Invention in the Alaskan wilderness

—by C. Jason Smith, Ph.D., with Eric Stahlke, LS CFedS
Photography: Nick Russill and Eric Stahlke

Survey team assembles an ingenious, low-cost, high-definition 3D aerial survey system using a leased helicopter, an off-the-shelf digital camera, and Topcon's new PI-3000 software

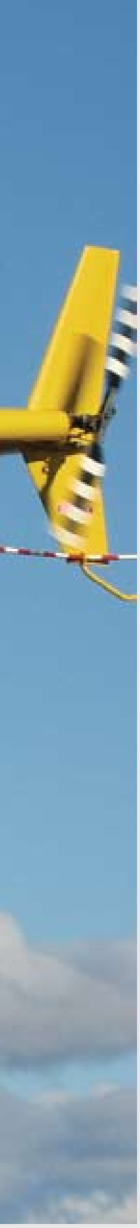
Hanging out of a helicopter with a five pound camera and gyroscope contraption in hand is not the usual modus operandi for a surveyor, but that is what survey manager Eric Stahlke found himself doing in May 2007. Stahlke and his survey team from Alaska's Tanana Chiefs' Conference were trying to solve a problem that had plagued them for years—how to conduct low-cost, three-dimensional aerial surveys for isolated Native villages where most of the surveying work is difficult and pro bono. No one had every done it before.

Founded in 1962, Tanana Chiefs' Conference (www.tanana-chiefs.org) is a non-profit corporation based in Fairbanks, Alaska. The conference is a partnership of 42 member Athabascan Indian villages located in an area of 235,000 square miles in the Alaskan interior. The primary function of the corporation is to administer health and social services assistance to the outlying villages. Most of the professionals, outside the administrative units, are doctors, dentists, and social workers.

The primary work of the Tanana Chief's surveyors is the surveying of the boundaries of Tribal lands. But as they work in the Alaskan bush, the teams generally base in one of the local villages where they are often called on to survey subdivisions for new housing and solve local boundary disputes. Surveys in the Alaskan interior are prohibitively expensive for most residents.

Calling in a survey crew generally entails chartering a flight into areas with few, if any, roads and local budgets that can't bear the burden of such an expense. Therefore much of the work Stahlke's team does is pro bono: "As travel to the villages is the greatest single expense in the performance of a boundary survey, and as our crews happen to be in the area doing other boundary work for a client with deeper pockets, we can usually find some time to work in a few local survey requests." Word of the survey team's presence in a town can spread quickly. "Generally, we hear about everybody's particular boundary problem within an hour of our arrival."

There are few places more challenging to survey than in the Alaskan bush. One of the difficulties with this work is that much of the monumentation from the original government surveys—conducted primarily between 1920 and 1960—has



been lost. For the Athabascan people of the Alaskan interior, property lines have traditionally been more a matter of practical need than legal ownership.

As Stahlke describes it, "the Athabascan culture is not one that abides fences. People are used to sharing both their food and their land. In a culture that recycles nearly everything, any open space not taken up by buildings is often filled with old trucks, snow mobiles, and dog yards." Essential in the winter, the dogs have nothing to do in the summer but take up a lot of space. The dog yards, which hold between 40-60 dogs each, often sprawl haphazardly across property boundaries.

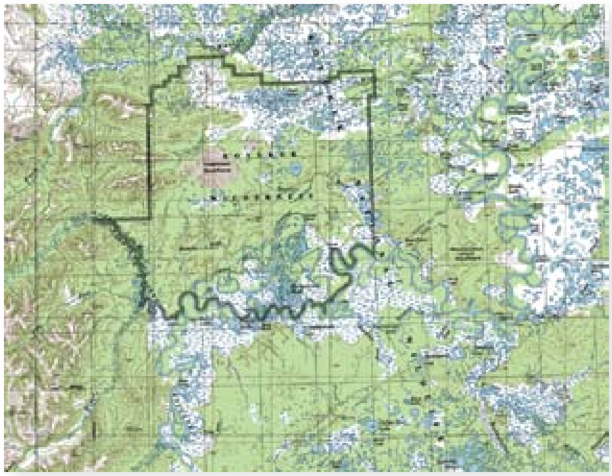
The dog yards are just one example of how the Athabascans tend to think of property along occupational lines—how much space is needed for their possessions—rather than along actual surveyed property lines. Even streets and utilities may wander off the original right-of-way lines and across personal property. "As long as land remains in original ownership," Stahlke says, "this system works without too many problems. But if anyone wants to sell a home, or borrow money on a home, or sell their lot, a boundary survey is required by lending companies the same as if these properties were located in a big city."

