OPTIMIZED PROCEDURES FOR SLOPE INVENTORY IN PHOENIX, ARIZONA: "Y=MX+BPG – SOLVING FOR M"

WITH THE HELP OF ORBIT GT, ESRI AND THE TRAINED STAFF AT BPG, WE HAVE MANAGED TO CREATE A SLOPE TOOL THAT IMPROVES PRODUCTION, IS REPEATABLE AND DOCUMENTED, AND CAN BE USED FOR MANY PROJECTS TO COME!

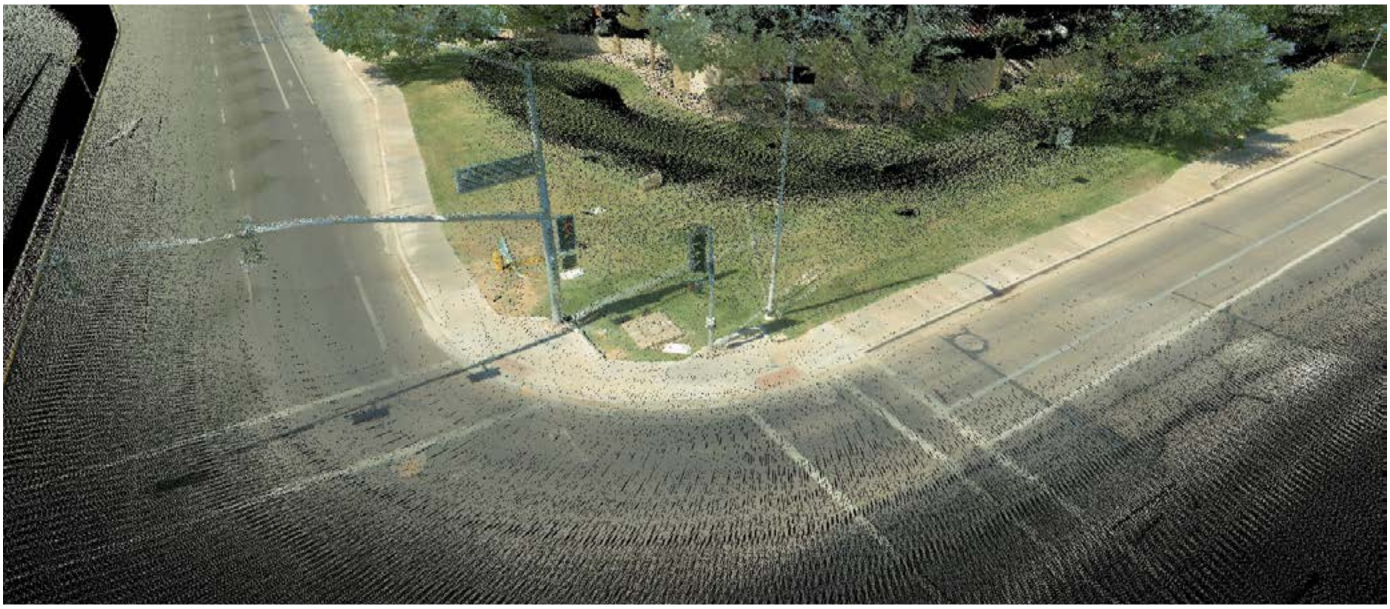
Background

A typical motorist often overlooks the importance of a maintained traversable path. This specific driver normally commutes from point A to point B with ease and in the comfort of their own vehicle. Their worry lies mostly on the influx of traffic and approaching E on the fuel gauge. There is little thought on the potential trials and tribulations of commuting via pubic sidewalk to their destination.

Unfortunately, not all have this same sense of effortlessness in their commute. The United Nations reports over 15% of the world population live with one or more disabling conditions, and more than 46% of the population aged 60 years or older have disabilities. According to US Census data compiled by the American Community Survey (ACS), population aged 65+ is growing at a higher rate than the total population by a ratio of 2.5:1. With the growth rate there will be an increased number of mobility–impaired individuals who will need to navigate public right of way paths with the same ease as the everyday motorist. Luckily, the American Disabilities Act (ADA) recognizes the significance of a city's pathway infrastructure and is set out to make certain they pose no barrier to the mobility-impaired pedestrian by implementing a Public Right of Way Accessibilities Guidelines (PROWAG).

