# Automated Pole Functionalities for Advancing Productivity of Total Station Workflows

**Hannes MAAR, Switzerland**

**Key words**: AutoPole, total station, surveying, productivity, tilt compensation

## SUMMARY

Effective management of land, a scarce natural resource, is essential to macroeconomic development and requires accurate geospatial information. Similarly, well-managed infrastructure creation and maintenance are crucial to modern urban development, which is consistently growing more complex. A shortage of skilled workforce hinders productivity and heightens the need for automation across measurement processes. Resulting market requirements include methods for simple, fast, and frequent data acquisition that can be easily integrated into land management and construction workflows in the right format and at the right time.

Robotic total stations with automated features are common tools of choice to meet these challenges. Their continuously improving sensor capabilities and software applications support precise survey and layout. However, similar advances to the surveying and construction pole, an integral component when measuring with total stations, have remained absent over the last decades. Functioning as a mechanical extension to overcome obstacles, many constraints hinder the pole operator from optimal productivity.

This paper introduces the latest pole-side innovation complementing Leica Geosystems' robotic total stations, describes three distinct functionalities enabling increased productivity and reviews the impact on the total workflow for measurement professionals across industries. This innovation, the Leica AP20 AutoPole, extends reliable sensors onto the surveying pole to allow measurements with an arbitrary tilted pole, speeding up work and increasing access to points; enables automatic detection and recording of height changes of the pole in the field software; and makes it possible for the total station to search and lock only to the intended target.

Integrating this technological innovation into the overall measurement workflow enables the total station and surveying pole to become an interconnected survey solution which increases both flexibility and productivity.

# Automated Pole Functionalities for Advancing Productivity of Total Station Workflows

**Hannes MAAR, Switzerland**

## 1. INTRODUCTION

Accurate geospatial information is essential for land management, infrastructure development and maintenance, building construction and more. While complex projects requiring spatial data are growing, a shortage of skilled workforce to acquire it highlights the need for automation across measurement processes. To meet market needs and support economic growth, methods for fast, simple and frequent data acquisition that integrate easily into measurement workflows are crucial.

Robotic total stations help address these challenges with automated features enabled by continuously progressing sensor capabilities and software applications. However, the surveying and construction pole has not made similar strides towards automation, leaving an integral component of the automated workflow as a manual process. Pole operators are distracted by handling constraints of the pole, preventing full focus on the actual measurement task and raising safety concerns when working in areas with increased risk of injury, such as on construction sites. This can hinder optimised productivity and accuracy otherwise offered by robotic total stations. Traceability and quality of the captured data is therefore limited.

To overcome the corresponding pain points, Leica Geosystems developed the Leica AP20 AutoPole. This pole-side innovation complements Leica Geosystems’ robotic total stations and extends reliable sensors onto the surveying and construction pole to addresses major problems across survey and layout workflows. The first-of-its-kind development of an IMU-based tilt compensation for Leica Geosystems’ GS18 T Smart Antenna was a primary factor leading to the creation of the AP20. The GS18 T has overcome the levelling constraint of GNSS poles and provided a proven technology suitable for integration into the total station environment. Merging this capability with other concepts to automatically detect height changes of the pole and eliminate manual searches, the AP20 was developed as a comprehensive solution.

The technological convergence in the AP20 addresses core pain points by making it possible to measure with a tilted pole, automate height changes in the field software and have the total station search and lock only to the correct target. Integrated into the overall measurement workflow, the AP20 enables the total station and surveying pole to become an interconnected solution which increases flexibility and productivity.

The following chapters describe each functionality in more detail, including market problems addressed, technological insights into applications across fields and key performance characteristics, such as accuracy.

## 2. TILT COMPENSATION

Levelling the pole for every point measurement is a prominent pain point in handling reflector poles. This constraint causes a variety of problems for the operators, ranging from losses in productivity to safety concerns to a lack of trust from missing traceability of the manual levelling quality.

### 2.1 Underlying market problem

Survey engineers, construction surveyors and layout engineers face similar time pressure and quality challenges. Time slots to fulfil specific measurement tasks are often narrow and delays can have a direct influence on the following work, potentially resulting in penalties for the company. For example, in building construction, all involved companies and trades are accountable for finishing their tasks, like layout work, on time to avoid any delay or interruption during construction phases. Unexpected increases in workload can arise, while workforce shortages or staff turnover means experienced professionals must quickly train new crew members on the equipment.

