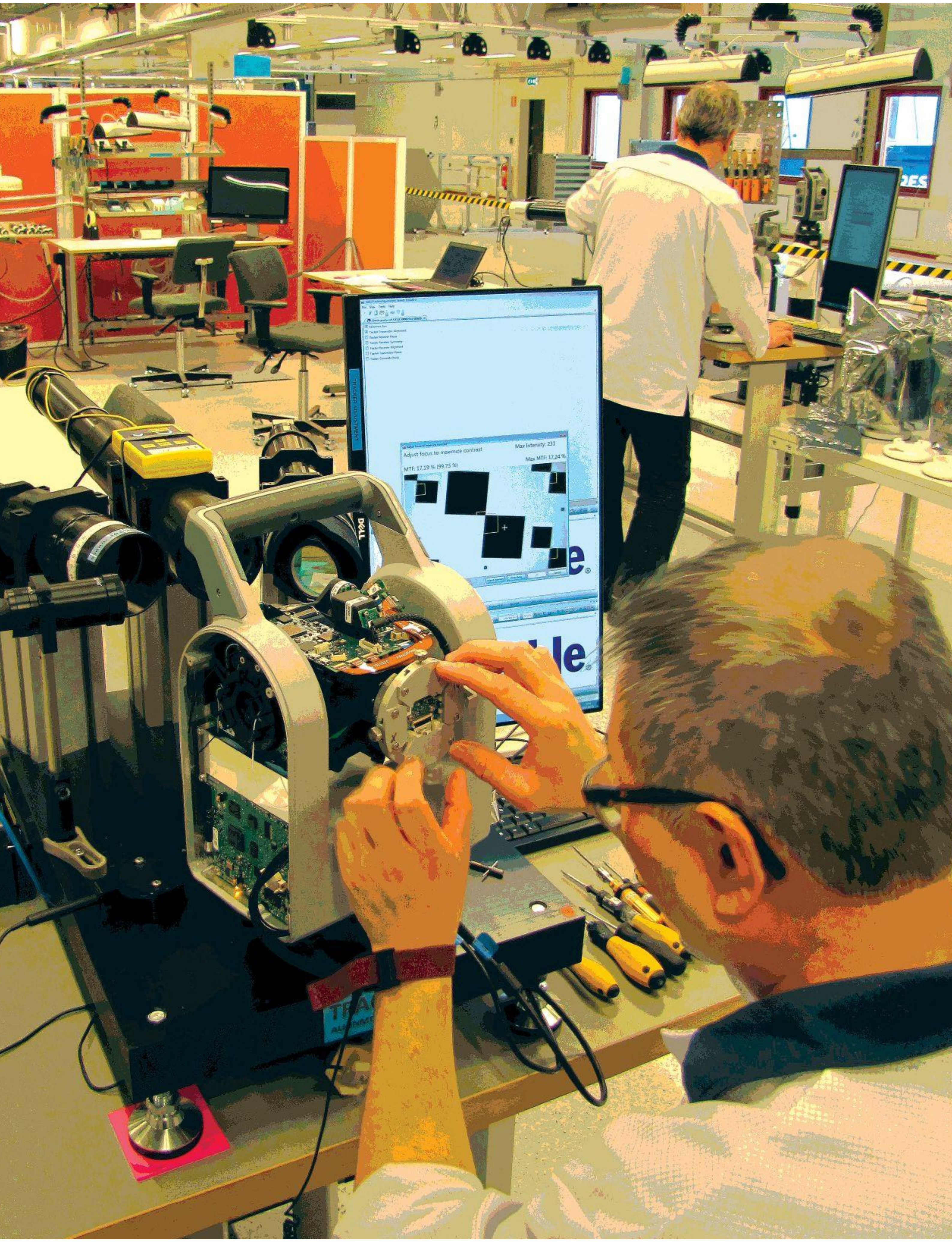
BEHIND THE BIG EYE

A visit to Trimble's engineering and production center in Danderyd, Sweden, reveals the story of the SX10's development.

Total stations, scanners, and the new SX10 are assembled and tested at the newly refurbished Danderyd facility. Each instrument progresses through dozens of assembly, adjustment, and test stations.