Occasionally residents will approach the surveyors complaining that a neighbor is encroaching on their property, though, as Stahlke says, "few people have a clue where the actual boundary is." To make matters worse, the monumentation markers have a tendency to disappear. "In a typical village," Stahlke said, "your garden variety lot corner is either located under a pile of used equipment, in the middle of a dog yard, under a building, or it's missing completely."

Sometimes villagers build dog pens or pile snowmobile carcasses on top of them. Sometimes a property owner doesn't want the boundary line to be exact. The following is not atypical: "In the village of Galena, the surveyors marked a new boundary which showed a neighbor to be encroaching by nearly 30 feet onto our client's property. When we returned two years later, our boundary monuments were nowhere to be found and our original client was now encroaching a similar amount onto his neighbor's property."

Missing monumentation pushes the cost of the surveys even higher. In many villages so few of the original survey corners remain in place that it may take two or three days just to recover enough control to re-establish lost boundaries. All things considered, the typical boundary survey in these villages can run upwards of $20,000, in an area where the average annual income is around $15,000.

Though traditional survey methods have worked, they are time consuming, particularly for pro bono work sandwiched between larger projects that needed to be completed as efficiently as possible. Given these factors, the surveyors started looking at other ways of dealing with village surveys. Stahlke realized that what was really needed was the ability to conduct detailed cost-effective aerial surveys on site. High-quality



Map of Huslia in the Alaskan interior

ortho-rectified images could be merged with vector information showing controlled lot and block lines, and most boundary disputes could be solved immediately. But, how was this going to be accomplished?

Children in Huslia where few surveys had been done

Thinking outside the box

Alaska fosters a practical problem-solving mentality that comes from living in a climate of extremes. Far away from supply centers or, in many cases, roads, finding solutions to seemingly insurmountable problems can be literally a matter of life and death. But in this case, each potential solution to the problem at hand seemed to lead to another insurmountable problem.

For example the free internet service Google Earth provides high-quality rectified satellite images but the images primarily focus on urban areas: "If you select a typical village in interior Alaska, the best resolution imagery available is in the ten to thirty meters per pixel range, which is completely useless for any detail work."

Traditional aerial surveys were also out of the question as the one pixel per half meter upper limit for true color photography was considerably less than the two to three centimeters per pixel Stahlke and his surveyors wanted—not to mention the cost of $15,000 per village survey, or the fact that ortho-rectified images would not be available for several months. Nevertheless, the surveys needed to be done, and a more efficient, less costly method needed to be found.

Stahlke needed an accurate high-definition survey that could be done with utmost efficiency and with as little delay as possible. He did not have the latest equipment for such a survey, but he had a helicopter—a Robinson R44 Raven leased every summer for work in remote areas—and a barge-houseboat. Could a helicopter be used for aerial survey photography of the quality they needed?

The helicopter is an amazing combination of force and counterforce. It can move in any direction and, barring inclement weather and strong winds, hover above one location. The Robinson R-44 seemed perfect for aerial photography with one notable exception: vibration. Compared to the twin-engine plane, the Robinson would be extremely "noisy" for the camera and was likely to produce blurred images. There was one way to find out for sure: buy an aerial camera and take some test photos.

The Selooghe summer houseboat

Stahlke's team did not just want to find another method for producing GIS-style depictions of approximate boundary line locations. "Our goal was to produce something new," Stahlke said, "an aerial survey plat that approaches the accuracy of an actual boundary survey plat." With a helicopter, photos could be taken at a much lower altitude, allowing for much more detailed depictions. Traditional aerial cameras employ the use of a large-format 23 cm x 23 cm image plate and need a lens with an aperture that will capture enough light for the exposure. Because of this limitation, the best shutter speed is 1/500 of a second or faster. At that speed, the forward motion of low-flying, fixed-wing aircraft inevitably impacts the resulting image.

Topcon's Nick Russil shooting photos with the Lumix camera

A helicopter can hover in place, thus eliminating distortion due to motion and improving resolution. And, Stahlke thought, "why spend $500,000 on a top-end digital aerial camera designed for airplanes when a $1,000, 10-megapixel, off-the-shelf camera might work just as well, or better, at a lower altitude?" The team settled on the Lumix DMC-FZ50 camera which has a buffer speed of 2 photos per second, 10-megapixel image quality, focus and aperture locks, and variable zoom function.

