GEOSPATIAL EXPLOITATION PRODUCTS (GXP®)

AUTOMATIC SPATIAL MODELER (ASM): ELEVATION BY INNOVATION

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BAE Systems, Geospatial eXploitation Products

BAE SYSTEMS

Contents

Executive summary

BAE Systems has been active in the use of digital photogrammetry for elevation extraction since the 1980s. The release of Next-Generation Automatic Terrain Extraction (NGATE) in 2006 pioneered the matching of every image pixel in a commercial software product. Subsequently, there have been significant advances in dense stereo image matching. Semi-Global Matching (Hirschmüller, 2005, 2008) enforces a smoothness constraint in a "semi-global" way, achieving close-to-global minimum cost to solve this non-deterministic polynomial-time hard (NP-hard) optimization problem. BAE Systems takes a new approach by enhancing algorithms from NGATE with adaptive pixel aggregation, enforcing a local smoothness constraint, and utilizing massive parallel computing power from graphics processing units (GPUs).

The Automatic Spatial Modeler (ASM) is designed to generate 3-D point clouds with accuracy similar to LiDAR, such as BAE Systems' Automatic Feature Extraction (AFE) functionality, which can extract 3-D objects from stereo images. ASM can extract dense 3-D point clouds from stereo images, and extract accurate building edges and corners from stereo images with high resolution, large overlaps, and high dynamic range. Tests indicate that ASM is much faster than NGATE and more accurate, especially for building edges and corners.

Introduction

BAE Systems has been involved in the automatic extraction of elevation data from overlapping imagery since its development of digital photogrammetric workstations for the Defense Mapping Agency in the 1980s. Early work focused on area correlation in harness with a range of empirical constraints and quality control metrics, which resulted in Automatic Terrain Extraction (ATE) and Adaptive Automatic Terrain Extraction (AATE). Both were included in the SOCET SET® commercial-off-the-shelf product in 1990 and 1997, respectively. Like all BAE Systems photogrammetric products, these were able to process imagery from frame cameras and a wide range of other airborne and orbital sources; government and commercial. The ATE and AATE modules were complemented by the Interactive Terrain Editing (ITE) module that included the manual measurement of elevations, as well as a host of tools for editing automatically generated elevations.

In 2006, the company established the use of matching on every pixel with NGATE, for both SOCET SET and the newer SOCET GXP® product (Zhang, 2006; Zhang *et al.*, 2006a, 2006b). A crucial improvement over ATE and AATE was the lessening of the assumption that terrain within the search area was a horizontal plane. The computational effort of matching on every pixel was improved by offering options to forego some precision in cases where maximum speed was essential.

A further benefit was that the software could compute digital surface models (DSM) as well as digital elevation models (DEM), from which buildings and trees had been removed. As NGATE developed, more tools were added to ITE. Cue cards with graphics and simple instructions were included in SOCET GXP to provide a visual representation of the use of the tool. The product range, which included Automatic Terrain Generation (ATG), a combination of ATE, AATE, NGATE and ITE, satisfied customers from numerous countries and market segments.

In 2012, BAE Systems introduced the associated product AFE for automatic identification and extraction of buildings and trees from both photogrammetrically derived and LiDAR point clouds (Smith *et al.*, 2011). BAE Systems enhanced NGATE, especially where high buildings caused particular difficulties. Considerable investments were made that resulted in new functionality, ASM. The crux of the new algorithms is the notion that the real purpose is not just matching every pixel individually, but generating the most accurate possible DSM, and maximizing the success rate, i.e., the number of pixels correctly matched as a proportion of the total.

Various techniques have been developed, for example, changing the direction of search according to the orientation of a building. A new approach has been taken to smoothing, based on a variant of the semi-global matching algorithm, which allows for smaller matching windows, yet increases robustness and reliability even within this smaller window.

BAE Systems acknowledges that the introduction of these complex algorithms sacrifices speed. Progress has been made to optimize computational effort. A version of the code is being written to run on GPUs, the low-cost computing engines that are present on modern high-performance graphics cards and offer remarkable power at minimal cost. ASM runs several times faster on GPUs than on CPUs alone.

Using ASM

The user interface for ASM is essentially the same as the one for NGATE – both are invoked from the ATG window. Figure 1 displays AMS as one of three options in ATG. New options are available for ASM as well as a number of strategy files starting with `asm_`.

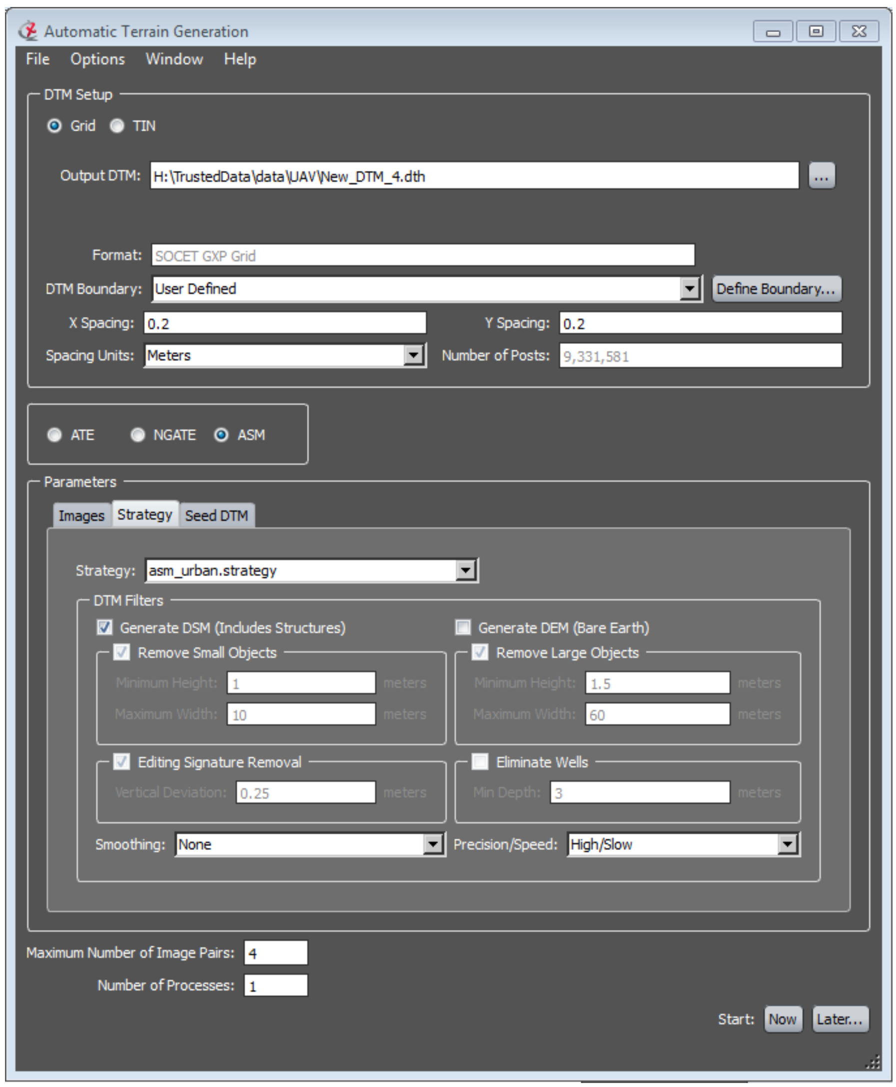


Figure 1
ASM GUI.

