Spatial Integration of Surveys Takes the Next Step

By Robert Jones, RLS

Soon, surveyors will be able to spatially integrate all their surveys, points, and lines within a GIS and have that information instantly available over the Internet while in the field. Looking at a laptop on the front seat of their trucks, they will see an image of all surrounding surveys transformed to a single low-distortion projection underlaid with high-resolution color aerial photography, PLSS lines, roads, and governmental division lines. They will be able to upload the integrated spatial information to their data collectors in such a way that Virtual Reference Stations (VRS) will automatically snap their GPS rovers to physical locations on the face of the earth using any coordinate and bearing basis they care to create on the spot.

National Survey & Engineering, a division of R.A. Smith & Associates, a civil engineering firm headquartered in Brookfield, WI, is bringing this to reality. They have developed an operational desktop GIS application called Boundless (patent pending) that integrates otherwise unconnected surveys within a unified low-distortion map projection using corresponding Earth Centered Reference Frame (ECRF)-related coordinates. They have under development a Web-based enterprise version that will operate on ESRI's ArcGIS Server 9.2 platform and incorporate ESRI's ImageServer 9.2. The Web version will be accessible via any wireless Internet connection.

Surveyors must meet two requirements for integrating surveys worldwide within a unified GIS: a survey drawing database consisting of points and CAD files, and corresponding ECRF-related coordinates for a subset of the drawing database points. Where or how any of this data is maintained is immaterial as long as it is accessible to the GIS software.

With the advent of Global Navigation Satellite Systems (GNSS), Continuously Operating Reference Stations (CORS), and VRS, it is becoming ever more practical and feasible for surveyors worldwide to obtain sub-centimeter-accuracy ECRF-related coordinates in their normal workflow. In fact, modern integrated survey systems designed to increase productivity automatically result in ECRF-related coordinates if used within a VRS.


▲ As a one-man crew, Carl Chaput uses a total station, RTK rover, VRS, data collector, and laptop to eliminate post-processing and break down the barriers in integrating survey data into GIS

Carl Chaput and the Modern Integrated Survey System

Carl Chaput has worked at National Survey & Engineering as a crew chief for 20 years, and in the past three years he has had to adapt to the advent of the modern integrated survey system. Usually working as a one-person crew, he operates a Trimble 5603 robotic total station in concert with a Trimble R8 RTK rover and GPS base station. Today, Carl uses his base station less and relies more on VRS. He has always logged data at his GPS base station, and National Survey & Engineering has always post-processed that data within Trimble Geomatics Office (TGO) to obtain high-accuracy static vectors to at least three CORS so Carl's work, in addition to the work of other crews, is linked to the National Spatial Reference System (NSRS). The result is a point database for each project with corresponding ECRF-related coordinates expressed in NAD 83 (CORS) Epoch Date 2002 latitude, longitude, and ellipsoid height.

Now that Carl and the other crews are working within VRS, the need to post-process to obtain corresponding ECRF-related databases is becoming a thing of the past. As soon as Carl initializes in a VRS, he obtains high-accuracy ECRF-related coordinates that will underlie and form the basis for any and all low-distortion map projections (in Trimble parlance calibrations) he creates. He does this using Trimble Survey Controller software on his data collector to transform those ECRF-related coordinates to usable grid coordinates that reflect the legal description for the parcel he is surveying.

When Carl's Trimble job files are transferred to the server from his data collector, they are automatically converted to Trimble data collector DC files, which are then imported into TGO. TGO preserves Carl's calibration (low-distortion map projection that includes a translation and rotation) and at the same time contains the underlying