CONTRARY TO A POPULAR MISCONCEPTION, developers of the sophisticated instruments we surveyors use do not want those instruments to be viewed as "black boxes." More-informed users make better users, and more-skilled users push these instruments to their full potential. This bolsters a reputation for excellence for the developers and provides feedback; users become better partners in ongoing development.

The following story is about the development and manufacturing team at Trimble's Danderyd, Sweden, facility. Their dedication (as part of an international team) has produced a long line of sophisticated solutions, including their latest creation, the SX10.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DISTANCE EQUALS VELOCITY MULTIPLIED BY TIME.

In 1941 scientist Erik Bergstrand, with the Geographical Survey of Sweden, had been trying to find a better way to determine the speed of light. He conceived of a system of electronically controlled light pulses as opposed to mechanical slotted wheels.

By 1947 he had working prototypes that could transmit 10 million light pulses per second to a mirror over 30km distant. The results could be computed to the nearest millimeter. (See more on this history in the online version of this article.)

Prototypes were so promising that AGA (Aktiebolaget Svenska Gasaccumulator, a state-founded scientific, energy, and industrial company) was backing his development of the first commercial electronic distance measurement devices (EDM). The Geodimeter 1 (GEOdetic Distance METER) was released in 1953 for geodetic measurements.

A rapid progression in EDM development—refinements, different frequencies, and lamps—followed. Model 6 in 1964 was completely transistorized and used lightweight rechargeable batteries. 1971 saw the first of what we now call "total stations," adding precise distance ranging to theodolites. In 1973 Geotronics became an independent company from AGA.

The 1978 Geodimeter 120 automatically computed horizontal distance. The Geodat 120 handheld peripheral was added the same year to record measurements. In 1986, the Geodimeter 440 was the first total station with onboard programs, and this was also the form factor users would become familiar with for decades to follow. The 1990s Geodimeter 460 was servo-driven, and soon would come the first robotic total stations.

In a development trajectory like what Dr. Bergstrand sparked for EDMs, the 1978 founding of Trimble Navigation brought commercial viability to high-precision GPS instrumentation. (Read more about the founding of Trimble in our interview with Charlie Trimble in the November 2016 issue of *xyHt*: goo.gl/4OeAgu). The Geotronics lineage would fold into Spectra Precision that was then acquired by Trimble in 2000.

The combined resources of these companies continued to develop the optical line, introducing the next era of the total station in 2005 with the "S" series, the VX in 2007, and now the SX10.

BEHIND THE BIG EYE

A lot's going on behind that distinctive large lens on the front of the SX10. And there's a lot going on inside the utilitarian yet pleasant "Swedish industrial-style" walls of the Trimble facility in the small town of Danderyd, just a few rail-stops north of Stockholm.

Here is where most of Trimble's optical instruments are designed, engineered, and manufactured. The SX10 is an instrument platform that departed from existing designs so much that the facility's recent modernization and expansion were mostly to accommodate its manufacture.

"We really wanted to make the best total station in the world," said Stella Einarsson, system project manager for the SX10. This project taxed the R&D skills and resources of the engineers and scientists in Danderyd who worked as part of the global team that would bring this bold idea to fruition. Danderyd is part of scientific, R&D, and instrument-production lineage that spans more than a century—and has garnered many "firsts and bests"; (see the sidebar above).

It's fair to emphasize how significant a departure from legacy instruments this new solution is, not only for the AGA-Geotronics-Spectra-Trimble lineage, but for the industry as well. The SX10 was not based on an existing platform; nearly every component had to be developed from scratch, from foundation science on up through completely new manufacturing engineering, production processes, and testing elements.

Einarsson has been at the helm of the SX10 development since its conceptual stage in 2007. "Development is spread around the world. Field software is developed in New Zealand, office software [TBC] in the U.S., scanning software in France. The global team works seamlessly, and it often does not feel like people are in different countries."

Einarsson added, "That is the power of this company. Everybody's focus is to serve our main markets: surveying, engineering, and construction.

"Total stations are complex by their nature, and in the same manner [the encompassing] R&D has a high level of competence or education. [Among roughly 300 on staff] we have PhDs and many university graduates—people very skilled—who get additional training here."

> **"We wanted to have our cake and eat it too."**

The demands may be high, as Einarsson noted, but "the culture has been that our people truly enjoy working here and are extremely proud of the products—and they stay!"