Two sets of ASM strategy files display: `asm_urban.strategy`; `asm_urban_CPU.strategy`. The `_CPU` component of the strategy name indicates its use when running ASM without a GPU. Generally, the use of a GPU is faster, depending on the capacity of GPU cards. ASM can run on all GPU cards that Accelerated Massive Parallelism with Microsoft Visual C++ (Microsoft C++ AMP) supports. The latest and most capable GPU card that Microsoft C++ AMP supports is recommend. Unsupported GPU cards can use the advanced algorithms in ASM on a multi-core CPU by selecting one of the "`_CPU`" strategy files. Custom strategy files can be created as well. The strategy files provide sufficient information for experienced users to modify and generate new strategy files for their particular images and terrain.

The Number of Processes or Number of Sections field in ASM is different from NGATE. NGATE is a computationally intensive, single-threaded CPU application that runs four or even more processes for the sake of speed. ASM uses GPUs and multi-threaded CPUs, which does not require four or more processes. For a single workstation, the Number of Processes is defined as 1 or 2; for powerful workstations, a definition of 4 is preferred.

ASM may encounter unknown issues when utilizing the GPU. Microsoft C++ AMP is still in its early stages of development and less reliable than the rest of Visual Studio C++. ASM has logic to recover, switch to CPU mode, and complete the job; however, much more slowly. For example, for the accurate urban modeling of houses and buildings, the Maximum Number of Image Pairs field should be defined as 4 or more if there are significant overlaps both in the flight direction and cross flight. A large value definition for the Maximum Number of Image Pairs field will slow down ASM significantly. ASM will do almost twice as many computations when the value increases from 2 to 4. And, ASM may generate very sharp building edges and corners, which are important for AFE. Post spacing also affects accurate modeling of buildings. A post spacing as small as the image GSD may be used in urban areas to achieve maximum accuracy.

It is very important that stereo images are free of Y-parallax before running ASM or NGATE. Images successfully triangulated with SOCET GXP display little or no residual Y-parallax and are ready for ASM. Images imported from other packages without triangulation in SOCET GXP should be checked for significant Y-parallax using Split Screen Stereo. Triangulation and sensor modeling in SOCET GXP can be quite different from other packages. Triangulated stereo images from other packages are not necessarily free of Y-parallax in SOCET GXP. Generally, when ASM or NGATE do not generate an accurate DTM, it is due to Y-parallax. Images must be free of Y-parallax before running ASM.

Areas with significant elevation differences, such as mountainous areas, require the use of a Seed DTM. The SOCET GXP functionality, Use Auto DTED, provides a beneficial initial elevation to start ASM. The Seed Point option Automatic works well in most cases.

Process ASM

1. Select the radio button **ASM**
2. In the text field, Strategy, enter the name of the strategy file
3. In the text field, Maximum Number of Image Pairs field, enter the parameters
4. In the text field, Number of Processes, enter the parameters
5. Select **Start Now** to immediately process the job
   Select **Start Later** to delay the process of the job

Case study 1: EuroSDR project

The data set in this case study was used for the European Spatial Data Research Organization (EuroSDR) project "Benchmarking of Image Matching Approaches for DSM Computation" (http://www.ifp.uni-stuttgart.de/eurosdr/ImageMatching/). It is used to compare the speed and accuracy of ASM with similar technologies from other commercial vendors as well as universities. Since the release of NGATE in 2006, with the matching of every pixel in a commercial product, dense matching has become the norm for DSM generation from stereo images.

SOCET GXP has a unique method of photogrammetric processing (sensor modeling, epipolar resampling, etc.). The majority of SOCET GXP customers use satellite images and images from other government sensors, which are very different from well known, aerial frame cameras. To make SOCET GXP terrain generation independent of different sensors, a generic algorithm is used for epipolar resampling, which may not work correctly with orientation parameters from third-party triangulation software. Most complaints about poor DSM quality from NGATE are due to significant Y-parallax, which may be a result of third-party orientation parameters. As recommended, always check Y-parallax and run triangulation to eliminate any issues before running NGATE.

Unfortunately, the participant who used NGATE in the EuroSDR case study may have overlooked the difference between SOCET GXP's photogrammetric processing and the standard photogrammetric processing found in competitors' offerings. As a result, the DSM from NGATE is poor. After triangulating the same images with SOCET SET, SOCET SET v5.6 was used to run NGATE and the DSM accuracy is comparable to the rest of the technologies evaluated by EuroSDR, as shown in Figure 2.