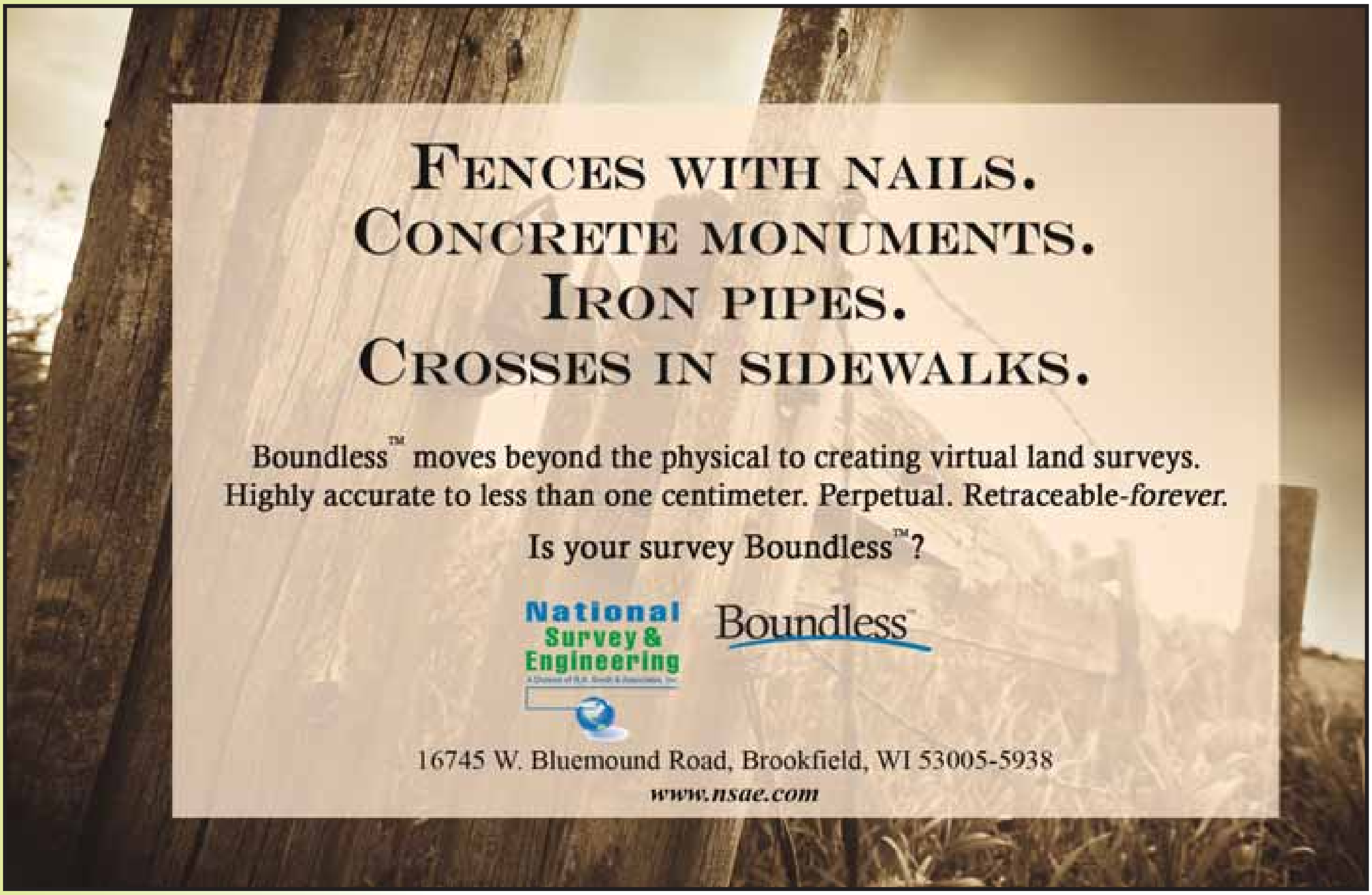
ECRF-related coordinates generated by the VRS corrector. The point numbers, northings, eastings, elevations, and descriptions are exported to a comma delimited CSV file for eventual import into Autodesk Land Desktop Development (LDD) for drafting. The VRS ECRF-related coordinates—point number, latitude, longitude, ellipsoid height, and description—for a selected subset of the points are exported to a CSV file imported into a GIS database. Alternatively, and more directly, Carl can export files containing the grid coordinates for his job and ECRF-related coordinates for a subset right out of Trimble Survey Controller and then copy them from his data collector to their appropriate locations on the server, bypassing TGO altogether. With the two simple requirements for integrating surveys met, there are no boundaries at National Survey & Engineering between survey databases and the power of GIS.