Robert Jung, technical product manager, outlined the types of products developed and produced at the Danderyd facility. "The SX10, S5, S7, S9, the SPS [total station series] for construction and machine control, and RTS [total station] series for building models [BIM]—all based on the S series. We produce the TX8 and TX6 in house, also some control units and targets."

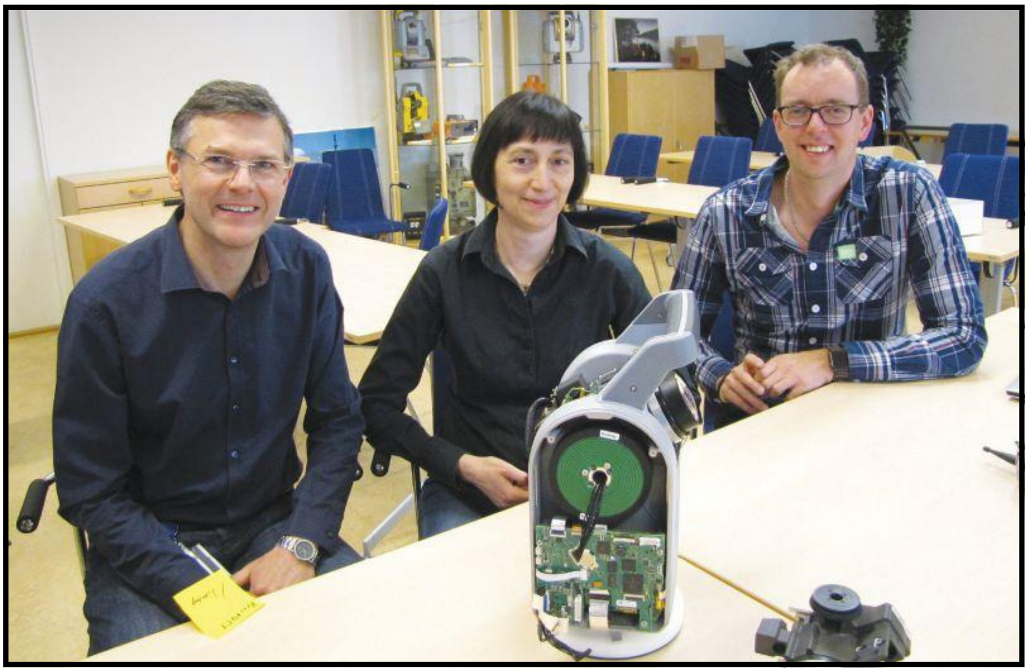
SALLY

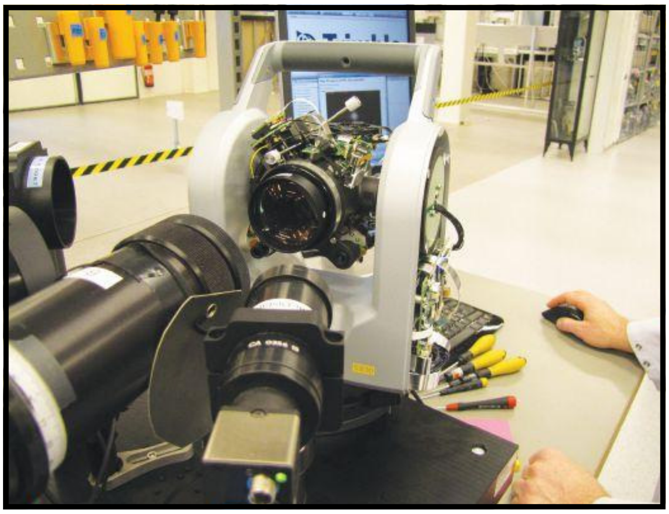
Einarsson said, "The SX10 development is also known as project Sally. R&D projects are given code names by Trimble management. [This] name was Mustang, so it became Mustang Sally."

What prompted the project? Einarsson explained, "Starting about 10 years ago, scanners were still for early adopters; the technology was rapidly evolving, new things each year, new flavors. The focus in scanner development was always [about] faster and denser point quality."

Trimble was producing and developing scanners at the time as well, like the GX. Trimble was undertaking what Einarsson calls "product development on all axes. Mechanical total stations, high-end S [series] total stations, [GNSS,] and the VX, which had imaging and scanning."