BPG Designs, LLC and their strategic partner paired with a large municipality to ensure ADA PROWAG were met throughout the project area. The ADA Self-Evaluation was used to help mitigate the city's risk as well as allow the city to efficiently respond to requests for ADA improvements from the public.

The evaluation called for BPG's advanced, high-accuracy mobile LiDAR technology to be at the forefront of this project. BPG collected over 630 arterial and collector road centerline miles using the state-of-the-art IP-S3 mobile mapping system, creating a 3D model of the city's street assets. The IP-S3's high density, high precision point clouds combined with high-resolution panoramas allow the Orbit GT user to access an array of data for the surveyed area. The IP-S3 positioning system is an integration of an Inertial Measurement Unit (IMU), GNSS receiver (GPS and GLONASS) and a vehicle odometer allowing the system to maintain positional accuracy within a dynamic



Colorized point cloud from IP-S3

environment. The rotating LiDAR sensor captures the environment with a rate of 700,000 pulses per second at a range of 100 meters. This point density provides a picture-perfect 3D model of the scanned area. The six-lense digital camera system provides 360-degree high-resolution spherical images that allow for feature recognition and precise measurements. After the LiDAR data were collected and processed, trained BPG staff utilized Orbit GT software to extract the necessary ADA assets. These assets included: polygons that were traced over sidewalk panels ~50ft, all ramps and driveways, a point for any surface discontinuities (cracks, gaps, heaving, and obstructions in the traversable pathways) and slope lines for all surface polygons. Each feature has its own set of classifications and measurement attributions, which led to a robust amount of data collected.

The ADA compliance guidelines state sidewalk running slopes over 5.5%, driveway running slopes over 8.8%, ramp running slopes over 10.5%, and all cross slopes over 2.5% would be deemed non-compliant and sent to the city for further review. Each ramp, sidewalk, and gutter had its own set of cross slopes and running slopes. Sidewalks and gutters have 2 slope lines, ramp features have anywhere from 6 to 8, and driveways have 4 total slope lines. This meant the bulk of the data collected in Orbit GT software were slope lines associated to each polygon feature. Using Orbit GT's 3DM Feature Extraction package, the BPG team manually drew these slope lines over each polygon feature, as well as documented the slope measurement that represented the slope grade of the surface feature. Ultimately, BPG was responsible for the creation of hundreds of thousands of slope lines that would dictate whether the polygon feature was within ADA compliance.

The first square mile of data that BPG collected and extracted was sent off to our strategic partner for review and the results were undesirable. It was brought to BPG's attention that the manual slope measurements did not match the slope measurements they had taken in the field. About 50% of the slope lines were inconsistent with the field readings and failed to meet ADA standards. This forced a halt any further production until the inconsistencies were resolved.

The BPG Team quickly faced the realization that the manual creation of the slope lines which had occupied much of the time and energy spent on the project was not effective. Finding an efficient solution for collecting the slope lines and their measurements was crucial to the integrity of the project. In hopes of gaining a solution to this slope line conundrum, the BPG team reached out to its partners at Orbit GT for advice and technical help.

Technical challenges

ADA had allowed a 0.5% tolerance on all slope lines for the polygon features, meaning the team was fighting against the resolution of the IP-S3 to reach complete slope accuracy. Even using the most advanced mobile mapping system the machine still left BPG with a +/- 3.3% tolerance, which was well over the 0.5% allowed by ADA standards. The staff at Orbit GT quickly partnered with BPG and, through multiple phone calls and virtual collaborations per week, guided the team through different functions of their software that were relevant to accomplishing this type of precise measurement.

Of the functions, the Slice View function was exceptionally helpful in recognizing the inconsistencies within the point cloud data. The Slice View function allows the user to slice of the point cloud and examine its thickness, as well as any extra noise in the data due to multiple passes in the road or any miscellaneous interference. After extensive data collection, assessment,

Ramp and sidewalk features with running slope and cross slope lines and evaluation the teams were ultimately able to identify the primary reason for the inconsistency in the slope line measurements was this noise.