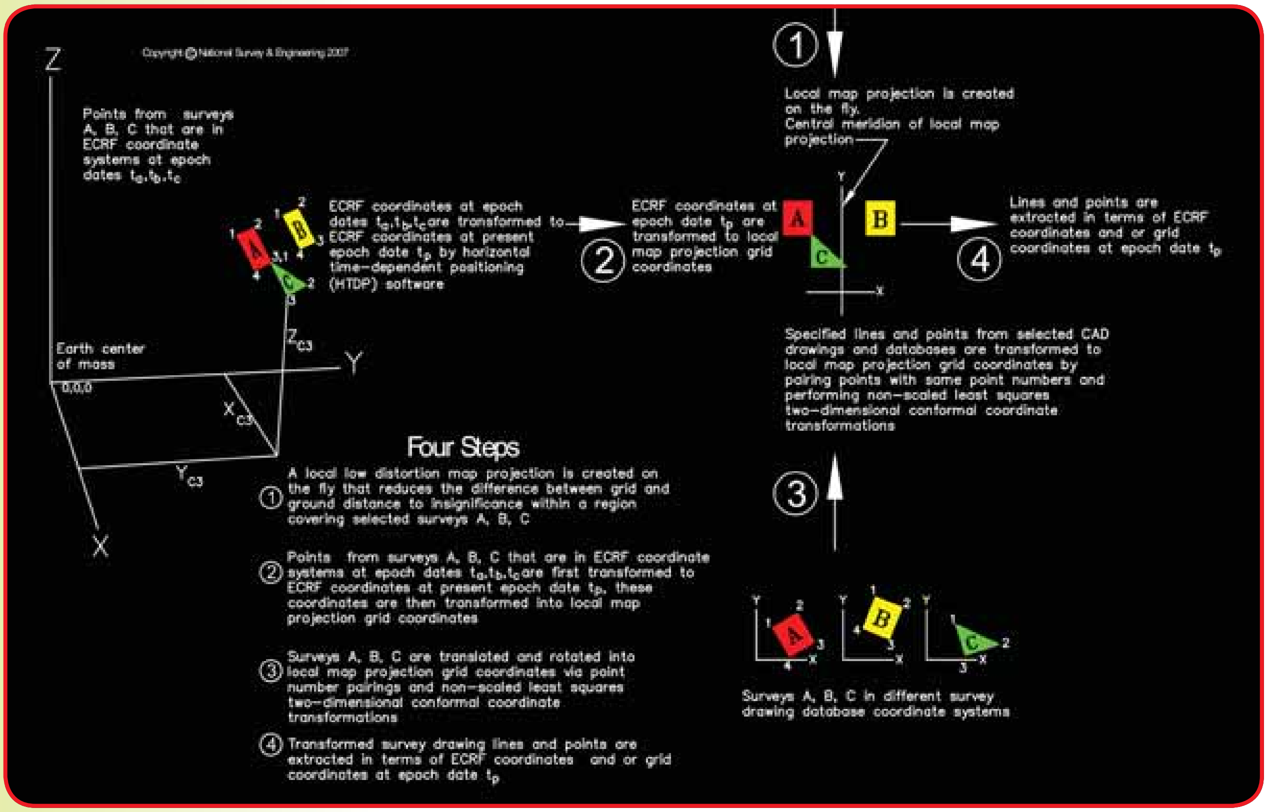
Carl Must Adapt Again

Within several months, the GIS department at R.A Smith & Associates will finish writing the Web-based enterprise version of our existing desktop Boundless application. When that happens, Carl will have to adapt again. Many days, he will not come into the office. Sitting at his breakfast table, he will connect to the Internet and read his e-mail that will inform him of his next job and provide computed coordinate files, scanned field notes, instructions, and other information.

At the dawn of this new day of enterprise survey GIS, Carl will probably begin an ALTA/ACSM land title survey for a proposed retail store development. As Carl will learn, the location of the parcel to be surveyed is surrounded by other surveys done over the years and that exist within the Boundless databases. At the job site, Carl connects to the Internet and Boundless by tethering the VRS cell phone to his laptop. He is operating what is called a thin client. All the computing he is about to initiate takes place on a central server, with the databases and aerial images all existing on that. The survey databases could be from surveys performed by the firm he works for or from multiple firms located anywhere in the world. The only data transmitted to Carl is the data he wants to see along with the results of the routines he will set in motion from his location in the field, which could be anywhere an Internet connection exists.