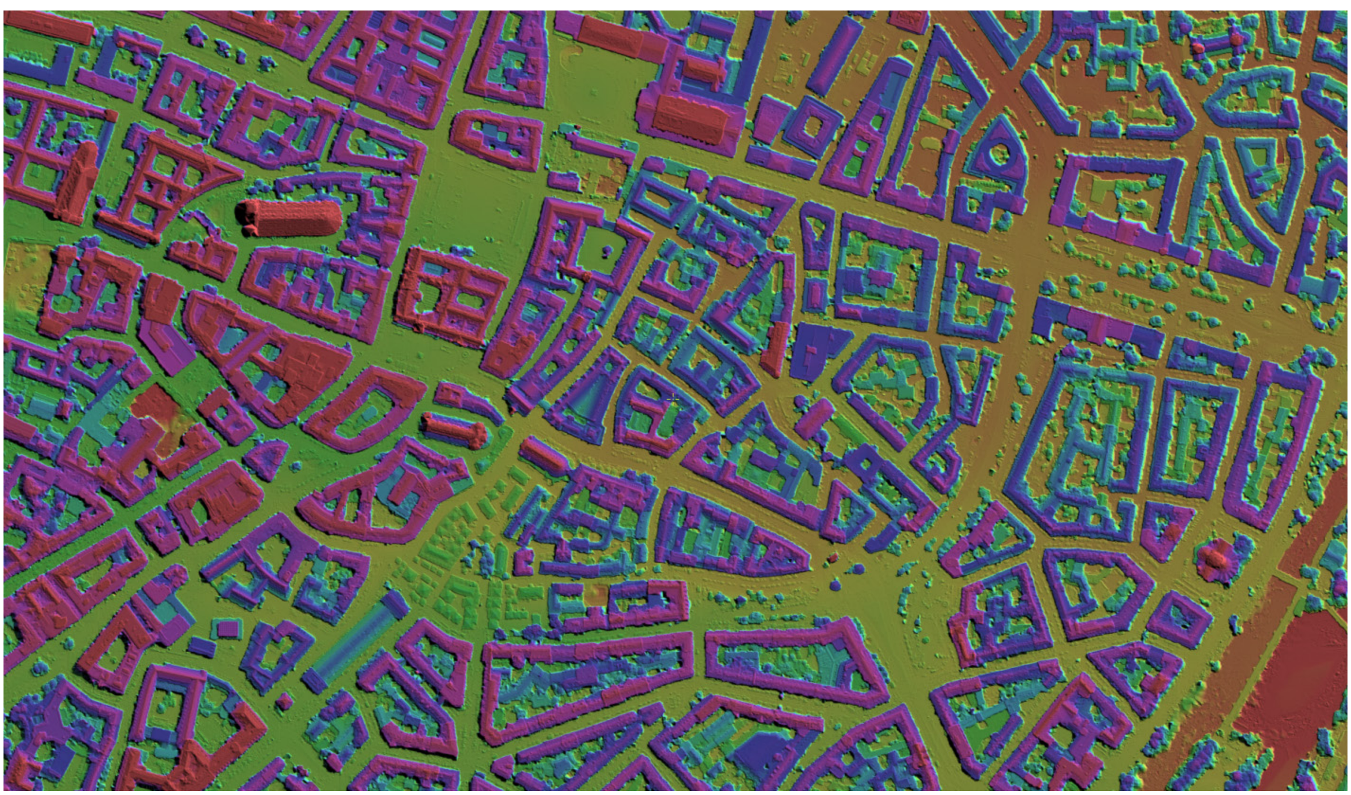


Figure 2
Terrain-shaded relief (TSR) image of DSM generated by NGATE after the triangulation of images.

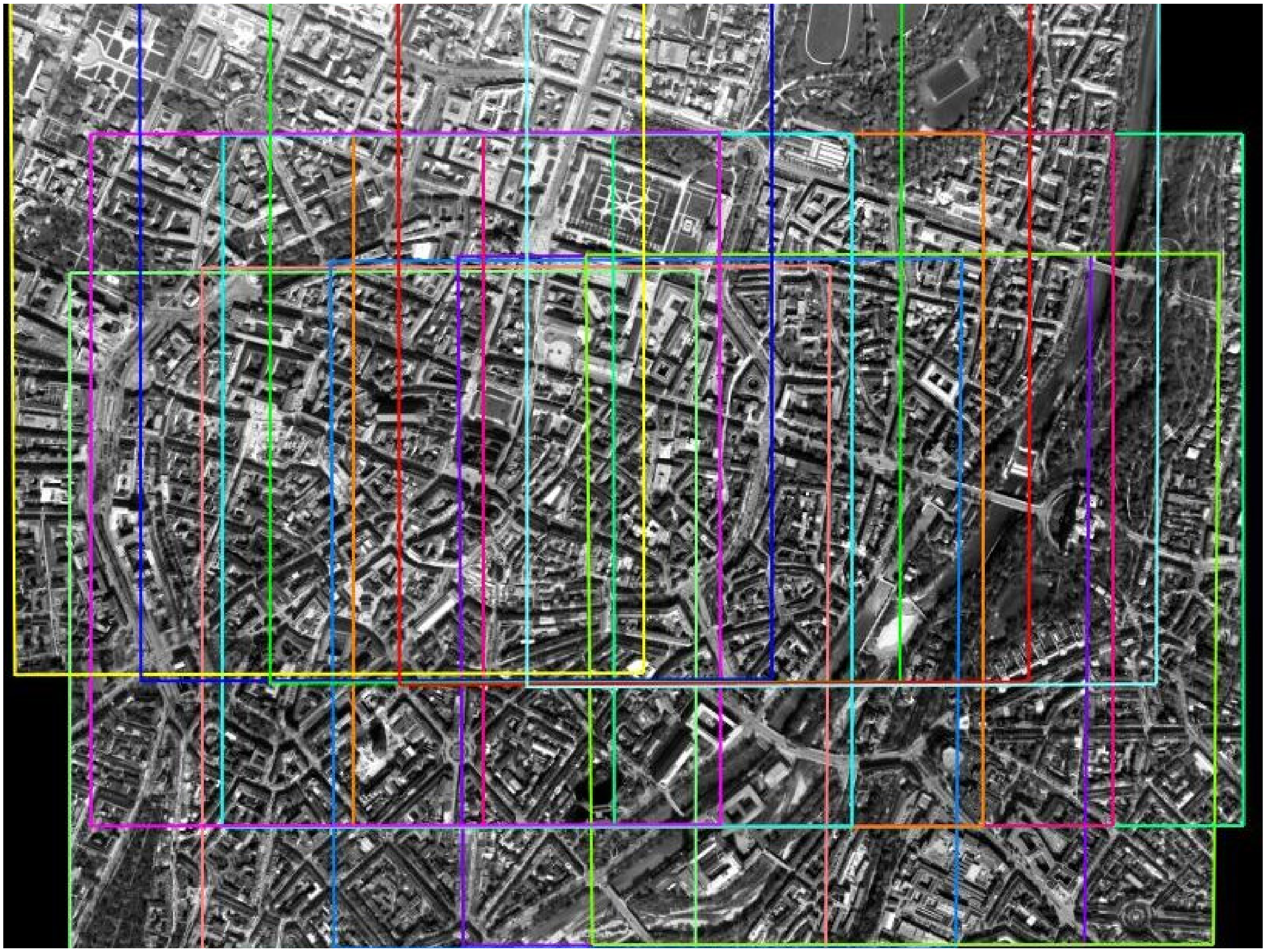


Figure 3
The München dataset from the EuroSDR project.

The test data set consisted of 15 panchromatic images from an Intergraph DMC II 230 digital airborne frame camera with 15,552 x 14,144 pixels per image, 16 bits per pixel, 10 cm GSD, as shown in Figure 3.

The 15 images consist of three strips and five images per strip covering the central part of the city of München, Germany. There is 80% overlap in both directions, which results in 15 stereo pairs being available for certain areas. The terrain is fairly flat, with trees, rivers, bridges, moving vehicles, streets, buildings, shadows, grass areas, etc. The area is densely covered by buildings with heights of up to 50 m. The buildings result in occlusions, especially for surface areas close to building facades. Visibility can be limited for such regions, which will potentially affect the matching processes during DSM generation.

Figure 4
TSR image of DSM generated by ASM.

ASM processed on a desktop workstation with an Intel Xeon CPU running at 3.2 GHz (two processors), 24 GB RAM and a Geforce GTX Titan GPU. It generated a DSM with 10 cm post spacing and 569 million posts. The DSM covers the entire area of stereo image coverage as shown in Figure 4.

The Maximum Number of Image Pairs field was defined with a value of 12 to generate sharp, accurate building edges and corners from different perspectives. Some of the posts were matched 12 times. ASM performs blunder detection on the 12 different Z values, and selects the most accurate and reliable Z value. The Number of Processes field was defined with a value of 2, which generated in 6 hours and 27 minutes. ASM used the GPU for extra speed.