The question facing Einarsson and the researchers and developers





Above, left to right: Christian Grässer, R&D specialist; Stella Einarsson, system project manager for the SX10; and Mikael Nordenfelt, R&D specialist.
Left: One of many assembly, adjustment, and test stations for the SX10.

was, "Is there a way to combine the speed of a scanner with the accuracy of a total station? Would it be possible at all?"

NODDING AND SPINNING

The developers first wanted to see what could be done by adapting and expanding the capabilities of existing designs. The Trimble VX, introduced in 2007, was based on a high-end total station platform; it included the imaging capabilities of the S series but also the ability to "sort of" scan. This was achieved by having the telescope assembly "nod" as it panned. Scan rates were limited, but it proved such functionality to be useful in surveying workflows. Other manufacturers would employ "nodding," but the speed was still limited to about 1,000 points per second.

Which path should the team take? Start on a scanner platform and add total station capabilities? Or take a total station platform and add scanning? The school of thought changed back and forth, and concepts were tried using existing elements. I was shown a video clip of a test using the fast (but not fast enough for scanning) mag drive of a total station, spinning furiously. Calculations indicated many hours for a full "dome scan" (360° horizontally and 300° vertically).

From many considered platforms, two form factors emerged as front runners. One was taller to accommodate cooling elements and a possible spinning telescope unit, and another shorter and more like the final design. Scanning was only one goal; high-quality measurements were needed for the traditional surveying markets. "We wanted to have our cake and eat it too," Einarsson said.

How? Nordenfelt answered, "We could get away with this if we designed a completely new EDM style." The technological breakthrough was inspired by a method for creating a sweeping motion in a wholly unrelated instrument (see the sidebar, "The Envelope Sketch" on page 21).

With the new spinning prism, 26,600 points per second (in first release) was achieved: a full dome scan in coarse mode in 12 minutes. A full dome photo pass, if desired, is added in 2.5 minutes. The spacing is always at one milliradian, so by shifting the pattern on subsequent passes densifies in increments of 4, 16, or 64 passes.

THE SEED

The new telescope assembly would be multitasking at a level never tried before. Advances in technologies developed for telecommunications would be applied, fiber optics in particular. Multiple cameras would have to work seamlessly and switch automatically. There would be no manual eyepiece (impractical to place down the middle of multiple beams, prisms, and sensors), and the team would need to develop a tracking system not tried on previous models.

There are multiple hearts in the SX10. One is a crystal oscillator, synchronizing the laser pulses, rotating prism, sampling returns, and processing. The other is the MOFA, or master oscillator fiber amplifier, about the size of a deck of cards. It has a "seed laser" and two pump lasers that amplify the signal by, as Nordenfelt says, "pumping in dirty light. The seed laser gives a very nice short pulse with a peak power of 0.1 Watts, then gets amplified in two stages. After one pump laser it is 10 Watts, and the second turns it up to 1.3 KW."

Beams are isolated from these amplified signals to perform multiple duties: scanning and total station shots, with another laser for tracking. The team has dubbed this multi-tasking EDM as the "3DM."

To produce an extremely narrow and tightly controlled beam, the fiber is polished in-house; off-the-shelf fiber could not meet standards. Manufacturing technician Maik Tegge explained this crucial process. "We have a polishing table that [rotates] to eight positions so that the same spot is never repeated. [We use five steps] with

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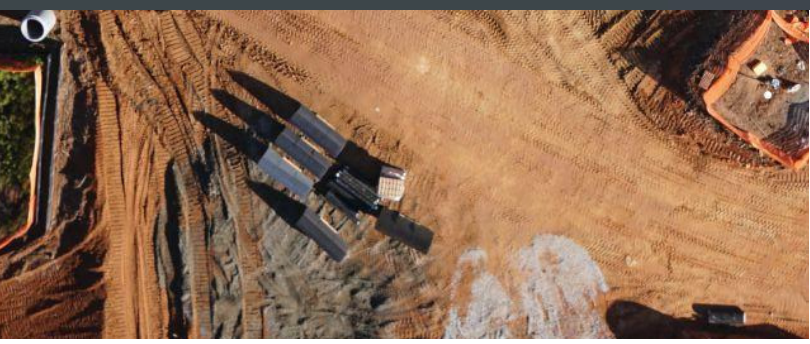

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diamond-infused [sandpaper] finer each time." Maik showed me microscope views of the finished ends that looked amazing compared to images of standard fiber ends.