The laptop screen displays a scattering of blue dots representing the locations of completed surveys. At this point, Carl knows what other surveys exist nearby and their project numbers. He creates a virtual rectangle around the nearby surveys by windowing the screen. What happens next is automatic and unseen by Carl. Through USGS digital elevation models, the mean elevation covered by the rectangle is extracted, and via Geoid03, the mean geoid height is extracted. The earth radius at the center of the box is calculated. Using these inputs, along with the central meridian of the box and its intersection with its base, a local low-distortion map projection is created on the fly that reduces the difference between grid distance and ground distance to insignificance over the area covering the selected surveys. The ECRF data is now accessed, and the points for the selected surveys within this database are first transformed





Points from surveys A, B, C that are in ECRF coordinate systems at epoch dates t_a,t_b,t_c

ECRF coordinates at epoch dates t_a,t_b,t_c are transformed to ECRF coordinates at present epoch date t_p by horizontal time-dependent positioning (HTDP) software

ECRF coordinates at epoch date t_p are transformed to local map projection grid coordinates

Local map projection is created on the fly.
Central meridian of local map projection

Lines and points are extracted in terms of ECRF coordinates and or grid coordinates at epoch date t_p

Specified lines and points from selected CAD drawings and databases are transformed to local map projection grid coordinates by pairing points with same point numbers and performing non-scaled least squares two-dimensional conformal coordinate transformations

Surveys A, B, C in different survey drawing database coordinate systems

Four Steps

① A local low distortion map projection is created on the fly that reduces the difference between grid and ground distance to insignificance within a region covering selected surveys A, B, C

② Points from surveys A, B, C that are in ECRF coordinate systems at epoch dates t_a,t_b,t_c are first transformed to ECRF coordinates at present epoch date t_p, these coordinates are then transformed into local map projection grid coordinates

③ Surveys A, B, C are translated and rotated into local map projection grid coordinates via point number pairings and non-scaled least squares two-dimensional conformal coordinate transformations

④ Transformed survey drawing lines and points are extracted in terms of ECRF coordinates and or grid coordinates at epoch date t_p

▲ At its essence, the **Boundless program** combines Earth Centered Reference Frame-related coordinates with survey drawing database points

to the current epoch date using horizontal time-dependent positioning software developed by the National Geodetic Survey (NGS), after which they are transformed to the low-distortion map projection grid coordinates.

Carl now decides which drawings from the selected projects he wants to access and, given those drawings, which points he wants to transform, as determined by point codes. He will select the drawings he wants via default settings or from drop-down lists showing all the drawings in each project. Carl will also decide which line layers he wants to import and transform. He will make these selections via default settings, or he can make the selections unique to each project by specifying point code ranges for selecting points and wild card settings for selecting line layers. In addition to wild card settings, he can also pick the line layers he wants to transform by selecting from drop-down lists that display the layers existing in each drawing he has selected. In short, Carl has carte blanche in how he selects the data he needs.

Carl uses the default settings for drawings, points, and line layers. This will return the drawings that contain the boundary line information and all the points for control and monumentation. After he has selected the spatial information he wants from the drawing databases, Boundless automatically transforms it into the low-distortion map projection via point number pairings between the previously transformed ECRF points and the corresponding points in the drawing databases. The multiple point pairings define unique non-scaled least squares conformal coordinate transformations. These transformations translate and rotate the selected drawing database spatial information into the low-distortion map projection while returning a table of residuals between the transformed ECRF points and the now-transformed drawing database points. The drawing database spatial information is not scaled, as this would distort the work as it has been measured and platted on the ground per legal description. The residuals returned are on the order of one or two thousandths of a foot and reflect slight differences between the individual projections first created for each project and the low-distortion projection just created on the fly.

Points and lines from the projects selected for integration—which up to this point existed in different isolated coordinate systems—are spatially unified in a GIS on a low-distortion projected grid system with underlying ECRF-related coordinates in sync with the VRS corrector.

From the Truck

Sitting in his truck, Carl sees the information displayed on his computer screen. He sees all the monumentation located and control set from the prior surveys. He is aware of the type of monumentation found or set, its accuracy, and from which projects it derives, and he sees the boundary and easement lines of the prior surveys.

