Integration of GPS and total station technologies

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The idea of combining GPS and total stations is not new. Stansell [1] predicted that by the year 2000 surveyors would combine conventional survey instruments and GPS as an integral part of every survey job. The release of SmartStation from Leica Geosystems marked a significant step in making integrated GPS and total station technology commercially available.

Traditionally, surveyors used angles measured with theodolites and distance measured with a steel band or electronic distance measurement (EDM) device to propagate coordinates from one point to another using the technique of traversing. The total station simplified the procedure of traversing by integrating the EDM into the theodolite and reading all measurements digitally. The introduction of satellite positioning systems has provided the surveyor with an additional measurement technology to perform survey tasks.

GPS, in particular realtime kinematic (RTK) GPS, provides surveyors with an efficient tool to conduct their survey activities. Although RTK GPS is now widely used, there are still many surveyors who do not benefit from GPS technology because of a perception of complexity and expense. Integrated GPS and total station systems significantly improve the efficiency of surveyors, are easy-to-use and provide a cost effective entry point to RTK GPS technology.

Survey equipment advances

Survey instruments have come a long way since the days of transits and steel chains. Modern total stations now include reflectorless EDM measurements, have a broad range of on-board application programs, automatically conduct fine pointing to prisms, automatically find prisms and allow one-man robotic operation to conduct stakeout and detail surveys in a highly efficient manner.

With regard to GPS, since the first introduction of GPS equipment, there has been a significant reduction in the size of the equipment coupled with significant improvements in the accuracy of the measurements. Today, almost all survey grade receivers have RTK functionality to provide centimetre accuracy in the field. RTK GPS allows surveyors to conduct stakeout and detail surveys in a highly efficient manner. In many regions, the availability of a GPS reference station network means that surveyors can utilise RTK GPS without the need to setup their own local reference station. They simply enter the field, dial in to their reference station network and begin RTK GPS surveying.

Reference station networks are increasing in popularity as many government agencies have found it more economically viable to invest in GPS reference station networks rather than maintaining ground control. In addition, many private companies have seen opportunities in setting-up reference station networks and selling the data to an increasing number of users.

Despite many advantages, surveying using only total stations or GPS has disadvantages. Surveying with a total station, unlike GPS surveying, is not disadvantaged by overhead obstructions; however, it is restricted to measurements between inter-visible points. Often control points are located distant to the survey area, and traversing with a total station to propagate the control is a time consuming task.

For this reason, GPS is frequently used to bring control to the survey site before continuing the survey with a total station in areas with overhead obstruction that limit the use of GPS. This procedure is a two-step approach that requires multiple set-ups on points, one with GPS and then again with a total station. Lengthy traverses and multiple set-ups are eliminated by integrating RTK GPS into a total station to provide maximum efficiency for common survey tasks.

The technology

A new generation of total station (TPS) and GPS equipment, was introduced in February 2004 [2]. This was the first step toward a complete integration of GPS and total station instrumentation. The integration covered all facets of the equipment including user interface, database, batteries and chargers and office software.

The total station equipment provides angular measurement accuracies ranging from 1” to 5” of arc and distance measurement to prisms at distances of 7.5 km with an accuracy of 2 - 5mm + 2 ppm and to other surfaces (reflectorless) at distances of more than 500 m with an accuracy of 3 - 5mm + 2 ppm. The GPS equipment includes advanced technologies to provide accurate and reliable GPS positioning. Today the total station and GPS equipment are used in harmony as efficient survey tools to complete challenging tasks.

Recent advances introduce the next logical step in the integration of total station and RTK GPS technology. In these applications the antenna is located collinear with the vertical axis of the total station equipment. Once the antenna is connected, to the total station, all operation is conducted through the keyboard of the total station.