Conventional reflector poles require the survey engineer and layout engineer to put emphasis on precisely levelling the pole before each point measurement, which takes precious time and concentration. In the example of a topographic survey with hundreds of points captured over a day, a considerable amount of the time in the field is typically spent on the manual levelling effort. In the case of mechanical, electrical and plumbing (MEP) work, layout engineers can get frustrated and slowed down when dealing with complex design data and doing several layout steps for each point simultaneously by

1. watching the direction guidance on the field software
2. observing the analogue bubble to keep the pole levelled
3. moving the pole to iteratively find the exact location to layout.

Apart from the time needed for levelling, the necessity of an upright pole alignment restricts accessibility to certain points of interests, such as:

- manholes obstructed by a parked car or wall corners where the spatial conditions do not allow vertical pole alignment
- points behind a tree or other obstacles which are blocking the required line of sight between the total station and upright pole
- nearby points behind a fence or in a trench which are not directly accessible by an upright pole due to legal or safety reasons

These restrictions often lead to time-consuming workarounds requiring either additional accessories to be carried, such as applying manual point offsets using a tape measure, or imposing the need to move the total station to an additional setup location.

Another aspect is the lack of quality control. Using the highest-grade and accurate total stations cannot prevent coordinate errors caused by mistakes in the manual levelling of the pole from human error or by a misadjusted analogue bubble (as it might occur during the lifetime of a pole). Therefore, the manual levelling step represents a gap in the otherwise sensor-based, reliable data capture and digital dataflow and does not provide evidence about the current point quality. Even for highly experienced professionals, concentrating on an analogue bubble over the whole working day is challenging and moments of distraction can cause a loss in data quality which may have a considerable influence on the subsequent work. Additionally, new crews rarely reach the skill level of professional and experienced surveyors. Therefore, an easy to use and robust surveying equipment which reduces human handling errors to a minimum is even more crucial.

### 2.2 IMU-based Tilt Compensation

The AP20's tilt compensation functionality allows operators to disregard the analogue bubble to survey and layout points with an arbitrary aligned pole. This increases productivity in the field and allows nearby hidden point measurements which were previously cumbersome to capture.

**Figure 1** Examples of points which previously were impossible to measure with an upright levelled pole

With the AP20, the whole measurement chain is based on reliable sensor input instead of manual levelling constraints. Therefore, the progress and quality of fieldwork is less affected by the skills and concentration of the individual operating the pole. IMU technology is used within the AP20 to determine the 3D pole alignment in space. Similar to the Leica GS18 T (Luo et al., 2018), an IMU based on industrial-grade microelectro-mechanical systems (MEMS) include a three-axis accelerometer and a three-axis gyroscope to measure precisely acceleration and angular velocity. These observations, together with continuous target positions from the total station, are provided to a customised inertial navigation system (INS) integrated into the AP20. The INS algorithm mathematically rotates and integrates the IMU measurements into the coordinate system of the total station and determines the attitude of the pole and its associated quality measure. In this context, the term "attitude" describes the 3D orientation of the pole in the given coordinate system of the total station.

In addition to the total station and AP20, a new Leica Radio Handle and Leica AP reflector pole are essential to successfully integrate the INS into the total station environment and therefore profit from an accurate and reliable tilt compensation functionality.

The new Radio Handle (RH18, CCD18) allows a simultaneous connection to the field controller and AP20 and ensures an exact synchronisation of the total station’s and AP20’s sensor clocks, which is needed for processing tilt in real-time. The new AP reflector poles provide a mechanical interface to precisely align the AP20 to the pole axis. Without such precise axis alignment of the IMU sensor to the pole axis, accurate and reliable tilt compensation would not be possible. Carbon material is used to ensure mechanical stiffness and a straight pole axis over time, while the upper tube part of the pole close to the AP20 antenna consists of non-conductive material to ensure no disturbances on the Bluetooth range performance.

Starting tilt compensation is simple for the operator. Apart from initially establishing a Bluetooth connection to the AP20, tilt compensation starts after the target is locked and the pole was exposed to some motion. This initialisation movement is needed in order to solve for the pole attitude and for the IMU biases. The internal quality control mechanisms allow an automatic start/stop of tilt compensation if the estimated 3D attitude uncertainty is below/above a certain threshold. Under normal conditions this can be achieved within seconds of pole movements. Accelerations enable valuable IMU data, while a higher range of supporting target positions give better reference trajectories from the total station and enable a stable performance of active tilt compensation.