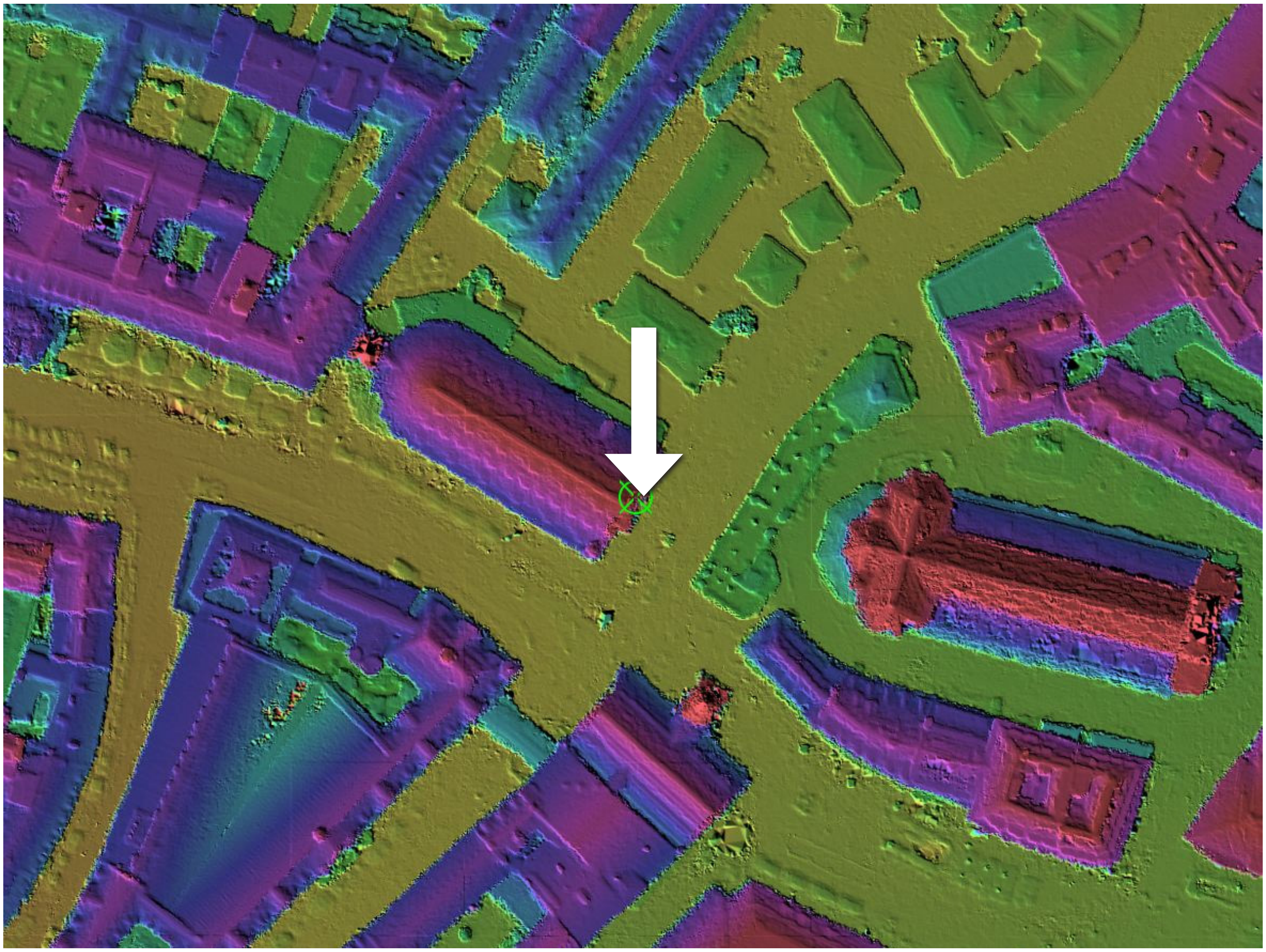


Figure 5
Accuracy evaluation site of the EuroSDR project.

Figure 5 displays a TSR image of the DSM generated by ASM at the benchmarking site. The highlighted building was used to compare accuracy among the different DSMs from participants using different digital photogrammetric software. ASM accurately generated building edges and corners, which use different strategy files for different types of terrain.

Selecting the appropriate strategy file enables ASM to apply different algorithms, or different parameters for the same algorithms, to generate a DSM reliably and accurately based on the underlying terrain. For example, a close to vertical elevation discontinuity is considered correct in urban areas, but it is likely to be a blunder in rural areas. The strategy file `asm_urban.strategy` was used in this case study.

