ACCURACY ACCELERATED

A PIONEERING NEW APPROACH IN DENMARK IS BOOSTING PRODUCTIVITY IN MAINTAINING PRECISE VERTICAL DATA. JOHN STENMARK REPORTS

For such a flat country, Denmark is surprisingly interested in elevations – and for good reason. The low-lying nation is made up of a peninsula and an archipelago of large and small islands surrounded by the Baltic Sea. The country's mean elevation is roughly 34m and much of its terrain is flat plains. As a result, Denmark is particularly vulnerable to the effects of rising sea levels. The concern over elevations is driving an innovative application of geospatial technologies.

Work is underway in Denmark to modernise the collection and maintenance of geodetic heighting information. Having accurate, up-to-date data is crucial, especially in the low areas of the country where rising water levels may affect dams, transport infrastructure and agriculture.

The work to gather and maintain data on Denmark's network of vertical control benchmarks falls to the Danish Agency of Data Supply and Efficiency (SDFE). For years, SDFE has used a combination of conventional geometric and trigonometric levelling to maintain the control points. Recently, the agency began an effort to check benchmarks over the entire nation. To meet the technical and budget requirements, surveyors needed to develop an approach that would increase measuring efficiency while preserving precision and accuracy. The new approach combines motorised trigonometric levelling (MTL) with new total station technology and customised software. The experience gained from work on initial projects has produced encouraging results.

Under MTL, surveying total stations and prism targets are installed in two vehicles and driven from point to point. The vehicles use leapfrog techniques along a route conducting reciprocal measurements. The reciprocal measurements enable analysts to remove systematic error due to refraction and account for small errors to produce precise vertical differences between the two points. Specially designed mounting systems ensure that the equipment is stable whenever measurements are in progress.

The MTL procedures used by SDFE call for multiple observations in Face 1 and Face 2 positions. The process produces very good accuracy and is much faster than walking and using tripod-mounted instruments and targets. For projects that require second-order precision, motorised trigonometric levelling is an attractive option.

After analysing the MTL process, geospatial specialists at Copenhagen-based Geoteam A/S realised that much of the field time consisted of physically operating the total station to obtain multiple measurements. They found that by using robotic total stations to make the observations, they could significantly reduce the time needed for the survey.

Using a robotic instrument to perform the sightings instead of manually-operated total stations increases the accuracy immediately. When taken over a full day of observing, an observer's performance will be affected by weather, distractions and fatigue. By contrast, the performance of a robotic instrument is much more stable and is not affected by time, lighting and environmental conditions.

"The speed of the observations will increase substantially," says Geoteam director Henrik Johansen. "The time savings in the observation phase should increase the accuracy by minimising the influence of fluctuating refraction. Alternatively, the saved time could also be used to measure more rounds, which would also increase the accuracy and precision."

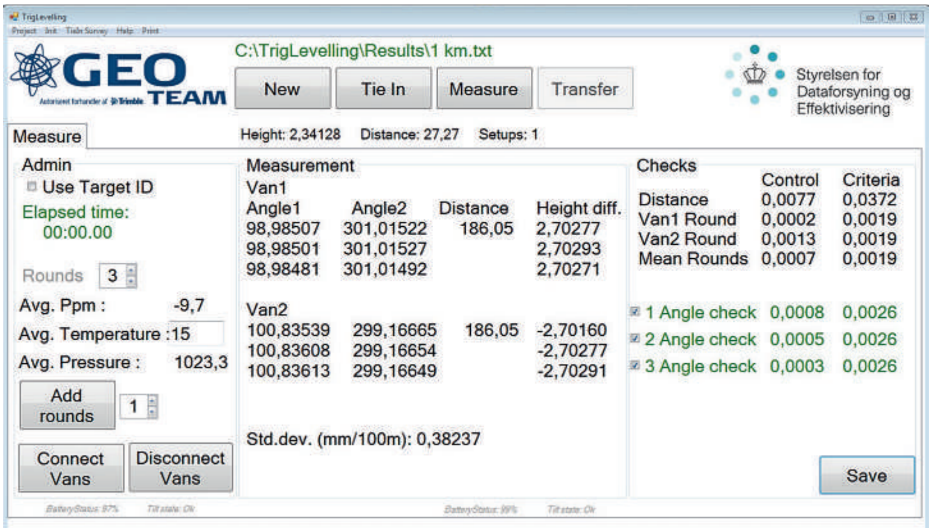
New designs for productivity

Working closely with SDFE, Geoteam specialists developed an approach that would integrate robotic total stations into the SDFE operations. The basics of the solution were formulated to follow very strict requirements and based on many years of experience. To meet accuracy specifications, Geoteam used Trimble S9 HP total stations with 0.5" angular precision and robotic operation. The instruments are equipped with Trimble Vision technology, which enables operators to see what the instrument is seeing through its telescope on the laptop controlling the surveys.