A more detailed overview of the individual steps within the internal system workflow is given as following. Once the AP20 is connected, all sensor clocks are automatically synchronized. Having the time stamps of the individual total station and AP20 observations in the same time frame is mandatory for the real-time computation of the pole attitude. Once Tilt Compensation starts, the following system workflow occurs:

1. The total station starts continuous distance measurements onto the locked target and streams the captured 3D target positions and quality to the AP20.
2. The IMU inside the AP20 continuously measures accelerations and angular rates.
3. The INS processes total station and IMU observations and computes current pole attitude.
4. The pole attitude and attitude quality is streamed back to the total station.
5. The field software within the total station computes pole tip coordinates and quality based on the current target position, target height and attitude.
6. The total station forwards the data to the optional field controller, in case of 1-person operation.

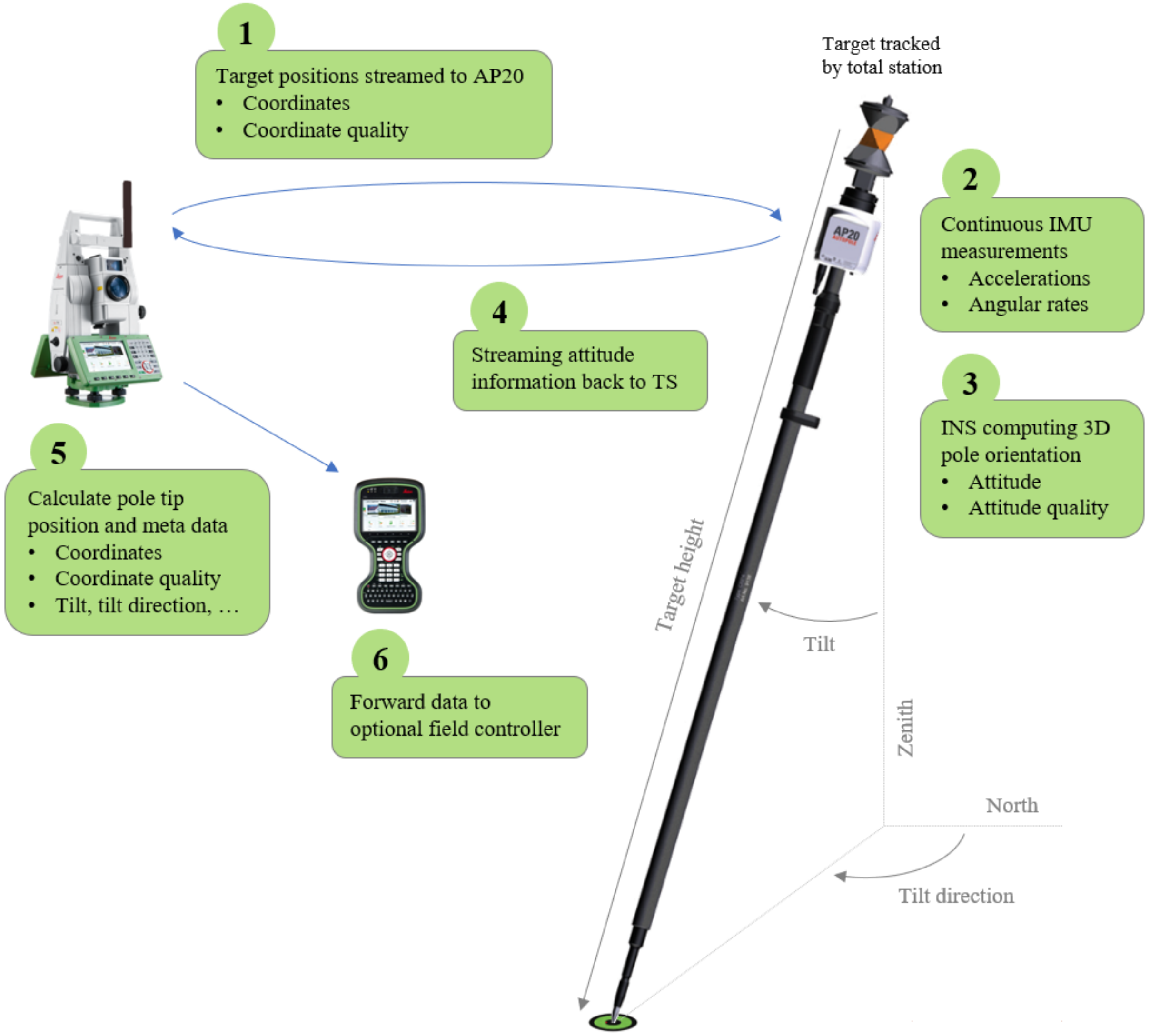

**Figure 2** System workflow of running tilt compensation

### 2.3 Accuracy aspects

The pole attitude can be expressed in different components such as the tilt and tilt direction. Since these represent angular corrections from the target centre to the pole tip, position errors of the pole tip due to INS attitude errors depend on two main factors: the used target height and the amount of tilt (see Figure 3). The target height is used together with the target position and