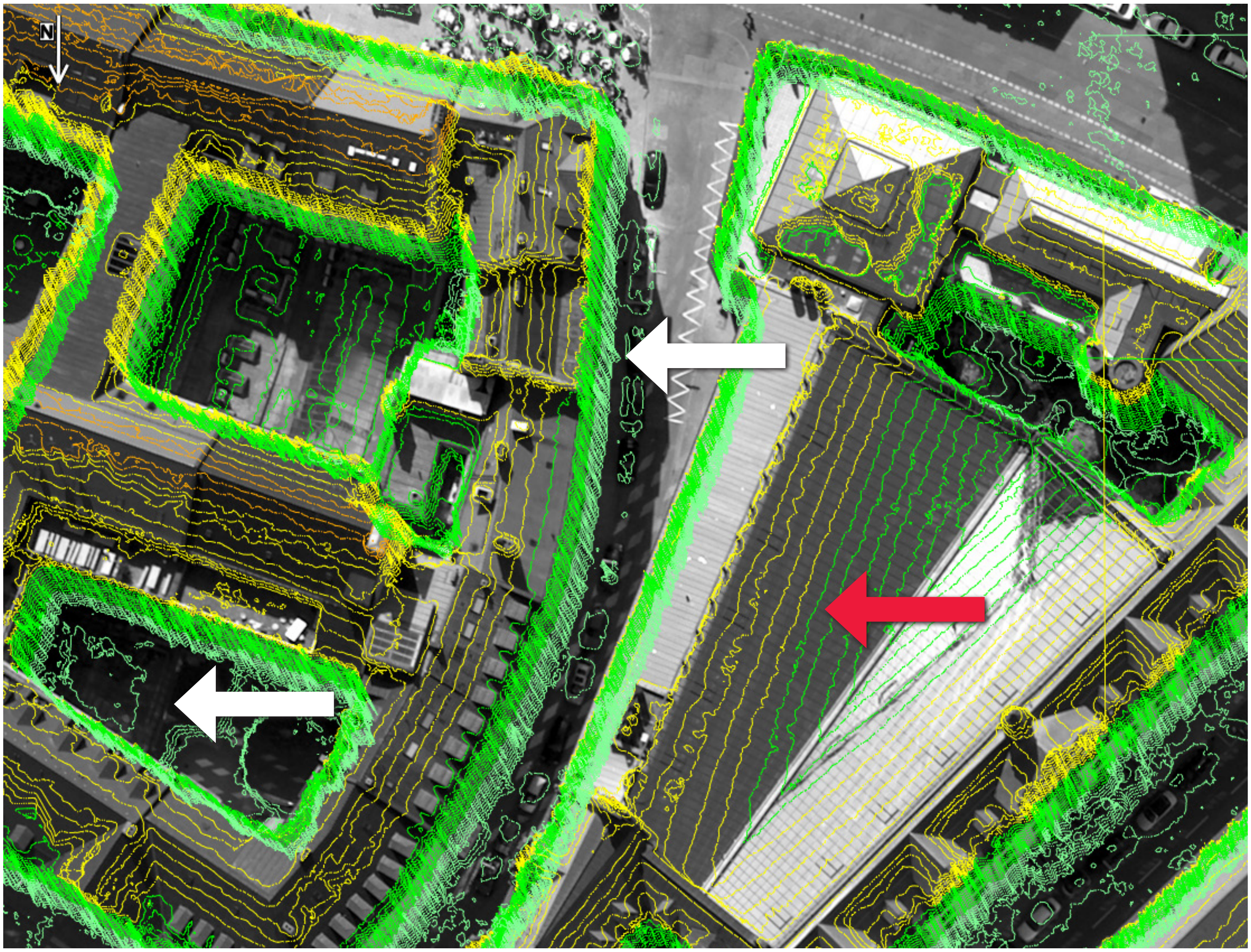


Figure 6
Contours (0.5 meter) of the test area of the EuroSDR project.

Vertical building edges, image shadows and rooftops with repeated patterns and featureless man-made areas such as streets are challenging problems in stereo image matching in built-up areas. Figure 6 displays the repeated patterns highlighted in red.

ASM has a shadow detection algorithm that allows it to use shadow-specific image matching logic. With 16-bit images, a value of 12 defined for the Maximum Number of Pairs, and the shadow-specific image matching algorithm, shadows become less of a problem as long as they are not in featureless areas.

To match vertical building edges, there must be at least one stereo pair in which the vertical building edges are visible. ASM used up to 12 stereo pairs to match every pixel. ASM selected the most reliable matches from 12 of them based on their visibility, figure of merit, precision, and consistency.

ASM generated an accurate DSM on repeated patterns using its advanced new algorithms. ASM has the capability to use images with multiple bands, which also improves dynamic range since pixel values are additive. For example, a three-band, eight-bits-per-band color images can have 9.5 bits dynamic range when the bands are added together. ASM generated an accurate DSM in shadows as shown in areas highlighted in white.

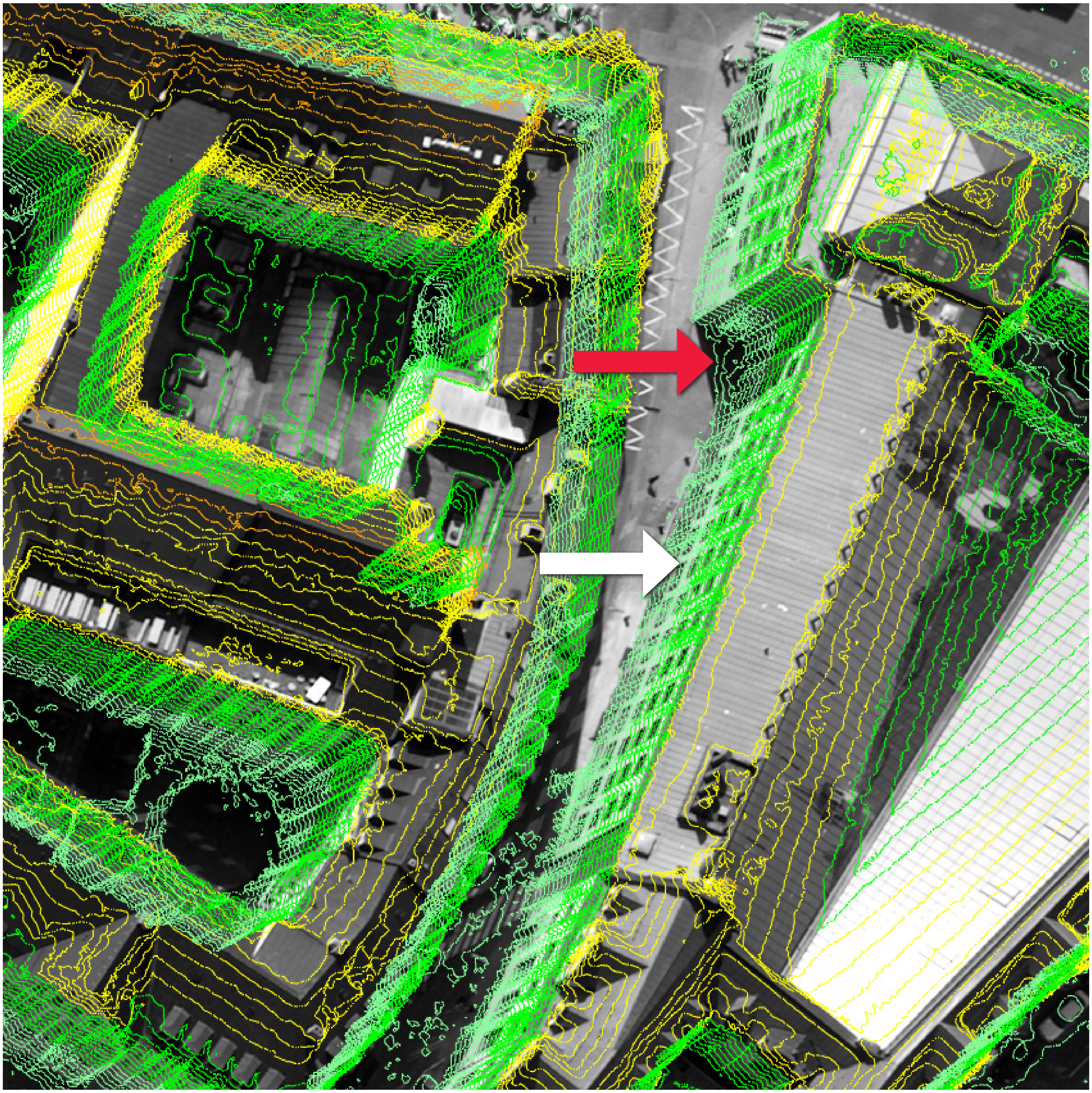


Figure 7
Vertical wall on the left side of a building.

To generate sharp building edges on the left side of a building, use stereo pairs looking from the left perspective. It is important to have large overlaps in both directions. It is also important to define a large value for the Maximum Number of Pairs field for ASM. Figure 7 shows a vertical wall on the left side of a building.

Highlighted in red is a shadow in a featureless area, which is still a difficult problem for ASM. The DSM in this shadow may have elevations up to 1.5 m above ground at the intersection between the vertical building façade and the horizontal street. In built-up areas with large overlaps, define a value of 4 or higher for the Maximum Number of Pairs field, 12 was defined for this example. ASM DSM generation speed is directly related to the Maximum Number of Pairs. For example, ASM may take up to twice the amount of time if the Maximum Number of Pairs is defined as 8 rather than 4.