Since aerial photography cameras use external gyro stabilizers to isolate the camera from aircraft vibration, and the surveyors rightly expected the vibration to be severe, they also ordered a gyro stabilizer. "There were a number of other questions that had to be answered besides what kind of camera to buy. For example, what would be the best focal length, what was the optimum aperture setting, at what height above ground should we fly? Also, how much ground coverage could be expected at different focal lengths and at different altitudes, and what size ground targets should be used? While there are formulas that can be used to calculate all the above parameters, for us it seemed more intuitive to answer these questions by common sense combined with trial and error, Stahlke said."

Aside from money, computer programming was needed to quickly convert digital images into a precision ortho-rectified mosaic. The software packages used by photogrammetrists run upwards of $50,000, well beyond their budget. Stahlke set about familiarizing himself with helicopter aerial photography. His diligence finally paid off.

While reading an article titled "Mapping small areas using a low-cost close-range photogrammetric software package with aerial photography" (*The Photogrammetric Record* 20.122), he stumbled across a reference to Topcon's PI-3000 that seemed ideal to solve the imaging problem. Best of all, the program would run on a conventional laptop so, if it worked, the team could complete the images on-site.

Stahlke got on the phone to Topcon distributors and was put in contact with the U.K.-based managing director of TerraDat Geophysics, Nick Russill. "My initial reaction," said Russil, "was that here was an excellent opportunity for a novel application

A PI-3000 image on Eric Stahlke's computer

of PI-3000. I knew from my experience with low-altitude kite photography that the results would be impressive." The PI-3000 software package was soon in the mail.

With only a few days left before the supply boat for the interior, it was time to test the camera. Team members cut up some makeshift circular targets of varying diameters and scattered them on the tarmac in front of the hanger at Quicksilver Air at the airport in Fairbanks. Since they did not have the remote control or special mount for an aerial camera, they improvised. "We removed a rear door from the helicopter and I flopped down in the back seat and hooked into the airframe with a safety strap," said Stahlke. "The technique was simple: lean out the door as far as possible, point the camera straight down and start taking pictures. We flew the target sight over and over again, from different altitudes and using different focal lengths on the variable zoom lens. This took about a half hour, which was about all my body could take, as handling the gyro stabilizer with one hand uses more muscles than one can imagine."

From the resulting images Stahlke's team was able to determine the optimal resolution and target size. They were ready for the next step—practical application. But, as the PI-3000 had yet to arrive, they were facing the possibility of having to install the program and learn how to use it all on-site.

Just hours before they were to head up-river for the summer, Russill e-mailed Stahlke that he's willing to change his travel schedule and join them for the first test. As an expert on the software (and a professional photographer), Russill's presence would greatly reduce the learning-curve of attempting to use the software cold. Stahlke readily accepted Russill's offer and made plans to fly him and the PI-3000 out to the first site on the helicopter upon his arrival.

Field Test: Up the river, up in the air

On June, 1, 2007, the survey team sailed up-river on the Selooghe (an archaic Russian-Eskimo word meaning "large boat"). The Selooghe is a trimaran houseboat sitting atop six homemade hulls made of Siberian birch plywood and epoxy, and powered by two 130hp Honda outboard motors. The boat boasts a full office with computers, living quarters, a shower, and a washer with space left over to carry food and supplies for two months, as well as enough helicopter fuel for several weeks of flying.

The teams' first stop, the village of Huslia, on the Koyukuk River, is about 10 days (700 miles / 1127 kilometers) by river from Fairbanks. Huslia is a village with few existing surveys. The village council wanted the team to create lots for about half of the village occupants, based entirely on current occupation lines. Given the entangled nature of what constitutes occupation lines in remote Native villages in Alaska, a traditional as-built survey to gather all improvements, roads, trails and utilities would easily take a week to survey. And it would take another week to work out all the new boundary locations by consulting each villager as to who owns what. But, with a good, high resolution ortho photo, one displaying small objects, the surveyors could get the villagers to help "thread the needle," so to speak, and create new lot lines that traverse between identifiable objects that people could visualize. Stahlke hoped the process could be performed in significantly less time than under normal circumstances because, when it comes to surveying, time is money.