the attitude estimate to compute the position of the pole tip. Therefore, the lower the target height, the smaller the tilt error on the pole tip. The second main factor is the amount of tilt. The less the pole is tilted from zenith or nadir, the less the impact of the tilt direction and furthermore its error component on the pole tip.

**Figure 3** The smaller the target height, the smaller the projected footprint of a certain tilt error $\alpha$ (see left). The smaller the tilt, the smaller the impact of a certain tilt direction error $\beta$ (see right).

Using known reference points given in the coordinate system of the total station, the contribution of the mentioned error sources to the overall pole tip position error can be tested and analysed. Figure 4 shows the 2D and 1D root mean square (rms) error of the pole tip position, which is purely caused by the INS attitude error over a target height of 2.0 m. 2D refers to Easting/Northing component while 1D refers to the Height component. The green rms dots represent an overall dataset of 2'200 tilt compensated point measurements captured with different total stations and AP20s.

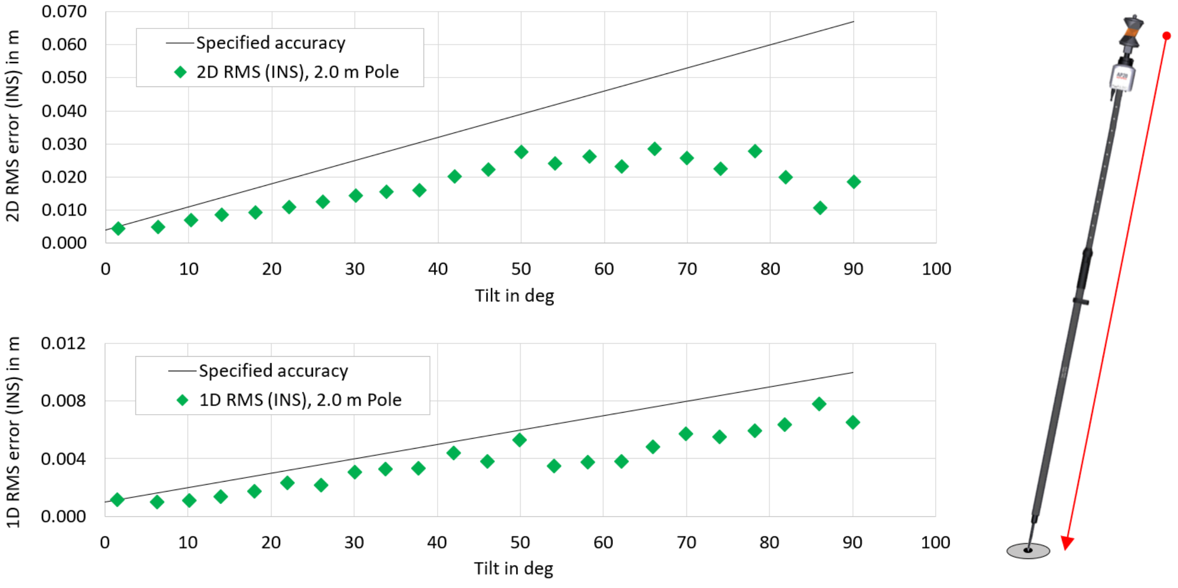

**Figure 4** 2D and 1D root mean square (rms) error of the pole tip position due to the INS attitude error (target height: 2.000 m, tilt bin width: 4 degrees)

In contrast, Figure 5 shows the reduced rms error using a smaller target height of 0.228 m. Such low target height can, for example, be set up by attaching the exchangeable pole tip CRP10 to the upper prism interface of Leica GRZ122 (5/8” screw thread).