Nordenfelt explained that fiber coils in the MOFA provide delays needed to rest the electronics between outgoing and incoming signals, as the laser is so intense. The result of using such finely produced components together, says the team, "is the smallest spot size in the business. You get a very nice, small spot: 8mm at 50m and only 14mm at 100m."

The benefits of a small spot size would be evident in observing, say, a building corner; a large spot size will average over a large area giving a false location for the corner.

The scale of the sampling of signals in EDMs and scanners is rather mind-boggling. Nordenfelt explained, "If [you picture] a single pulse as one raindrop, and we are sampling at 2 gsps [2 billion points per second], this would fill 600 barrels. And we are looking for one bucket—every second. This is a huge leap forward compared to anything that a total station would typically be doing."

How does this translate to precision? Nordenfelt responded, "The speed of light is 300,000km per second, and at 2 gsps the spacing between samples is 7.5cm. You have to do a lot of processing to look at the shape of the pulse to get down to one hundredth of this length."

EXCELLING AS A TOTAL STATION

The unit not only had to provide scanning capabilities but had to be as good as, if not better than, any other total station, as well. As for the scanning capabilities, the speed would not rival the high-end dedicated scanners, but the SX10's scanner actually yields a few advantages.

In many dedicated scanners, the range noise starts small but steadily deteriorates over distance. The ill effects of range noise in most scanners can be seen as duplicated surfaces and features in point clouds. The team was able for refine the SX10 scanning to remain lower over most of its range. Nordenfelt said, "The range noise up to 200m is only 1.5mm, and 2mm out to 250m."

The field test and adapting to the tablet posed no challenges but instead added advantages.

The team emphasizes that their products are developed with direct input from many surveyors; feedback influenced the direction of development several times.

"The [SX10 was envisioned] to be a 2 arc-second instrument," said Nordenfelt. "And [originally] we thought the EDM might be accurate to 4mm, later 2-2.5mm, and the scanning range at only 250m. But we kept grinding and grinding. Every shot in the scanner was good, and we have a good EDM, so we could build statistics and keep moving things around until we could make things better. Progress was incremental, and we could in the past year go to 600m, increasing the DR (reflectorless) range, and [got to] 1 arc-second."

The team also set out to push the limits of another technology, developing a new camera-based passive tracking system. Said Nordenfelt, "The basic principle is the tracking laser illuminates the prism, and you capture an image. You then switch the laser off and capture another image. Subtract these images from each other, which should [exclude] anything lit by ambient light."

I tested this in the field and deliberately aimed at potential false light sources; it performed as well as any I've tried.

There is a very large combination prism in the SX10 is key to the instrument's multitasking. Early in development, Christian Grässer travelled to

The Envelope Sketch

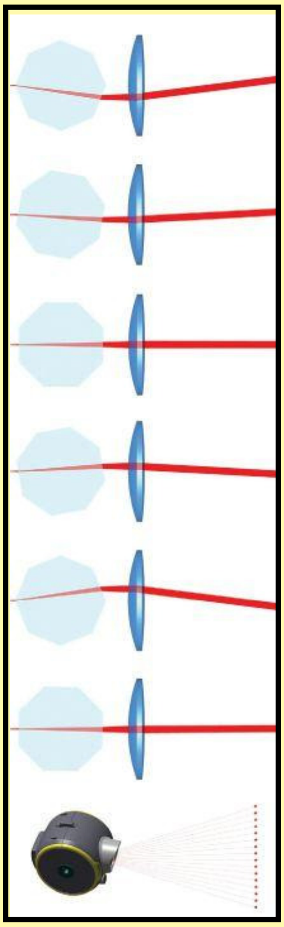
NORDENFELT SPOKE OF FELLOW DANDERYD DEVELOPER MIKAEL HERTZMAN and a particular "light bulb" moment. "He started 35 years ago in the AGA days: the most senior developer, a really ingenious guy. Many of our core technologies originated from him."

Hertzman remembered a technology developed by AGA in the 1970s, a thermal imaging camera. "The challenge for the thermal camera was how to scan [a wide area] using a single, very expensive, liquid nitrogen-cooled infrared detector. The solution was two rotating [octagonal] germanium prisms, one horizontal and one vertical."

Hertzman paid a visit to Flir (former part of AGA company) to look at the mechanism, came back, and, as Nordenfelt says, "sketched out the idea on an envelope. I ran some [simulations], and this worked out."