The original failed slope measurements were produced from sections of the point cloud that were not representative of the entire data set – the outliers. When drawing the slope lines on top of a sidewalk panel, the user might grab the first point directly on the sidewalk, but their second point may be placed in a small area of the point cloud with outlier points, leading to a misrepresentation of the actual slope value of that sidewalk panel.

Using the Slice View function, BPG could identify the level of noise in the section of point cloud for that specific ADA feature and take the slope measurements in an area that was a true representation of that surface. However, though this was an accurate solution, using the Slice View function for all slope line measurements was simply not feasible due to the numerous amounts of slope lines that were eventually going to be extracted throughout the entire 630-centerline miles of the project. BPG and Orbit GT were sent back to the drawing board. With the newfound realization of the direct correlation between the level of noise in the point cloud and the slope measurements, both BPG and Orbit GT were determined to find a speedier solution that would produce precise slope measurements in a timely fashion. The Orbit GT team focused their resources on creating a script that could eliminate any point cloud noise and automate the slope line collection process, eliminating any variability in slope line length and placement within the polygon feature.

Solutions

Over the next several weeks of slope line research between BPG and Orbit GT a few assumptions were made to aid with the scripting process:

- The features with slope lines associated to them require a running slope and cross slope. The running slope dictates the direction of travel on the sidewalk, ramp, or driveway panel and the cross slope bisects the running slope to form a cross in the middle of the polygon feature.
- It is imperative the slope line measurements are extracted from a point cloud that is dense and free of any noise or data discontinuities to truly represent the slope grade of the surface feature.
- The projection in which the slope line measurements are extracted requires metric meters instead of imperial feet to further tighten the measurements.

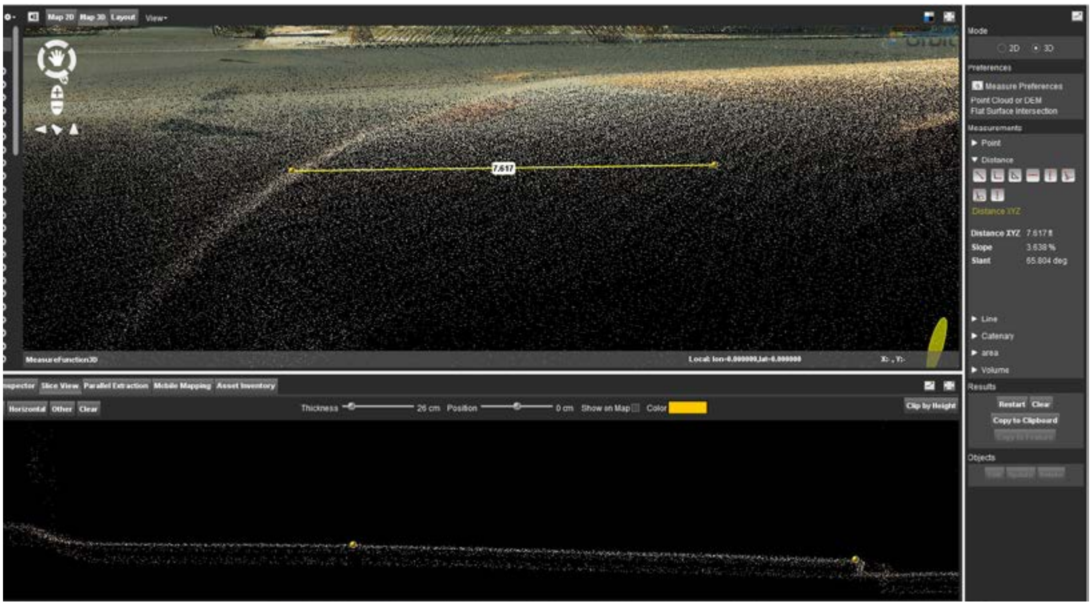
Orbit GT developed the final version of the slope script that encompasses all the parts needed to collect precise slope lines and measurements.

Script 1: Line Segment Bisector

The first script creates a line segment bisector, the running and cross slope, for each feature within the original polygon feature exported from Orbit 3DM software (sidewalks, driveways, and ramps). The first line segment is created parallel to the longest side of the polygon. The second line segment is then created perpendicular to the first line segment. The result is systematically replicated cross and running slopes identical in length and placed at the centroid of the polygon, improving length consistency and eliminating human error variability.