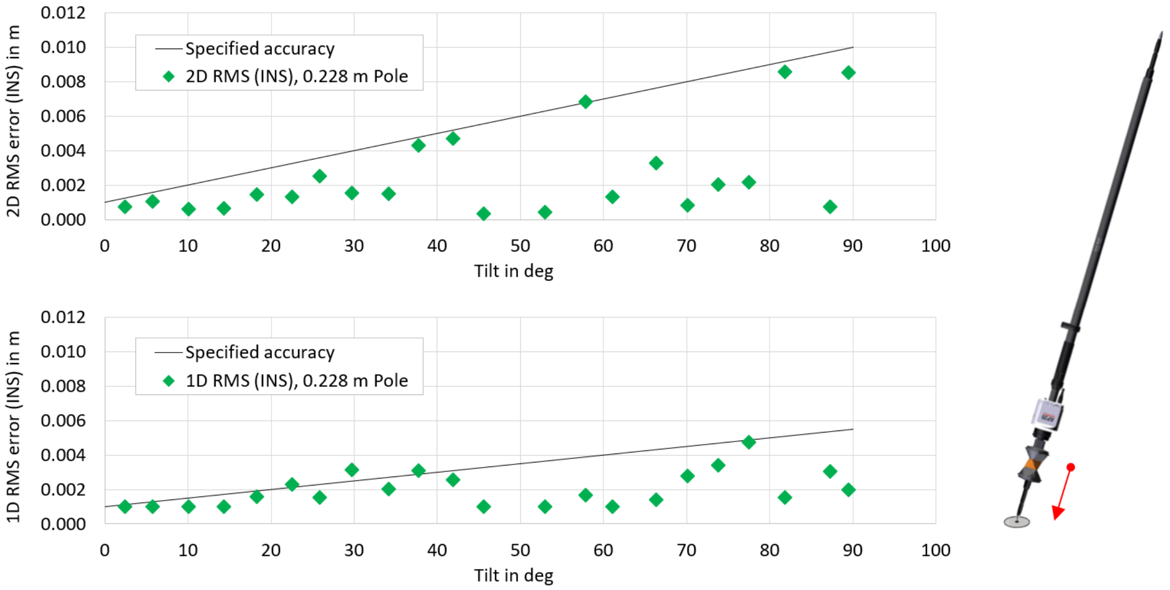

**Figure 5** 2D and 1D root mean square (rms) error of the pole tip position due to the INS attitude error (target height: 0.228 m, tilt bin width: 4 degrees)

In the field, the operator therefore has the flexibility to overcome challenging site conditions and has control to adjust the pole handling according to the required demand in accuracy. Measure points faster and with highest accuracy using a small target height and a small degree of tilt. Measure previously inaccessible points and overcome obstacles using a highly extended pole tilted in an arbitrary direction.

In addition to providing continuous attitude information for tilt compensation, the INS gives an estimate of the attitude quality. Knowing both the estimated target position quality from the total station and the attitude quality from the INS, the field software can express the overall pole tip coordinate quality according to the error propagation law. Considering the high accuracy of angle and EDM measurements of the supported total stations, target position errors are typically in a level of some millimetres and therefore do not significantly increase the overall pole tip error compared to the magnitude of the INS attitude error shown in Figures 4 & 5. Shown as coordinate quality within Leica Captivate field software, the operator is continuously aware of the current survey and layout quality and has a traceable quality control over all stored points.


Leica AP20

1D 0.001 m
2D 0.008 m

Easting
546772.894 m

Northing
5250725.213 m

Height
451.030 m

3D quality
0.008 m

**Figure 6** Real-time representation of the estimated overall coordinate quality of the pole tip (incl. target position and attitude quality) within Leica Captivate field software

## 2.4 Dataflow

Many software applications not only rely on provided 3D point coordinates but also on the related meta data, such as total station observations, used target height, etc. This allows later adjustments in field and office and maintains certain dataflow compatibility.

One example of a later point adjustment is the update of the target height. When measuring with a tilted pole, it becomes even more important to set the correct target height. Applying the attitude on a wrong lever arm affects not only the height component of the calculated pole tip but the overall 3D coordinate. Therefore, Tilt Compensation and PoleHeight (described in chapter 3) is an essential combination of functionalities. Nevertheless, there might be cases which require a later update of the stored point to a different target height. By knowing the attitude of the stored point, both Leica Captivate and Leica Infinity office software allow such later target height update and re-calculate the 3D pole tip coordinate accordingly. This is only supported with the original DBX format or when exporting the job as HeXML v2.0, since these formats include the necessary attitude information.