The SX10 team developed an octagonal prism that rotates at 1000 RPM. As the beam passes through one facet of the prism it deflects sideways, back again through the opposite facet, then through a positive lens translated as deflection.

A swath of sixteen points across (at an angle as the whole mechanism is on a tilt) sweeps up and down, automatically repeating as facets progress. Precisely synchronized, this process can be repeated to fill in between previous patterns to densify.



Japan to visit the Nikon-Trimble Joint Venture (NTJV) to see work done on such combination prisms and returned quite excited. There are about half a kilogram of highly refined glass is in the SX10.

CAMERAS

All the total stations produced at Danderyd have multiple digital cameras, but the SX10 has five. Grässer said, "This is a fully integrated camera system for documentation, measurement, and instrument operation."

Starting with the plummet camera, Grässer said, "At 1.5m in height, one pixel opens to 0.3mm down on the ground." The plummet camera, as well as all the other cameras, are engineered and assembled in-house.

"The bundled camera system is three cameras: overview camera, primary camera, and coaxial tele-camera," said Grässer. "Users experience that as one camera; zoom in and out and they switch on and off very quickly. [Combined,] this gives a field of view from 0.65° to 57°. The tele-camera has eight levels; the first six levels get you to 84x zoom, plus in levels seven and eight the pixels are quite small and can blow up even further by digital zoom."

The benefit of these capabilities was evident during field tests and (among other reasons) convinced me that the loss of the eyepiece might not be a bad thing.

"The difference with conventional [survey instruments] is the digital crosshair," said Grässer. "This is overlaid on the screen, and there are settings for brightness, spot exposure, white balance and so on: manual or auto focus. We compensate for parallax between cameras for distance when we overlay the crosshair. You do not have to trigger distance measurement to do this; it is always on."

Terrestrial photogrammetry is another measurement option, done in TBC as overlapping images are already registered.

Manufacturing technician Maik Tegge demonstrates how the SX10 is being hoisted into climate-controlled chambers for testing from -20°C to °+50C.

THE FACTORY FLOOR

The entire facility looks shiny and new, as there was a recent expansion and remodeling to accommodate the new SX10 line. I saw what could be described as a Swedish-ness reflected in the exacting nature of the working environment, but there is no stuffiness. The work day is 7.6 hours, production workers are highly educated, trained, skilled—and cheerful—and they rotate assembly and test stations daily.

"Assembly is done here," said Tegge. "Parts are from all over, but most subassemblies are done here as well."

I saw numerous mounts to test the EDM and cameras, hitting targets very near and as far as 167m away across the floor: collimation targets, checkerboard and color patterns, and prisms.

Two climate chambers enable tests at a range of -20°C to °+50C.

In another room is a window for very-long-range EDM and camera tests to targets on distant buildings: one 2.43 Km away. There are also large stone tables for calibration and testing of compensators.

Tegge said, "There is total traceability of all components—when built, when inspected, various calibration processes—all in the database."

THE HAIR CROSS

The SX10 does not have a physical crosshair (or "hair cross" as they call it in Danderyd). Crosshairs were traditionally the single reference for all collimation calibration and testing. Physical crosshairs can be adjusted to only a few microns, but a laser spot at very short range can be a single micron. The team had to rethink legacy processes.

Tegge explained that the beam axis of the main EDM laser is calibrated, and then all other collimation uses that as the reference.

Test and assembly stations are present for other products; only a few stations are the same for both the S series and SX10, such as for compensators and tilt sensors. Tilt sensors are liquid-surface and camera-based, with two-axis mirrors and silicon oil. Optics are individually calibrated and tested, and each laser is pre-adjusted for strength and position. This is microscope work, and some work is reserved for the clean room. Nearly every jig and test station is designed and manufactured in-house; the factory has a well appointed machine shop.

TX8 and TX6 scanners are assembled in Danderyd with much of the engineering done in a facility in France. In 2003, Trimble acquired MENSI, the French company specializing in scanning hardware and software. They also produce the Real Works scan software and scanning module for TBC.

Tegge showed me an interesting solution installed in the factory for testing the scanner beams: a series of long corrugated pipes connected by mirrors to test the beams over different distances in a laser-safe environment.