Carl notices that some of the section corners have multiple symbols on them, indicating they have been located multiple times in association with different survey projects. He knows, based on empirical statistical testing, that if he averages the multiple coordinate values for these points, the resulting coordinates will more likely be closer to the true values than any one individual value.

▲ This VLBI radio telescope at North Liberty, Iowa combines with other radio telescopes around the world to determine GNSS satellite orbits and give the required accuracy that makes concepts like Boundless possible. The author stands near the CORS NLIB in the foreground.
—Image courtesy National Radio Astronomy Observatory

The multiple symbols for the same physical points are within the expected range for measurement error, and Carl has no reason to suspect that any blunders occurred in the prior measurements resulting in their displayed positions. He averages the northings, eastings, and elevations for these points before exporting all the points in terms of latitude, longitude, and ellipsoid height for import to his data collector.

Because point number conflicts almost always exist between the integrated points that come from multiple project databases, points exported from Boundless are consecutively renumbered beginning with one. To maintain traceability after export, Boundless appends to the point description of each exported point a client ID number, project number, and original point number. Because the exported points will end up in a new project database, which may one day be integrated with other surveys in Boundless, the software also appends a universal identifier to the point codes. If the new project Carl is working on is selected for integration at some time in the future, Boundless will filter out those points with the universal identifier, allowing only points with original observations associated with that project to pass through. This way, repetitive data representing the same observations will never occur when projects are integrated. The occurrence of multiple coordinate values based on the same actual observations for the same physical point would confound coordinate averaging and statistical process controls.

Coordinate averaging, statistical process controls, and point filtering assure that the integrated data coming out of Boundless is as accurate as when it comes in. The tendency of the system will be toward ever increasing accuracy over time. This is a necessary condition for any system used for long-term perpetuation and retracement.

Someone working at a computer in the office would probably export the points and lines in terms of the low-distortion map projection grid coordinates for import into a new project drawing and point database. When the data is imported into a new drawing, the original line layers and point codes are preserved. Once imported to a new drawing, the integrated spatial information from multiple surveys can be run through pre-boundary analysis.

Role of the Data Collector Software

Carl, on the other hand, has chosen to export ECRF-related coordinates out of Boundless. Based on a section line-bearing basis from the legal description, a surveyor in the office pre-comped the boundary of the parcel Carl is about to survey. Carl received an ASCII file with this information in his morning e-mail and has imported the data into Trimble Survey Controller as keyed-in class points. He has also just imported the ECRF-related coordinates for the section corners from Boundless. They now exist in Trimble Survey Controller as GPS points and will be so treated in performing a calibration along with all the other ECRF-related points Carl has imported.

Within Survey Controller, Carl now performs a one-scale calibration, which creates a new low-distortion map projection. He does this by pairing the office-computed (keyed in) points for the section corners with their ECRF-related values imported from Boundless. The result is a transformation that takes all the uploaded ECRF-related points into grid coordinates in harmony with the legal description bearing basis.

Carl will initialize his GPS rover in VRS. The calibration he has created will immediately transform the VRS corrector into the spatial world of the survey he is performing. He will navigate to and check a point located by one of the prior surveys before navigating to the office-computed locations for the property corners, where he will search for monumentation. Should Carl want to base the survey on something other than the section line, he will re-calibrate to new keyed-in points. All the uploaded ECRF points and his observations will be transformed together to whatever he deems the best solution to the boundary based on the evidence he uncovers and observes, in conjunction with the evidence he has imported from Boundless.

In the course of his work, Carl will establish pairs and triplets of primary control points using VRS, and these points will be occupied and backsighted with his robot. Primary control constitutes 16 10-second VRS observations on four different initializations under two different satellite constellations with at least an hour intervening using a fixed-height two-meter pole. All observations use the same point number; those after the first are stored as check. The pole is rotated 90 degrees after each observation to take the error out of the plumbing bubble when all sixteen observations are finally averaged in the data collector. The PK nails, spikes, and caps atop rebar Carl will set have recessed center depressions that prevent the tip of his pole from wandering off center when rotated 90 degrees between observations. Based on statistical tests that include 31 primary control point repetitions on a single point over six hours, he knows that the absolute horizontal positional error is estimated to be plus or minus 0.02 feet at the 95-percent confidence level. This results in tighter relative positional accuracy than the standard of 0.07 feet for ALTA/ACSM land title surveys. If Carl wants any level of greater accuracy, he has a chart that tells him how many times to repeat these procedures to achieve it.