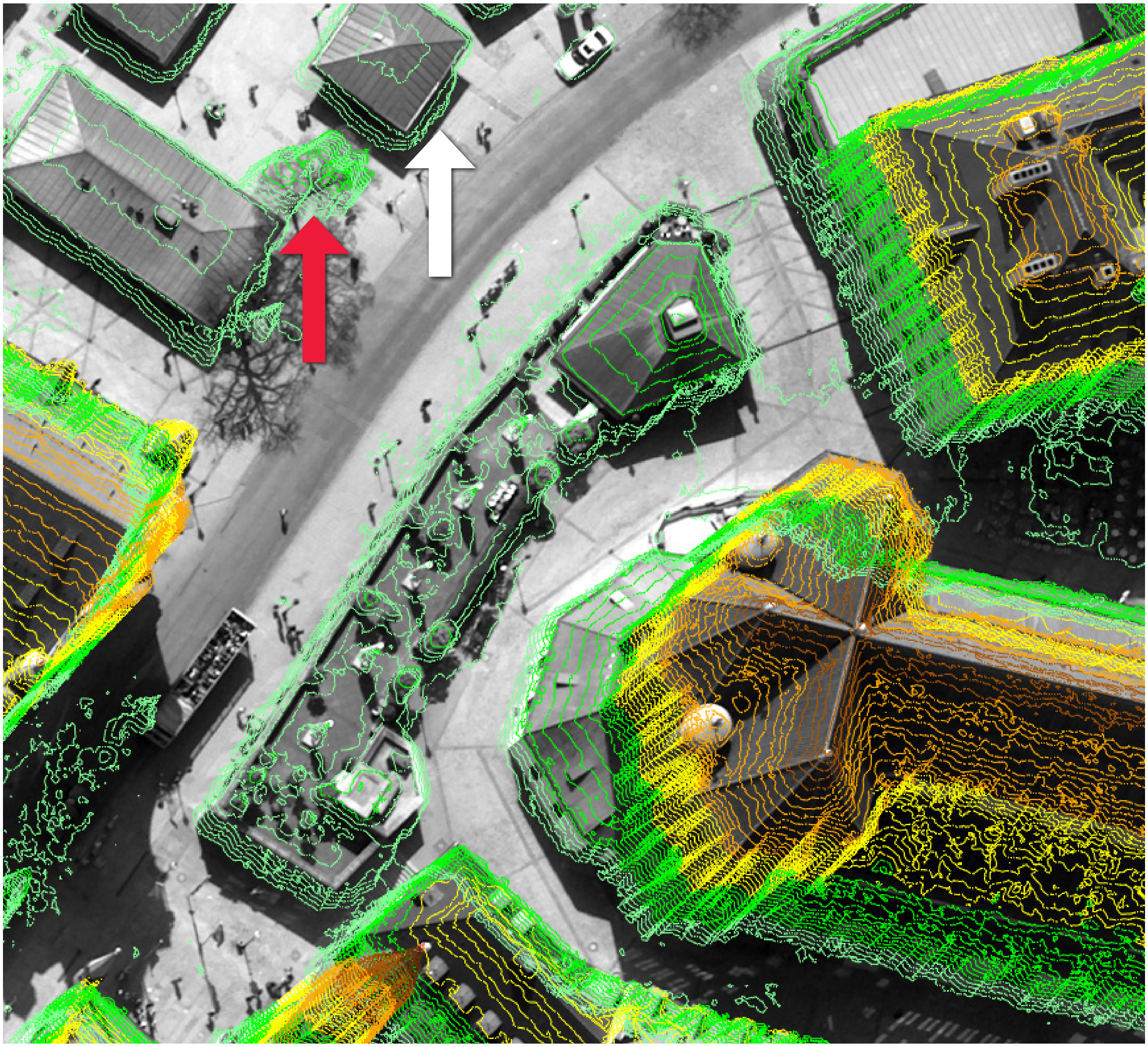


Figure 8
Trees without dense canopies.

Trees and shadows can be challenging for stereo image matching. Trees with dense canopies are not problematical as long as they do not move (windy day vs. calm day). Trees without leaves can be difficult since there is no continuous surface for stereo image matching. Shadows can be a challenge for stereo image matching depending on what is in the shadow. When shadows cover featureless areas, they can be difficult to match since the signal-to-noise ratio becomes very poor. In general, shadows are more of a problem for 8-bit images than for 16-bit images.

Figure 8 displays trees without dense canopies highlighted in red, which have no unique Z value. One DSM cannot model these trees. We are working on a true 3-D point cloud instead of one DSM and one DEM highlighted in white, dark shadows in featureless areas are still a problem for ASM.