Additionally, Geoteam was invited to suggest improvements to SDFE's existing procedures. For example, they suggested mounting a small prism on top of the instruments for tie in between instrument stations. The concept provided secure position and orientation of the prism for precise measurements. It enables rapid reciprocal measurements between two instrument stations and eliminates the need to remove or reposition prism targets. SDFE fitted custom-built tripods into the vehicles; the motorised tripods extend down through holes in the floor to provide a stable platform for the high-precision total stations. The tripods retract when the vehicles are ready to move to the next observing station.

To conduct operations in the field, Geoteam programmers used the Trimble Precise SDK (software development kit) to create specialised software to run on a laptop in one of the vehicles. Communication between the two survey vehicles is done over a mobile LAN using dedicated routers with a radio backup system. Additionally, the PCs are connected to the Internet to make it possible to use remote desktop software to manage the software and handle operations in both vehicles.

The laptop software controls both instruments to conduct measurements and then to store and analyse the data. The



The laptop software collects and displays measurements from both total stations. The solution processes the data and automatically flags observations that don't meet specifications. Operators can take additional measurements and avoid revisits to correct errors

A survey vehicle equipped for motorized trig levelling. The high position of the instrument provides flexibility in selecting locations for observations. The instrument can be lowered and roof retracted when not in use for measurements

Surveyors can operate the vehicle and measurements from the driver's seat. Custom software controls both instruments and enables operators to verify results before moving to the next set up

software provides measurement options and quality control on the spot to ensure crews meet the required accuracy of the project. It controls the needed functions of the instrument as well as temperature measurements, ppm calculations, averaging the rounds, calculating height differences, accumulated height differences and accumulated distances. Operators in the field can inspect the results, remove questionable measurements or add measurements as needed to meet the defined criteria for precision.

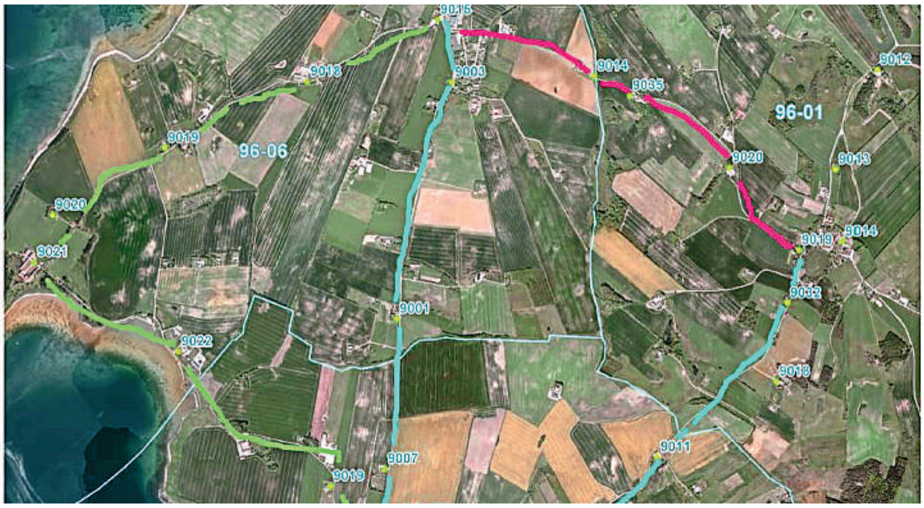
Combining accuracy and productivity

As Geoteam developed the system, they worked with SDFE to conduct a series of tests to better understand the performance and output. In early tests using a one-second Trimble S8 total station, they measured two known level lines using MTL and compared the results to existing data. The tests produced accuracy of roughly 1mm/km.