Fig. 1: Known back-sight.
Data from the GPS reference station to provide RTK positioning of the product is received through a communication device which is clipped-on to the product (radio modem, GSM, GPRS, TDMA, CDMA) or via a Bluetooth wireless connection between the total station and a mobile phone. GPS RTK positioning is integrated into the total station set-up procedure and is simply conducted with one key press to obtain the RTK GPS position. The integrated tool can be located at ranges of up to 50 km from a reference station and still provide accurate positioning (horizontal: 10 mm + 1 ppm; vertical: 20 mm + 1 ppm).

Set-up possibilities

Set-up on a conveniently located unknown point and back-sight to known point(s) (see Fig. 1):

• Determine the equipment’s coordinates from RTK GPS and orientation from observation to one (or more) back-sight point(s); if desired the RTK GPS height can be updated from total station observation(s) to point(s) with known height;
• Measure all points from current location and then move to another convenient known or unknown location.

Set-up on a conveniently located unknown point and back-sight to another unknown point (see Fig. 2):

• Determine the equipment’s coordinates of the first unknown station from RTK GPS and observe back-sight to another unknown point.
• Complete total station measurements from current station.
• Move equipment to second unknown point and determine RTK GPS positioning.
• Back-sight to previously occupied point; orientation is computed and all measurements are updated and coordinates are re-computed.
• Continue with total station measurements from current station.

Once positioning of the total station is complete, if desired the antenna can be removed from the equipment and used as an RTK GPS rover.

Survey scenarios

To describe the benefits of the technology, four typical survey scenarios are illustrated, namely:

• Remote area – topographic survey
• Rural area – boundary survey
• Construction site – stakeout
• Urban area – utilities survey

Remote area – topographic survey

Topographic surveys in remote areas often have vegetation that limits the exclusive use of GPS to complete the survey. In many cases, GPS is used to establish control before the survey is continued using total stations. Given that a GPS reference station is operating in the vicinity (up to 50 km) and transmitting RTK corrections, RTK GPS can be used to establish control points.

To complete such a survey using conventional techniques RTK GPS would be used to measure a series of control points. These coordinates would then be transferred to the total station and one of the newly established control points would be used as the total station set-up location and a back-sight would be observed to another newly established control point. All necessary detail points would be observed from the first station before moving to subsequent points to complete the survey. If the total station survey was conducted before the GPS control was established, an additional step would be required. The total station observations would need to be transformed in the office to be compatible with the GPS control points.

With the combined GPS and total station technologies, this survey would be conducted by setting-up the equipment in a convenient location and determining the coordinates with RTK GPS. A back-sight would then be observed to a second unknown point that will be used, but is not yet coordinated. All necessary detail would be observed from the current location before relocating to the second point. When set-up at the second point the coordinates are determined with the equipment’s RTK GPS. The availability of this second coordinate then allows the system to automatically update all observations made from the first set-up. After back-sighting to the first set-up point all detail can be observed from the second point in the required coordinate system.

Benefits

• Points are only occupied once.
• Two independent sets of equipment are not required.
• Survey is completed in less time.

Rural area – boundary survey

In rural areas, it is not uncommon that control points are located up to 5 km away. With a conventional total station this demands a time consuming traverse. An open traverse is liable to error, and a closed traverse back to the same point can take twice as long. Traversing is complicated and time consuming, especially in difficult terrain. Once control has been introduced to the area, the boundary survey can continue by traversing around the boundary of the parcel and taking observations to boundary markers.

With GPS reference station data available, the equipment can be set-up at any convenient location close to a boundary marker. After determining an RTK GPS position with the system, and observing a back-sight to another suitable located point (known or unknown), observations to the boundary marker can be taken. The equipment can then be taken to the next convenient location to continue the boundary survey.

Benefits

• No long traversing required.
• Fewer instrument set-ups required.
• Survey is completed in less time.
• Uniform, higher accuracy obtained.

Construction site – stakeout

Construction sites normally include a large number of control points, however, these points are often obstructed by machinery and material. In addition, frequently control points are damaged during construction activities, further hindering survey activities. Construction sites demand a high level of efficiency of survey tasks as designs are continually changing and many points need to be staked-out in a short period of time. GPS is increasingly being used for construction site survey activities and a GPS reference station is often set-up at the site office to provide RTK corrections for the site.