Cutting out aerial markers

And time they were going to use wisely. While sailing up river, two trainees—Charlie Yatlin and Colin Debler—were put to making 50 donut-shaped 3D aerial markers out of 18-inch white vinyl packed with sand. A hole was punched in the center to affix the markers with spikes. About a day out of Huslia, the helicopter bearing Russill and the PI-3000 cought up with the Selooghe. About five miles below the village, the survey crew took a small boat up-river to lay out the markers.

The 9th of June was a beautiful sunny morning and the air was crystal clear—perfect flying conditions. Stahlke and Russil piled into the helicopter and flew a number of lines over the village to make sure they would get the needed coverage. Each shot of


A raw photo of Huslia

an area was followed by another with a slightly different central focal point in order to produce a stereo-pair of photos that would be used to generate a three-dimensional image using the PI-3000. The digital photos turned out crisp and clear.

Stahlke and Russill printed the photos on a color LaserJet and spread them out on the office table to select the best images. They chose the best 14 photos of the part of the village to be surveyed. The stereo-pair photos were then loaded into the PI-3000 which registers all stereo pairs and indexes them with the coordinates of the aerial targets. Three "control points" were chosen for each stereo pair. In addition, four to six "tie points"—distinct, uncoordinated points easily identified in both images such as stove-pipes on flat roofs—were identified.

As tie points are added, the accuracy of all selected points can be examined with a bundle adjustment routine. This is very helpful for following the integrity of the network step by step as one progresses, allowing for re-measurement of wayward tie points or elimination of questionable control points. The calculation also provides camera position coordinates and a base-to-height ratio of the stereo pair, as well as the standard deviations for each control and tie point.

The next step was to define the digital terrain model (or DTM) boundaries and break-lines in a set of stereo images created by the software. Finally, they began to create the DTM.

A surveyor's dream

Four hours later they had a finished product: a high resolution ortho-rectified image of the village of Huslia in brilliant color, as well as a three-dimensional model of the village that could be zoomed, rotated and examined in computer space. "One unexpected but pleasant result was that the resolution of the image was so high that individual wires of overhead power lines could be identified, eliminating the need for time-consuming utility as-builts," said Stahlke. The resulting rectified photograph, nearly the size of a ping pong table, was hung on the council office wall and will be used by individuals and local government officials to locate property lines in relation to large and small physical features.

It was time to start the process of creating new lot boundaries based on inhabitants' occupation lines. Stahlke met village Chief Orville Huntington at the council office and encouraged him to get the word out about surveyors wanting to meet with the village people at the council hall. Each house in Huslia, (which has a population of about 200) is connected to a live chat room via VHF radio, so it didn't take long to drum up a crowd.

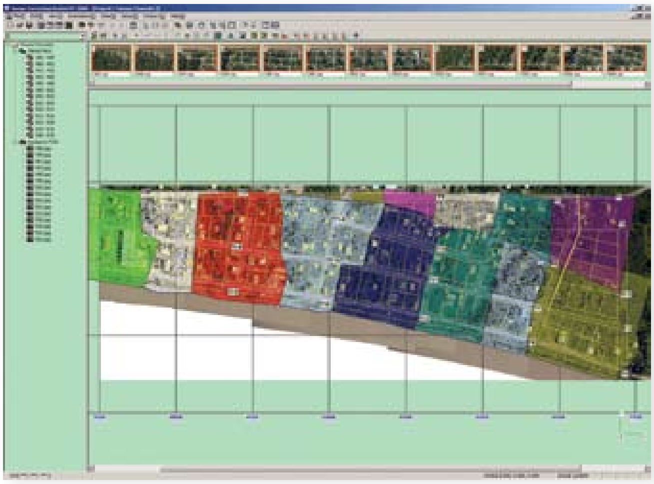
At the meeting, the villagers gathered around a giant ortho photo (a dozen or so printer sheets held together with cellophane tape) rolled out on a big folding table and offered comments as we examined different areas of the mosaic: 'This is George's stuff, his line needs to go to here; this is Thelma's dog yard; that old shed and snow machine belongs to Henry" and so it went for quite a while. Stahlke sketched in the boundary lines based on general consensus. "It took only 30 minutes to create the new boundary locations, there was a general agreement on the placement of the new lot lines, and, most important, all participants had a good time making the decisions. It was a surveyor's dream."