When he occupies and backsights his primary control point pairs with the robot, Carl obtains a definitive check of their relative positional accuracy. If he performs more VRS observations and averages again to further increase the accuracy of his primary control, Survey Controller will use the angles and distances observed by the robot to re-coordinate all points based on the updated primary control coordinates. The averaging routine in Survey Controller will re-compute the backsight checks and redundant robotic observations and display new departures relative to the newly averaged primary control.

If Carl wants to calibrate using primary control values for latitude, longitude, and ellipsoid height, he will store the averaged grid coordinates back as WGS84 coordinates under new point numbers. The new point numbers will be used as the GPS points in the calibration. After the calibration, Carl will re-average his previously averaged points to put them on the new calibration.

At the end of the day, Carl will download his data to the server from his truck. His download will end up in a project database, where a surveyor in the office may translate and rotate his work to further refine his boundary solution. An ECRF-related text file containing a subset of his observed points will be imported to the GIS database, where the cycle will begin again.

Interferometry Enters the Picture

Diverging somewhat, the accuracy and long-term perpetuation afforded by GPS derives from various measurement techniques referred to collectively as interferometry. From the operational definition of the meter to testing giant astronomical mirrors to the EDM in your total station, interferometry rules. Fifty-four globally spaced radio telescopes linked through high-speed communications perform very long baseline interferometry (VLBI) that involves simultaneous observations to quasars in distant galaxies. The resulting data defines and maintains spatial reference frames with incredible accuracy. The baseline distances between radio dishes at opposite ends of the earth are known to within two millimeters. Earth orientation parameters and Earth rotation parameters are determined daily in fractional units of milliarcseconds (0.001 arc second).

What does this mean for surveyors? VLBI defines an inertial frame called the International Celestial Reference Frame (ICRF) used to compute GNSS satellite orbits. The ICRF is spatially linked to the ECRF known as the International Terrestrial Reference Frame (ITRF). The master fiducial CORS within the NSRS, part of a global network of International GNSS Service (IGS) Reference Frame stations, are directly linked through ground-based interferometric methods to the network of VLBI antennas at collocation sites such North Liberty, Iowa, where the spatial relationship within the ITRF between the intersection of the radio telescope mounting axes and the phase center of the CORS NLBI, operated by the Jet Propulsion Laboratory, is known to a millimeter.

All CORS have ITRF values and associated velocities within the ITRF. The positions of all the CORS comprising the NSRS are continually monitored in relation to the master stations. Small daily variations in their positions relative to their published positions are plotted and published in long-term and 60-day time series. A percentage of the CORS are included in the VRS networks in the United States, Mexico, and Canada, which in turn produce the correctors that guide the steel tip of Carl's fixed height pole. However, not all VRS networks in the United States are maintained in accurate relationship to the NSRS fiducial stations.

The Challenge and Vision

The ability to spatially integrate all surveys and perpetuate them long term independent of the survival of physical marks with an accuracy meeting the requirements of ALTA\ACSM has become a reality. Surveys that are integrable and retraceable within a high-accuracy, continuously monitored and maintained reference frame acquire far greater value than unconnected lone data sets. The challenge for the owners and operators of VRS networks in the United States will be to synchronize and maintain the existing and expanding VRS networks in accurate harmony with the NSRS and the ITRF.

The vision is one of centralized and streamlined global management of real property using enterprise GIS applications that provide access to all related property records, including high-accuracy ECRF-related spatial data for surrounding development and infrastructure. Companies and government entities that must manage real property assets on a global scale can now also own, manage, maintain, and make available the spatial component independent of the proprietary databases of local surveyors and contractors. Surveys in Beijing can be ordered and overseen from Paris. Regardless of what firms are awarded engineering and survey contracts, the spatial information will be known, accurate, consistent, and immediately accessible right down to the crew in the field.

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