Stakeout activities using a total station on a construction site are often difficult and time consuming. Normally, the total station is set-up in a convenient location and a resection is conducted to determine station coordinates and orientation. Finding a suitable location...
is often not trivial; control points are frequently damaged or obstructed and the geometry of the resection also needs to be considered. All of these constraints regularly lead to a lengthy process in establishing station coordinates and orientation. Under time pressure, the extra time required to find a suitable location is undesirable.

Using integrated GPS and total station technologies, a location can be chosen that best suits the stakeout task at hand. Set-up the equipment and determine the station coordinates using RTK GPS, then simply back-sight to any control point to determine orientation. Stakeout activities can then begin immediately.

Benefits
- Set-up where convenient.
- No traversing or resection required.
- Obstructions on site are no longer a hindrance.
- Stakeout can begin rapidly.
- Construction work can be completed sooner.

Urban area – utilities survey
Increasingly, the positions of utilities are being coordinated with high accuracy to update spatial databases. The features that are surveyed include manholes, covers, hydrants, distribution boxes for water, gas and electricity. The features are often in locations where buildings and tree cover prohibits the exclusive use of GPS to coordinate such features.

A total station provides an excellent tool to capture utilities, however, often control points are obstructed by traffic, and parked vehicles, hence rendering traversing essential. Whenever traversing is required, careful reconnaissance needs to be conducted which is time consuming. Once traversing to the station location is complete, the total station is used to coordinate the utility features.

With the combined GPS and total station technology, no reconnaissance is required. Set-up at any convenient location, determine station coordinates using RTK GPS, and measure all features in the vicinity. If no control point was visible from the current location, the point used for a back-sight is occupied with the system and coordinated with RTK GPS. All measurements are automatically updated.

Benefits
- Control points are not needed.
- No awkward traversing required.

Consistent high accuracy.
- Complete survey quicker.
- Traversing skills not required.

Comparison with conventional traversing
A survey was conducted to compare the efficiency of conventional traversing and the combined GPS and total station technologies. The topographic survey of a car park (5700 m²) was conducted twice, once using a conventional total station and a second time using the combined GPS and total station equipment (see Fig. 3). Three control points (PM 115, PM 114, PM 227) existed in the vicinity of the area to be surveyed, one adjacent to the car park and another two on the main road, 200 m away from the car park and not visible from the survey area.

The conventional total station traverse involved four instrument set-ups (PM 114, 001, 002 and 003). The points 001, 002 and 003 were established during the reconnaissance period of 20 minutes. At each set-up, one round of face left and face right observations were observed to each back-sight and fore-sight point. The control portion of the survey took 55 minutes and the detail survey took an additional 60 minutes (see Table 1).

Closing the traverse from set-up 003 to point PM 227 generated a misclosure of 12 mm horizontal and 10 mm vertical. A portion of the detail measured can be seen in Fig. 4.

To complete the survey using the combined total station and GPS technology, two instrument set-ups were used. At each set-up RTK GPS positioning was conducted, and one set of face left and face right observations were observed to a back-sight. At station 003, PM 227 was used as the back-sight and at station 002, point 003 was used as the back-sight. PM 227 was not visible from point 002 due to obstructions.

A distinct advantage of the system is the reduced time needed for reconnaissance. To facilitate comparison calculations, the same stations were used as for traversing and the combined equipment set-ups (i.e. 002 and 003). The reconnaissance time needed for the combined system survey was half of the traverse survey as fewer set-up and back-sights were required. If one point could have been found that enabled the topographic survey to be completed while maintaining visibility to the control point PM 227, additional time savings could have been realised.