Heinzie Williams, Jr., ready to set the monuments on the ground

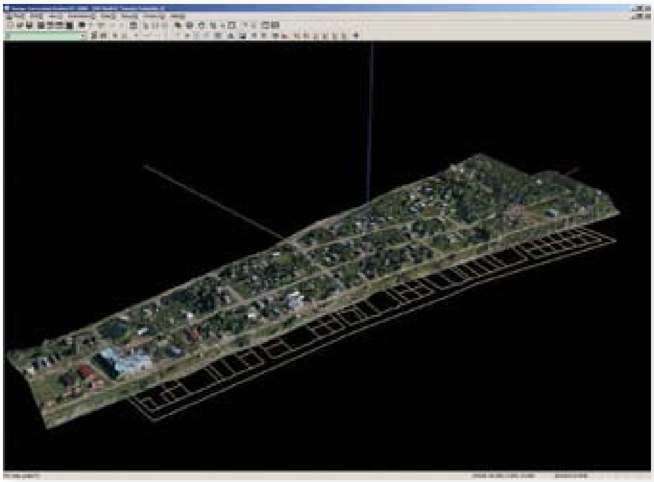
The ortho photo from PI-3000 was then downloaded into AutoCAD and new subdivision boundary lines were created that matched the village markup. By the following morning Stahlke and his team had the necessary stakeout data loaded into the GPS receivers and the survey crews proceeded, using RTK, to set the 150 or so monuments needed to define the new lots. By day's end the subdivision was finished and all that remained was to pull the aerial targets. "We couldn't have hoped for better results. The in-house digital photography and PI-3000 produced a perfect solution to a very difficult problem. An added benefit was a significantly reduced cost and time investment for the survey compared with the use of our normal methods," Stahlke added.

The birth of the aerial boundary survey

After Huslia, the Selooghe moved on to a number of other sites, including the villages of Galena and Tanana. Both of these villages had at their core a townsite survey, i.e., an entire village property layout of about 100 lots, originally surveyed by the federal government in the late 1950s. In both villages only scant remnants of these original surveys remain, and there is general uncertainty about the location of boundary lines.



PI-3000 main screen of Tanana village with TINs



The model of Tanana on PI-3000

Photogrammetric resurvey of Tanana village—the final product

The situation at Galena and Tanana exemplified typical problems found in Alaskan villages which the surveyors hoped to solve by performing photogrammetric resurveys. "By photogrammetric resurvey," Stahlke clarified, "I mean a highly accurate rectified ortho photograph which contains vector information of boundary lines that have been indexed by recovered monumentation. I hesitate to use the word GIS, because in the typical GIS compilation of imagery and vector data there generally are inaccuracies and distortions well beyond what most land surveyors would tolerate."

The photogrammetric resurvey that Stahlke and his team invented is based on a single network of accurate GPS measurements combining control stations and recovered corners. The resurvey is not designed to replace precise on-the-ground retracement of survey boundaries, rather, to augment the process and create a new product which has more immediate practical usage for residents in remote areas, at a fraction of the price of a ground survey.

Of course, the photogrammetric resurvey product could also serve as an incredibly solid foundation for any future GIS should the village have need of this. PI-3000 can generate fairly accurate one-foot contour lines with little extra effort, although some editing in AutoCAD would be needed to remove anomalies created by trees and buildings.

"The products we have produced thus far, in two short months, have generated such interest within Alaskan villages that we are now exploring using the same methodology with an airplane instead of a helicopter, which would give us greater range and further reduce time and cost factors." Considering their progress so far, Stahlke and his team might just redefine both aerial photography . . . and land surveying.

The Team
Eric Stahlke, LS, CFedS, survey manager
Nick Russill, managing director of TerraDat Geophysics (Topcon)
Albert Macica, LS, Project Manager
Todd Jantzi, Party Chief/ACAD Tech
Alvin Dayton, Survey Tech
Charlie Yatlin, Survey Tech/Trainee
Colin Debler, Survey Tech/Trainee
Ralph Woodford, Cook

The Equipment
Topcon PI-3000 software and laptop
6 dual frequency GPS/GLONASS receivers
AutoCAD Land Desktop 2005
Canon EOS 5D with calibrated 28mm lens
CF Memory and firewire reader
Lumix DMC-FZ50 with variable zoom calibrated lens
Kenyon Labs gyro stabilizer for camera
White neoprene disks 0.50m diameter (can be seen from 1250ft.)
Robinson R44 Raven II Helicopter

The Topcon PI-3000 Image Modeler software puts the power of photogrammetry into the hands of an everyday surveyor.—Scott Langbein, Topcon.

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