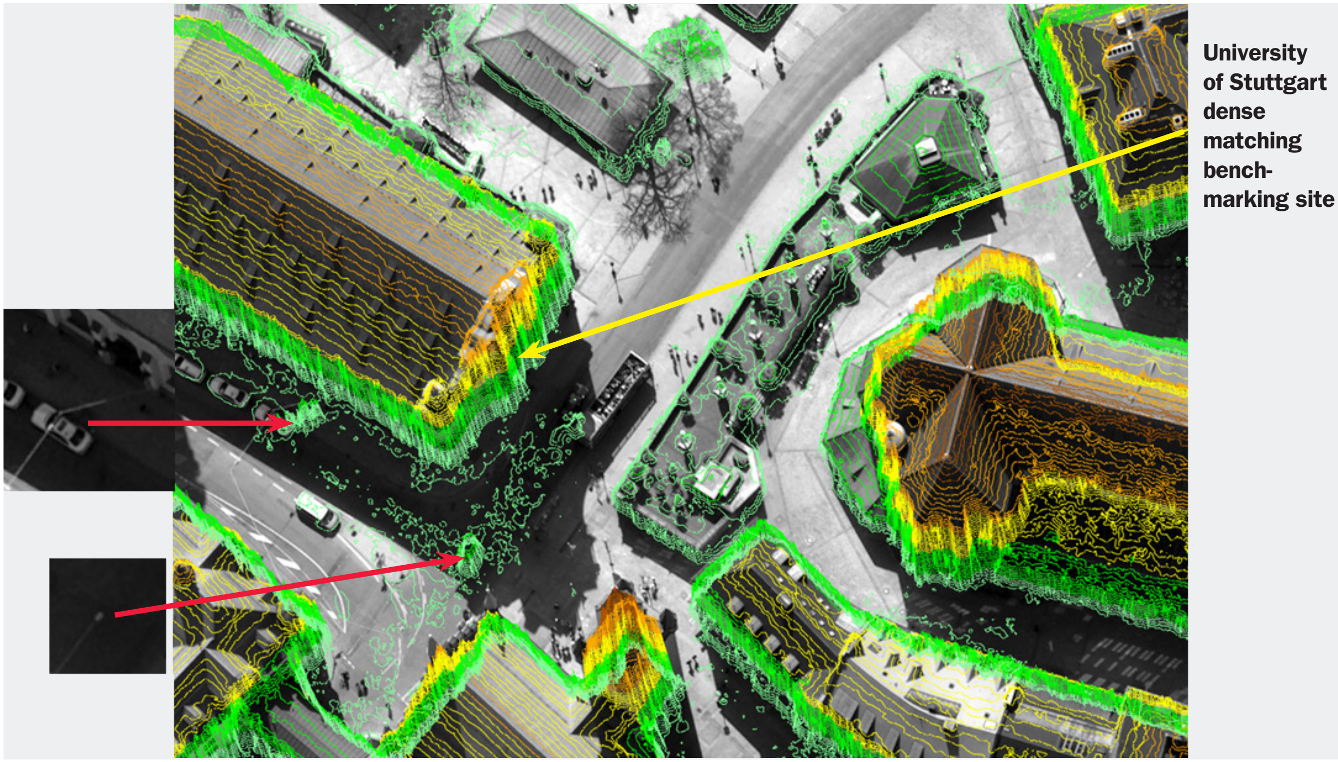


Figure 9
Light poles, traffic posts and moving vehicles.

Small but tall man-made features, such as light poles, traffic posts, flag poles or moving vehicles are commonplace in urban areas as shown in Figure 9. These features are not part of terrain, but they may be part of the DSM generated by ASM.

Since they are so small and there are not enough pixels to work with, ASM may miss them. And, since they are so different from their surroundings, ASM may actually match them. It is debatable whether these small made-made features should be part of a DSM, which depends on the applications that use DSM. Moving vehicles (highlighted in white) are abundant in urban areas and are a challenging problem. ASM has a special logic to detect them and remove them (Zhang and Walter, 2009).

SOCET GXP has terrain tracking functionality. A profile from the EuroSDR case study was used to assess the sharpness of building edges in the DSM generated by ASM.

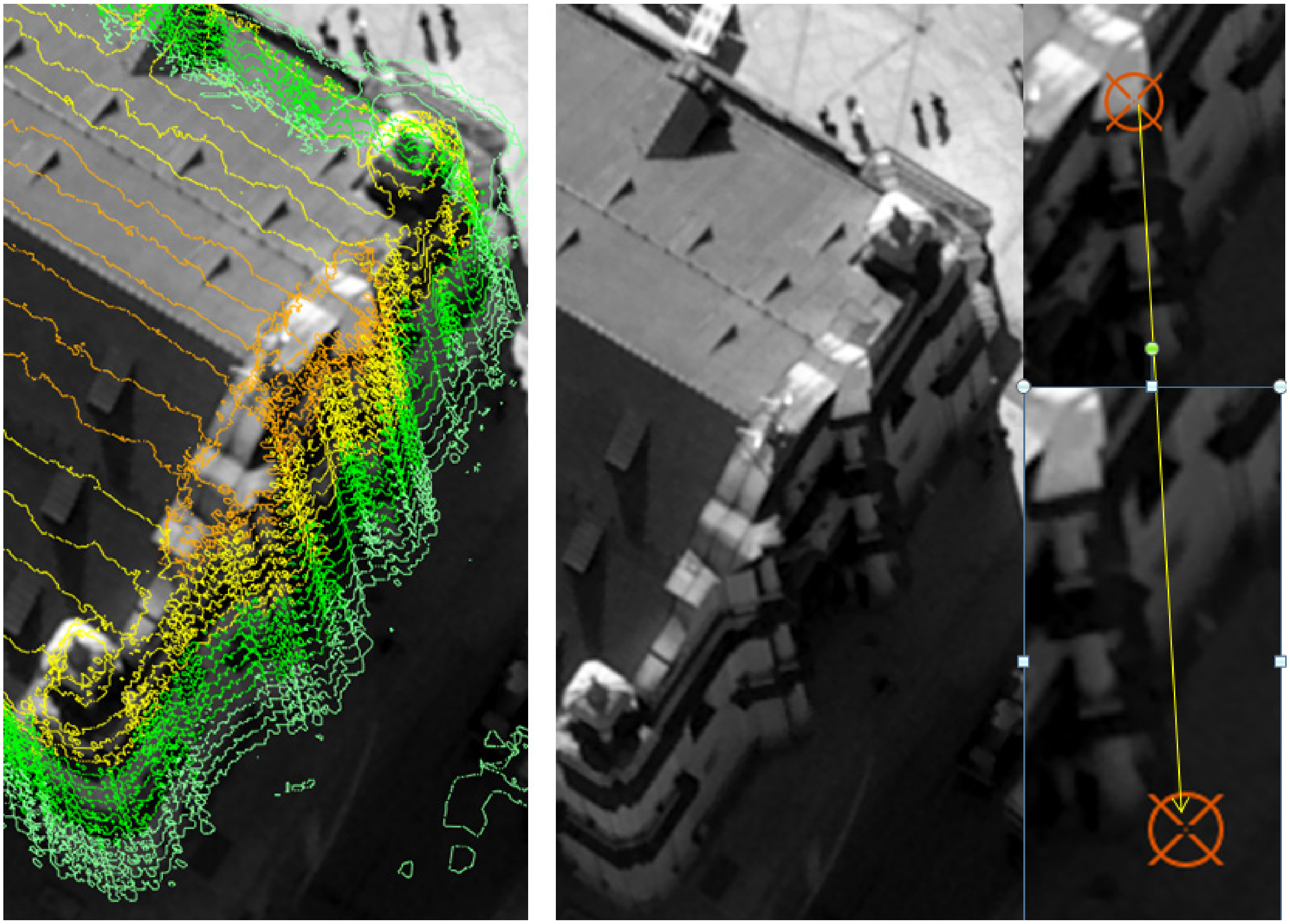


Figure 10
Sharpness of building edges in ASM generated DSM.

The DSM was loaded into the SOCET GXP Multiport and terrain tracking turned on. A point was measured at the top edge (X=25.13, Y=25.88, Z=98.33) and a point at the base (X=24.58, Y=25.91, Z=65.51) as shown in Figure 10. The XY coordinates are from the images and the Z coordinate is from the DSM. The measuring cursor was offset to measure a point at street level. Using the XY offset and Z difference, the slope angle of the building edge was computed in the DSM. The result is 89°, which is very close to vertical; 90° cannot be reached exactly because the DSM model can have only one Z per XY.

Figure 11
Used 316 point to assess DSM accuracy generated by ASM.

A rigorous method of assessing DSM accuracy is to compare a DSM against ground-truth posts. In Figure 11, 316 points spaced 100 meters apart were used. The points cover the entire DSM and are a good representation of the different types of terrain (trees, buildings, streets, grasses, rivers, shadows, etc.). The 316 points were not located with ground GPS. Instead, stereo images were used and all 316 points manually measured four times the zoom to achieve high accuracy. Several points were excluded and do not display because they are on the tops of trees that do not have dense canopies. For these points, there are multiple Z values that cannot be used for DSM accuracy assessment. A few points in occluded areas were also excluded because they could not be measure in the stereo images.