Another example showing the importance of the point's meta data is the compatibility with 3rd party software. Many applications do not import the 3D point coordinates but rather use original observations – such as Hz, V and slope distance (SD) of the total station – for calculations in their existing workflows. Due to the pole levelling constraint, those processing algorithms expect total station observations to be on an upright pole and conventionally subtract target heights in the vertical coordinate component only. To stay backwards compatible and further support those existing workflows, tilt compensated points include two sets of total station observations (Hz, V, SD) stored within the database:

- compensated observations which refer to a virtually levelled pole
- original observations to the actual tilted pole

The compensated observations are written to the default database entries of Hz, V and slope distance, so that the existing dataflow conventions are not harmed and workflow adaptions are unnecessary. The original observations to the tilted pole are stored as new database entries. Leica Captivate for instance indicates this compensated observation type in the observations page of the stored point, HeXML v2.0 include these new observations in the export as well.

By such enhanced workflows, earlier mentioned pain points are overcome both in field and office. Topographic surveys can be sped up significantly by accessing more points in less time. Measurement professionals of different industries can put full focus on the actual survey and layout tasks instead of concentrating to observe the analogue bubble. The captured data includes higher traceability and quality for later post-processing.

## 3. POLEHEIGHT

### 3.1 Underlying market problem

Survey engineers and construction surveyors need to deliver data with correct heights. An extendable pole helps them overcome line-of-sight interruptions, such as static obstacles on site or vehicles and people passing by. The resulting process of changing the height is repeatedly performed during the workday onsite and includes several steps for the operator. Once the pole is extended, the new height:

- needs be read from the printed height scale on the pole,
- needs to be communicated to the total station operator (in case of 2-person operation),
- needs to be entered into the field software (known as “target height” input field when using TS mode in Leica Captivate)

The described manual steps have several disadvantages:

- a new height can be misread on the pole and can be wrongly typed into the field software
- a new height can be incorrectly communicated to the colleague on the total station
- due to distractions on site, entering a height change can be completely forgotten

The consequence is a high potential for incorrect heights within the captured data. When measuring with a tilt compensated pole, as described in chapter 2, not only the height component of the measured point would be affected but the overall 3D coordinate would be calculated wrong. Updating the captured data later to the correct target height is possible but requires the operator to remember the correct height at the specific point in time, which is often not possible. Tracing back the actual target height and updating all affected measurements to save the job requires significant effort in post-processing or alternatively a return to the field for re-measurement.

### 3.2 Magnet-based snap lock detection and update

The AP20’s PoleHeight functionality eliminates the effort and risks of these manual steps.

A physical extension or reduction is automatically detected by the pole and immediately communicated to the field software of the connected total station or field controller. Within the field software, the target height input field is updated accordingly. Therefore, apart from extending the pole to the desired height, no further action is needed from the operator.

The technology consists of several parts. Starting from the supported Leica AP reflector poles (GLS51, GLS51F, CRP4, CRP5), the handgrip on the lower tube includes a built-in magnet inside the pin which snaps into the individual snap lock positions of the upper extendable tube. This upper tube on the other side consists of passive electronic components inside. Hall sensors behind each snap lock position detect the nearby magnetic field coming from the magnet at the handgrip and can therefore assess which position is currently snapped in (see Figure 7**Figure 7**).