Script 2: Slope Value by Linear Regression

For each line segment the second script calculates the true slope value and the Mean Square Error/Deviation (RMSE) using a linear regression model. To take advantage of the high relative accuracy and the millions of points generated by LiDAR, the script produces a count of the points used for the slope line within a well-



Slice view showing two points on the true surface and the noise below. The true surface is the dense line on top, the noise is the clutter underneath.

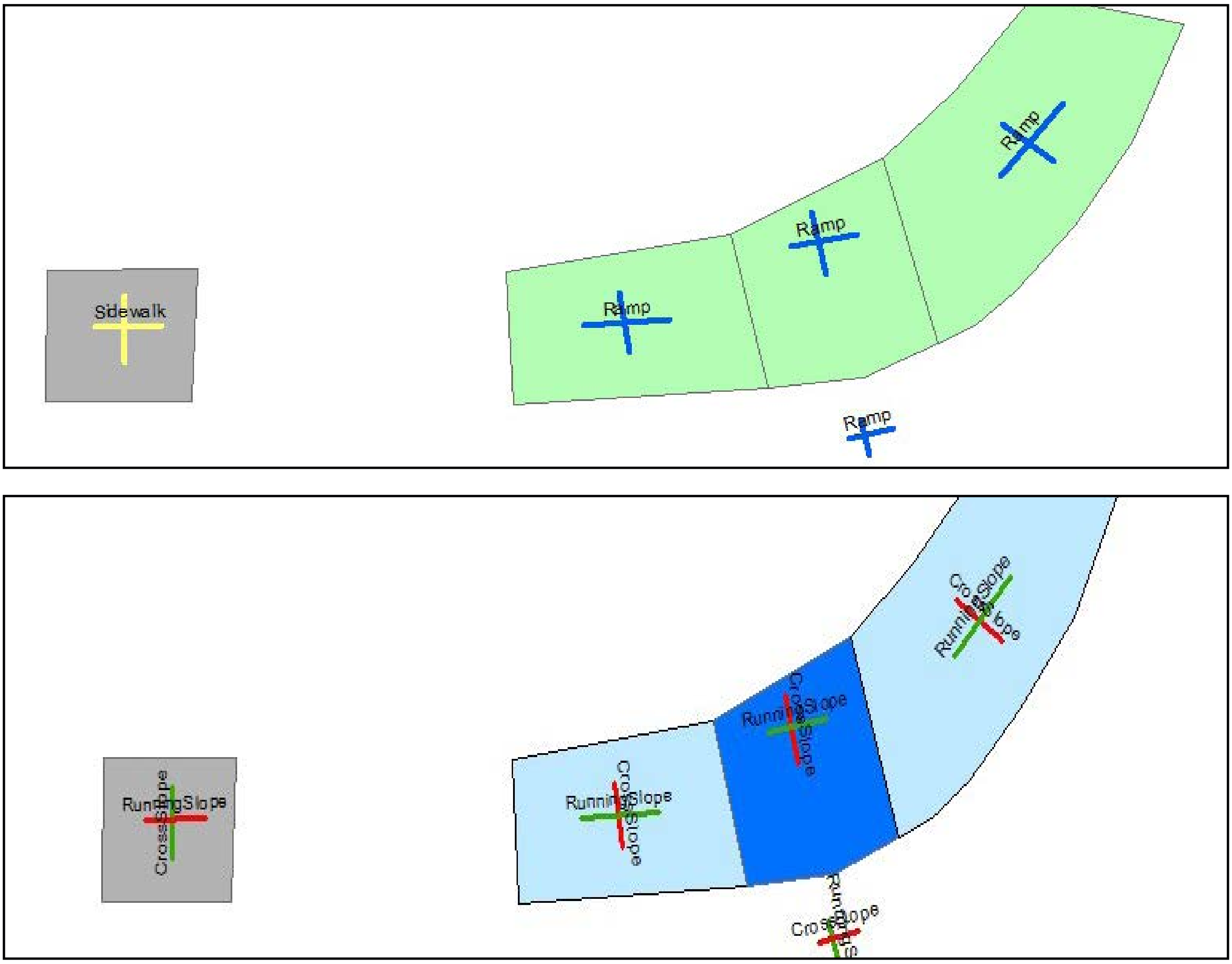
defined section of the point cloud. Using a multiple linear regression model, the script removes statistical outlying points, the miscellaneous noise, and uses a weighted average to help best fit the slope plane using 3 factors: the segment's length; a given width defined as the buffer of points around the slope line; and a positive, or negative, offset of the slope lines CenterZ (Z-Range). These settings all define the point cloud selection used for the measurement. The script allowed for BPG to manually fine-tune these preferences to find the best fit for the data collected. BPG added an additional quality check to eliminate additional variability in the slope line data by manually checking all slope lines with measurements greater than 4% slope and with an RMSE greater than 10. The slope lines that fell into this category were manually cross referenced for measurement verification.