The combined total station and GPS equipment automatically begins acquiring satellites and computing precise positions once turned on. By the time the instrument is leveled and positioned over

<table>
<thead>
<tr>
<th>Activity</th>
<th>Time taken</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reconnaissance</td>
<td>20 min</td>
</tr>
<tr>
<td>Control traverse</td>
<td>55 min</td>
</tr>
<tr>
<td>Detail survey</td>
<td>60 min</td>
</tr>
<tr>
<td>Total</td>
<td>135 min</td>
</tr>
</tbody>
</table>

Table 1: Time taken to complete the topographic survey using conventional traversing.

Fig. 3: Survey area.
the point, the system can immediately deliver precise RTK positions.

The time taken for each combined system set-up was the time required to set-up over the point and observe the back-sight (face left and right).

In normal combined total station and GPS applications, the instrument set-up can be greatly expedited (especially for inexperienced total station users) by not requiring a set-up over a particular point. All that needs to be done to set-up the system is to level the instrument using the foot-screws at any location that is conveniently located in the survey area and has visibility to a known point, press a single button to get the RTK GPS position and sight to the back-sight (see Table 2).

The differences between the coordinates derived from the combined system and from conventional traversing for points 002 and 003 are shown in Table 3.

Additional points were observed twice during the topographic surveys, once during the survey from the conventional traverse and once again from the combined total station and GPS set-ups. Each of the points delivered coordinate differences of less than 15 mm in both the horizontal and vertical components. This additional check confirms correct determination of orientation using the combined total station and GPS instrumentation.

In this survey, the time saving (41 minutes or 38% of the total time) was obtained by eliminating the

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**Table 2: Time taken to complete the topographic survey using combined total station and GPS technology.**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Time taken</th>
</tr>
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<tbody>
<tr>
<td>Reconnaissance</td>
<td>10 min</td>
</tr>
<tr>
<td>2 x SmartStation set-ups</td>
<td>14 min</td>
</tr>
<tr>
<td>Detail survey</td>
<td>60 min</td>
</tr>
<tr>
<td>Total</td>
<td>84 min</td>
</tr>
</tbody>
</table>

**Table 3: Coordinate differences between traversing and the combined total station and RTK GPS system.**

<table>
<thead>
<tr>
<th>Point</th>
<th>ΔHorizontal</th>
<th>ΔVertical</th>
</tr>
</thead>
<tbody>
<tr>
<td>002</td>
<td>11 mm</td>
<td>13 mm</td>
</tr>
<tr>
<td>003</td>
<td>9 mm</td>
<td>12 mm</td>
</tr>
</tbody>
</table>

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**Fig. 4: Car park – topographic survey.**
need to traverse from points PM 114 and PM 115 and reducing the time required for reconnaissance. In cases where control is located further away from the survey area far greater time savings can be expected when comparing conventional traversing and the product’s RTK GPS positioning.

Summary

The integrated GPS and total station technology removes the need for traversing to propagate coordinates from distant control points by providing RTK GPS positioning of the total station. To use the equipment, the surveyor does not need any specialist GPS know-how, RTK GPS positioning of the total station is achieved simply by the push of one button in the standard total station set-up application. The proliferation of GPS reference station networks means that in many cases a surveyor is within 50 km of a reference station and can dial-up and use the system to determine accurate RTK GPS positioning of the instrument.

The integrated total stations and GPS technology ensures that it is no longer necessary for surveyors to conduct extensive traversing, the equipment can be set-up at a convenient location and the survey can begin immediately. If at least one point with known coordinates exists in the survey area, then as little as one system set-up is needed that has inter-visibility to the known point to complete the survey. If no known coordinates exist in the survey area, a minimum of two inter-visible system set-ups would be required to complete the survey.

When compared to existing, commonly used, methods of traversing or separately establishing GPS control before the survey is continued with a total station, the equipment delivers substantial efficiency improvements.

Conclusion

A comparison between conventional traversing and the combined system on a topographic survey showed that the survey was completed 38% faster using the integrated technology while maintaining an accuracy of better than 15 mm in both horizontal and vertical components. The time savings were achieved through reduced reconnaissance and eliminating a control traverse to propagate control to the survey area.

References


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