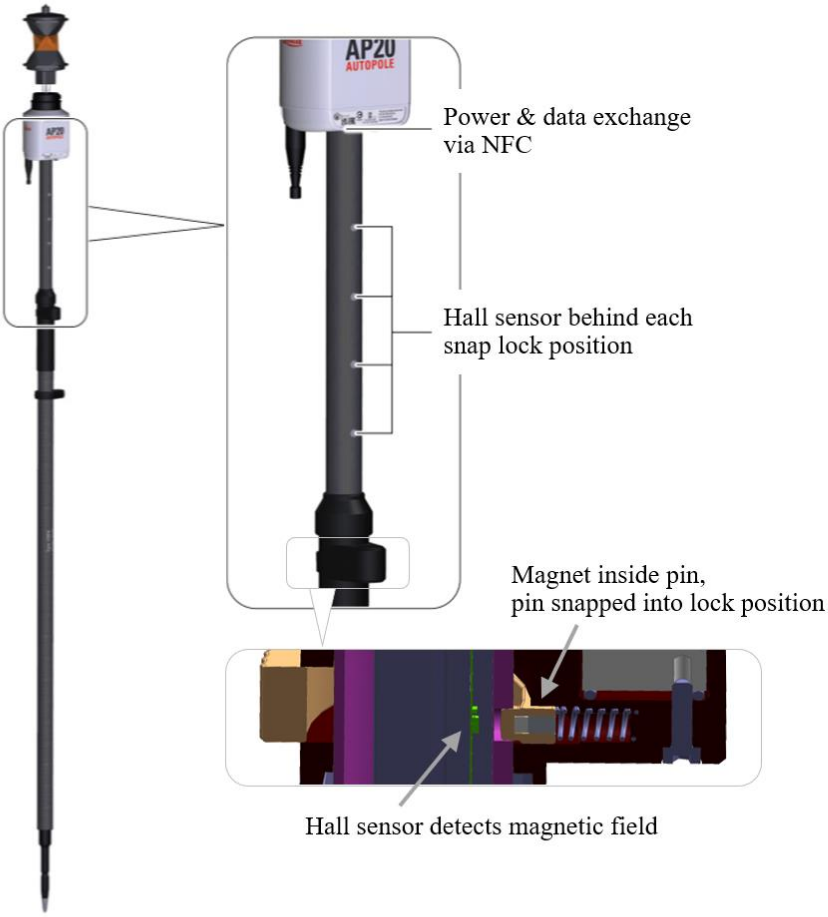

**Figure 7** Schematic view of relevant components to detect the current height

Pole dimensions and order of hall sensors behind the snap lock positions are known and, therefore, each detected position can be referenced to its according height value if the pole is engaged into a snap lock position. Near-field communication (NFC) is used to transmit the read height from the pole to the attached AP20, which forwards the update to the connected field software on the total station or field controller. Based on inductive coupling, the NFC technology provides data exchange and allows the pole to harvest energy from the attached AP20. This means, the pole itself does not require any internal power source. In case an intermediate position between two snap-locks is set, none of the hall sensors will reply to a magnetic field and based on that the pole can state an invalid height reading. This information is used within the field software to inform the user to manually enter the intermediate height. On the other side, using the combination of PoleHeight and Tilt compensation functionality reduces the need of intermediate, manual heights since instead the pole can be tilted towards a free line of sight to the total station.

## 4. TARGETID

### 4.1 Underlying market problem

Tight time schedules put a lot of pressure on surveying and construction professionals that need to execute tasks correctly and on time. This becomes even more challenging on busy construction sites, with different crews working in the same area. Crews from other companies can be around using their own surveying equipment – such as total stations and reflector poles – for their individual tasks. For data capture and layout tasks, this can lead to disturbances in the initial target search and later in case of line-of-sight interruptions.

Repeated search-find-verify steps take time, and the more different targets are around, the longer it can take. In particular when working in 1-person operation remotely from the field controller on the pole, it can be difficult for the operator to verify on which target the total station is currently aiming. This all leads to distraction from the workflow, frustration and an increased downtime, where no actual survey tasks can be performed. Productivity suffers and scheduled construction phases can be at risk to be delayed.

### 4.2 PowerSearch-based target identification

The AP20's TargetID functionality enables an automatic target search and identification and therefore extends the operative and productive time on the pole. Integrated into existing search methods, even moving foreign targets are ignored during the search process so the total station only stops at the particular pole equipped with the AP20. A lock onto a foreign target is prevented, user effort of manual target checks is reduced and time is saved to immediately start the actual work.

To provide this functionality, the AP20 includes a ring of 10 LEDs that transmit an optical signal with a specific identifier (ID) coded in its pulse frequency. This signal can be read by the PowerSearch (PS) receiver. A total station with PS capability is therefore mandatory to use TargetID functionality. The emitted frequency is set via the according ID number within the field software and allows 16 different IDs. After a Bluetooth connection is established, the total station or field controller automatically synchronises the chosen ID number with the connected AP20 and then only searches for this particular identifier and its corresponding target.

Once the user starts a target search via the field software, the following steps are performed automatically:

1. Total station triggers AP20 to enable target ID transmission
2. Total station starts horizontal search movement
3. Total station's PS receiver monitors incoming target reflections and target ID frequency from AP20 (see Figure 8)
4. Only if the correct target ID is detected, horizontal search stops and telescope aligns towards Hz direction of the target ID's peak signal
5. Automatic Target Recognition (ATR) performs a vertical search and aims to the optical centre of the attached target
6. After search is successfully complete, AP20 automatically disables target ID emission