TEST DRIVE

The scenario I tested with the SX10 included developed and undeveloped land, an existing building, and a road—as for a survey/property report (e.g, like a U.S. ALTA survey). Surveyors have been adding scanning and imaging to their property report surveys, and when I heard about the SX10 I thought it might be a good fit for a wide variety of surveys.

Jung guided me through operation of the SX10, and we were joined by Lennart Gimring, survey and mapping manager for ÅF Infrastructure AB, a large multi-disciplined international consulting firm and an early adopter of the SX10.

"ÅF does all kinds of work: topo for construction, project design, roads, indoors, runways," said Gimring. "We like scanning because we can combine with many other data sources, such as lidar data from helicopters. With the SX10, we can see inside areas we might miss with other types of point collection."

Gimring said, "What struck me as the best benefit is that before you leave a site, you can do sweeps of scans and images and get things we do not normally get, avoiding that second visit."

And you get advantages in richer data. "[Clients] can improve their engineering workflow. We try to [also] use the images as much as possible, definitely important so people can actually visualize what is there. Some people still want only CAD drawings, but show them you have this as well, then they definitely see that as an advantage."

How was roll-out with his crews? "It is just as capable as previous generations of total stations, and you do not have to drag a scanner along. One crew that always wants to use this as the first option is made up of two women who have no problem carrying it around."

Gimring also mentioned an airport runway project where the scanning would be essential due to limited site access.

For our test, we did a first set-up by simple resection. The operation of the SX10 is so familiar and simple, essentially that of a typical total station with some enhancements and working through a tablet. With the split screen, I could see what the SX10 sees on one side and control the instrument on the other side of the screen.

Capturing an image with potentially every shot is going to settle a lot of arguments back in the office. We picked up features individually, both with the rod and DR. The tele-camera and digital zoom levels made for interesting shots.

For example, an electrical tower over 200m away was a good test for the zoom and cross-hair control. Sags on overhead lines were well defined in scans and easy to collect in DR mode.

Tegge and technical product manager Robert Jung explain the design of the S series total stations to the author. Credit: PMAGI AB.

We easily picked up an insulator on the tower we would otherwise barely be able to see without the digital zoom.

You can (roughly) aim the instrument manually but also more precisely via the tablet by holding keys down for rapid movement and nudging when you get close. At digital zoom level seven we could nudge the cross hair by one pixel at a time via keys on the tablet.

No eyepiece? I know that an image though an eyepiece can appear crisper than through a camera's image, but when you have higher magnification plus digital zoom available, I am pretty sure many folks (once they've tried it) might conclude that this is an improvement.

I looked for objects that might have otherwise caused a false lock when using legacy active tracking, like a distant road sign that had glint from the low March sun. The tracker had no problem distinguishing the prism from glare hazards, as well as in tests next to windows reflecting the sun. We did selected scans of small areas of the building at different scan levels; the areas of interest were easy to pick on the screen.

> **"Someday these [features] will simply be what is expected for total stations."**

And while the scanner went about its business, we got to do integrated surveying: picking up additional features with a GNSS rover. We shot things the scanner and images might not be able to see without extra setups, like flowlines of gutters and objects behind cars and hedges.

When the survey was complete, we did as Gimring suggested: a near-full 360 scan (cropping off the sky). This took about 10 minutes in coarse mode, and then we added a full dome of images after, about three minutes more. One advantage of using a total station as a scanner is that the scans are pre-registered, so you don't have to provide as much overlap as you would with conventional scanners.

Looking at the data in TBC afterwards had me thinking about all this rich data collected on one instrument, far more data than I could have gathered with a conventional total station in the same amount of time. Registered images and selected scanned features are all tied into the adjusted control, integrated GNSS shots as well.

The SX10 represents a big stride ahead, and the global team involved should be proud of their accomplishment in developing a whole new platform: new, but one that can be operated with the ease of familiar instruments.

I asked Einarsson what the future might hold for the SX10 and instruments to follow. "I think that someday these [features] will simply be what is expected for total stations." I tend to agree.

I hear some folks ask, "Why add such features," and I have not found a compelling reason not to say, "Why not."

In short, of course I enjoyed learning about and trying this new solution; I was as giddy as I was when I tried my first EDM in the 1980s and first robotic geodimeter in the 90s. I'm so glad there are folks like Einarsson and her team looking ahead for us. ■