Johansen says that subsequent testing using the Trimble S9 HP instruments over a 36km course showed an error of 0.9 mm/km. "These results are very impressive," he says. "Further investigation of temperature measurements, number of rounds and operational experience indicates that this result can be even better. The speed of measurement and elimination of operator error and fatigue will enable the users to take more data and produce higher accuracy."

The value that the system provides extends well beyond its accuracy. Johansen says that the new approach is proving to be very fast. As crews gain experience with the motorised techniques and software, he expects that they will be able to perform precise trig levelling at a rate of two to three kilometres per hour. The savings stem from the faster operation together with the ability to make fewer setups over a given route than using conventional levelling. At the same time, crew sizes can be cut from four people down to two.

Taken together, the changes translate into expected cost savings of 35% compared to current techniques.



Testing routes for the instruments and software. Levelling routes were surveyed twice (blue) and the result was compared to a precise geometric route (red). Another route (green) was used to test the distance meter and prisms.

A total station and top-mounted prism assembly for reciprocal measurements. The prism rides in a rotatable bearing to provide stable orientation while the total station turns beneath it

A total station installed in the survey vehicles. Custom-built tripods provide stable mounts and the ability to extend and retract as needed.

The solution also offers advantages in safety and convenience. Operators rarely need to leave their vehicles to work in traffic, and setup locations can be chosen with safety and visibility in mind. Because the instruments are installed in a high position in the vehicle, line of sight is improved, which creates more flexible operation. The vehicles can be parked in locations not suitable for survey crews working on foot and with standard ground-mounted tripods. The public can travel the roads safely and with little disruption; in many cases the passing cars may not be aware of the precise measurements taking place just above their heads. The higher instrument positions also help mitigate errors due to refraction.

Looking ahead, Geoteam and SDFE also hope that MTL methods can become an adequate substitute for motorised geometric levelling using conventional level instruments – provided that the accuracy reaches the required levels. There are already indications that this is an achievable goal: Johansen says that survey crews using the new solution have delivered accuracy result in the range of 0.6mm/km.

The efforts of the Danish teams are helping to expand and cement the role of trig levelling. The use of precise total stations driven by well-designed software can transform the work of establishing and maintaining networks of high-accuracy vertical control.

THE EFFORTS OF THE DANISH TEAMS ARE HELPING TO EXPAND AND CEMENT THE ROLE OF TRIG LEVELLING

John Stenmark is a writer and consultant working in the geospatial and associated industries

A NOT-SO-NEW SOLUTION

Conventional geometric levelling uses high-precision levels and invar staffs to conduct precise measurements. The approach provides excellent accuracy, but is constrained by differences in terrain and limited lengths of sight lines. As a result, geometric levelling is expensive. Motorised geometric levelling uses vehicles to move instruments and targets quickly along a levelling route. The vehicles simply reduce the time to move from point to point, which helps to reduce the costs.

Trigonometric levelling is a viable – if not widely used – alternative to geometric levelling. With sufficient care, it's possible to measure longer lines and larger height differences with at least second-order accuracy.

Trig levelling is not a new concept. Soon after the introduction of the first high-precision integrated total stations in the early 1980s, Adam Chrzanowski of the University of New Brunswick tested the technology. He showed that trig levelling could produce accuracy of 2mm√km (at the one-sigma level) with sight lines as long as 300m and at a speed compatible with conventional geometric levelling. The technique could prove to be especially valuable in hilly or mountainous terrain.

Trig levelling was a featured topic at the 1985 International Symposium on the North American Vertical Datum and again at the 1986 FIG Congress, where a report from the National Land Survey of Sweden also demonstrated good results. And the Swedes added a twist – they used vehicles. It was one of the first demonstrations of motorisation for trig levelling.

In a 1989 paper, Chrzanowski provide a detailed description of motorised trig levelling techniques to produce high-quality results. Chrzanowski used half-second total stations mounted in pick-up trucks and tested leapfrog techniques and reciprocal measurements. He obtained accuracy of between 1mm/km and 2mm/km and concluded that trig levelling could be a logical replacement for conventional geometric levelling.

Chrzanowski found that accuracy of measurement of vertical angles was an important factor in the overall achievable accuracy. Angular accuracy could be improved by taking more observations at each station. But he pointed out that to do so using the manually operated total stations available at the time increased observation time to the point that trig levelling would be rendered uneconomical. The experience in Denmark with robotic total stations has removed this concern.

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