The result produced a new spatially correct shapefile of the cross slopes, running slopes, and their newly calculated slope measurements. The script also rendered separate Orbit Vector Files for every slope line that showed the specific slice points from the point that they were used for the slope measurement, the potential slope errors and the start and end points used for measurement. These OVF files hold extremely valuable data for the client. They show, based on mathematics, how the slope measurements were decided and why the measurement makes sense. By utilizing these two scripts in conjunction, the client was confident that the analysis was based on statistics, whereas field measurements taken with a manual level have multiple stages of variability based on location and equipment used.

With the help of ESRI software, BPG then performs a final process with automated QC routines that remedied any misclassified slope lines and polygon features. This resulted in a data set that was free of errors in classification, measurement, and variability.

Conclusion

Without the help of Orbit GT and the use of the Slice View function in the Orbit 3DM Feature Extraction software, BPG would have taken longer to produce the quality products our core values require. The creation of the scripts and extensive help and patience from Orbit GT helped BPG significantly reduce the number of hours that would have been



Sidewalk panel showing created slope lines (above) and labeled lines (below) required to re-measure hundreds of thousands of slope lines across the city.

The most significant contribution that the scripts have made to the BPG process is that our projects are now consistent, repeatable, and we are able to provide detailed documentation with our results. The time savings, repeatability and documentation allowed BPG to provide an accurate, quality result for over 630 centerline miles that was delivered on time and exceeded the expectations of the clients. The city can now use the information to help improve the capability of its community to traverse the sidewalks and right of ways. The script has also been successfully used on two additional ADA projects since this project. Today Orbit GT implemented the tool into production to assist other clients and projects of similar scale in the future.

The mobile mapping system attached to a vehicle

ABOUT THE AUTHORS

Gentry Nissen is a GIS Specialist with a new focus towards data analytics. A 2015 graduate from Arizona State University, she earned her B.S. in Urban Planning but quickly fell in love with her minor in Geographic Information Science. Residing in Phoenix, Arizona, she is currently using her GIS prowess working as an independent in the Geospatial Services industry with top industry leaders.

Brandon Sisco manages a team of 20 geospatial professionals and surveyors for BPG. Brandon earned his Bachelor's degree from the United States Naval Academy in Control Systems Engineering. He has also earned Master's degrees in Aeronautics from Embry-Riddle Aeronautical University and in Geographical Information Systems from Arizona State University. Brandon has over 1000 flight hours in various military aircraft and Unmanned Aircraft Systems with over 15 years of experience with remote sensing. He is a Part 107 certified UAS Pilot.

ABOUT BPG DESIGNS

Founded in 2000, BPG Designs is a small business and limited-liability company with one-hundred and ninety employees. BPG has a simple vision that if they can provide their customers confidence in knowing they are working with the most innovative, creative, forward thinking, technology advanced companies focused on producing results, they can reach their dreams and make a difference in the community they serve.

Over the years, BPG has developed a robust Design and Mapping Department's that includes a team with a deep knowledge and passion of all facets of design development. Their team consists of multiple software programmers, CAD technicians, designers, and surveyors that collectively have over a century of design experience. This talent, along with their commitment to employ the latest technological advancement in design development, has led them to support major organizations like Cox Communications, Verizon, and Salt River Project. The team completes over 1000 miles of design for broadband infrastructure annually throughout the southwestern United States, utilizing the latest and most advanced technology on the market today. One of BPG's greatest assets is the ability to quickly mobilize and to scale appropriately for any size job. For more information, please visit their web site at bpgdesigns.com.