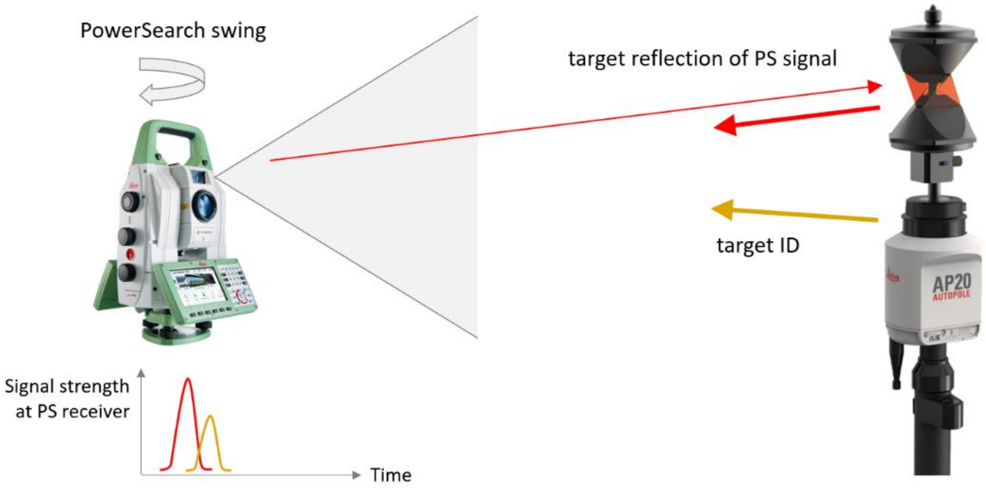

**Figure 8** Schematic illustration of incoming signals on PS receiver

The wireless communication via Bluetooth makes it possible to change the desired ID number by setting it within the field software of the total station or field controller. The AP20 is synchronised automatically. This connectivity also informs the AP20 about the start and end of the total station's search procedure. The ID transmission is only active if a search is in progress. Having several crews on site, each equipped with an AP20, the individual operators can coordinate their IDs before starting work. With this, up to 16 AP20 operators could work on the same site without interference during target searches. Even if two operators would have set the same ID, the probability for interference is low since ID transmission is not permanently active, but only during the search period of the individual total station. This additionally saves battery consumption.

By separating the source of the ID signal from the actually measured (optical) target, the morphology enables compatibility with any existing Leica Geosystems reflector that fits on the pole. Thus, TargetID functionality works regardless of whether a round prism or 360° prism is attached and the measurement performance onto the precise target centre remains at the high level of the given total station.

## 5. CONCLUSION

This paper presented the new AP20 AutoPole, a smart system that converges latest sensor technologies to effectively automate the so far manual processes in an otherwise digital workflow with Leica Geosystems robotic total stations.

Testing demonstrated that using the AP20 significantly increases productivity, with time savings across the workflow. When all three AP20 functionalities are used in conjunction, operators can:

- Measure points faster without the need to level the pole.
- Measure previously inaccessible points and increase direct point measurements without offset calculations, additional total station setups and registering process to access private property
- Measure safely on construction sites, along roadways and in other settings with potential hazards through flexible pole handling. Being able to keep higher attention to the surrounding and spend less time in possibly dangerous conditions, rather than being distracted by levelling or recording height changes.
- Begin work faster and have less interruptions over the day with the assurance of correct target lock on dynamic sites with multiple operators.
- Automatically acquire all needed data in the field without the need for post-processing corrections, saving time in the office and enhancing quality assurance.

These possibilities create the opportunity for current skilled professionals to complete more work in less time, while also lowering the technical entry barriers for newcomers, alleviating market issues like workforce shortage and tight schedules. Considered altogether, the AP20 enables a transformation of the measurement professional's processes within automated total station workflows.

## REFERENCES

Luo, X., Schaufler, S., Carrera, M., Celebi, I. (2018), High-precision RTK positioning with calibration-free tilt compensation. In: Proceedings of FIG Congress 2018, Istanbul, Turkey, May 6–11, 2018, 17 pp

## BIOGRAPHICAL NOTES

Mr. Hannes MAAR is a Senior Product Engineer in the TPS Product Management group at Leica Geosystems. He received his M.Sc. degree in Surveying and Geoinformation from the Vienna University of Technology, Austria.

## CONTACTS

Mr. Hannes Maar
Leica Geosystems AG
Heinrich-Wild-Strasse
9435 Heerbrugg
SWITZERLAND
Tel. +41 71 727 3198
Email: hannes.maar@leica-geosystems.com
Website: https://leica-geosystems.com/