The SOCET GXP Quality Statistics module was used to assess the accuracy of the DSM. For every manually measured point in the Master DTM, consisting of the stereoscopically measured points, the Z value was interpolated at the same XY coordinates from the Slave DTM, which was the DSM generated by ASM. The differences in Z were used to generate accuracy statistics. For the 316 points, the root-mean-square error (RMSE) was 0.23 m, and the standard deviation 0.22 m, as shown in Figure 12.

Comparison of two DTM files

Master DTM File:`\EDIT_MASTER2.dth`
Slave DTM File: `ASM_10cm_12pairs_2sections_3.dth`

num_pts = 316, rms = .2308, std = .2248, bias = -.0539
percent blunders = .0000

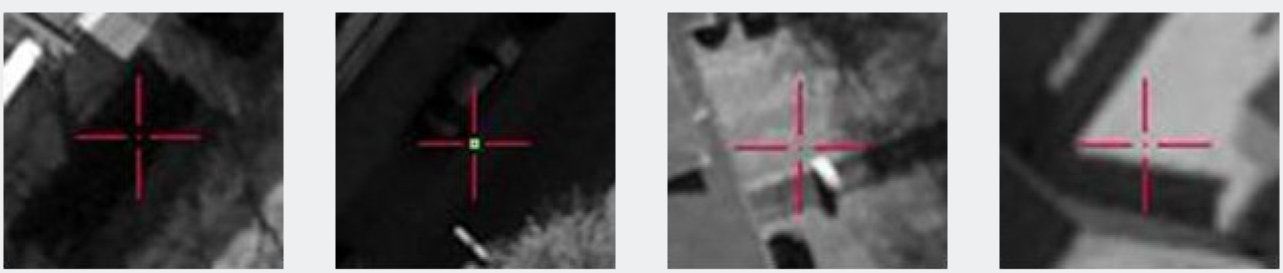
After two outlier removal
num_pts = 313, rms = .1745, std = .1699, bias = -.0409
percent blunders = .9585

After three outlier removal
num_pts = 312, rms = .1707, std = .1665, bias = -.0389
percent blunders = 0.9615

NOTE: bias = (Z from Master) - (Z interpolated from Slave)

Figure 12
Output from SOCET GXP Quality Statistics module for the 316 points.

Figure 13 displays the maximum Z difference of -2.34 m. The first point is in a dark shadow, close to a building base; the second point is on a street and in a dark shadow; the third point is on a featureless street, and the fourth point is at the edge of a man-made structure. All four points have Z values from the DSM higher than their ground-truth Z values.



-2.34 meters **-1.01 meters** **-0.88 meters** **-0.66 meters**

Figure 13
Four ground points with large Z differences.

Case Study 2: UAV images

UAV images represent a new trend in the geospatial industry due to their high resolution and low cost. Ten UAV images were used for this case study (6132 x 8176 pixels, three-color bands, eight bits per band, 2.9 cm GSD).

Figure 14 displays one strip with 10 images in which SOCET GXP triangulation successfully eliminated Y-parallax. ASM generated a DSM with 5 cm post spacing and 141 million posts, and a value of 6 defined for the Maximum Number of Image Pairs in order to generate building models accurately.

Figure 15 displays houses, vehicles, trees and even small bushes accurately modeled.

Figure 14
UAV images and their footprints.

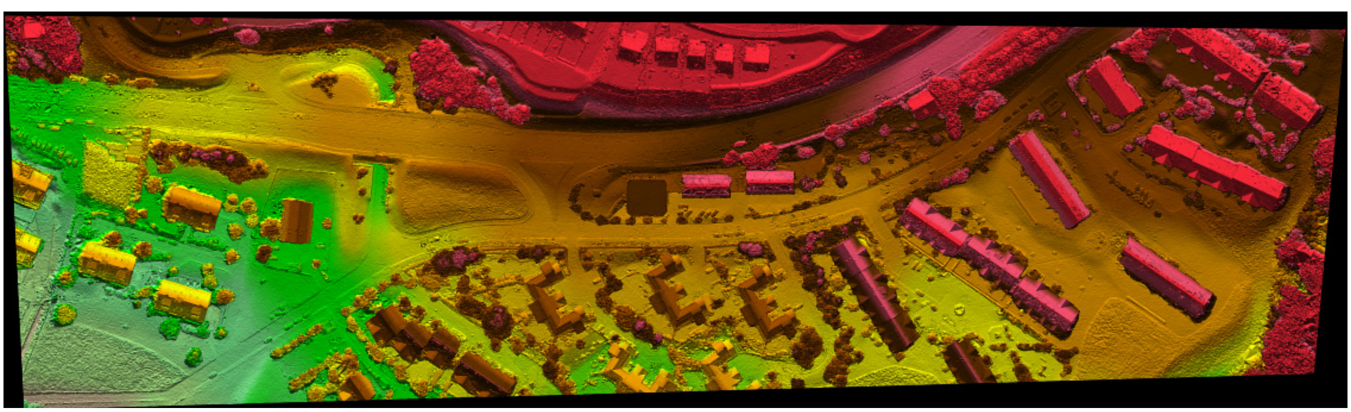


Figure 15
TSR image from the DSM generated by ASM with 10 UAV images.

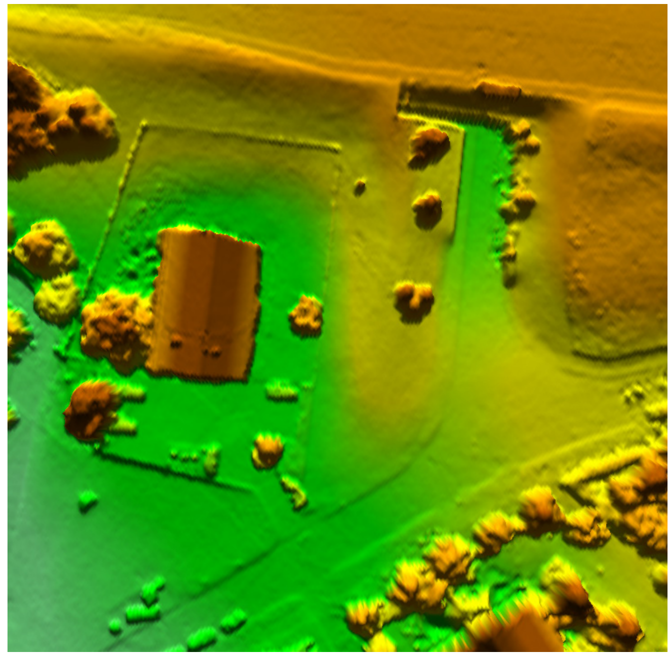


Figure 16
TSR excerpt from the DSM generated by ASM from 10 UAV images.

Figure 16 displays the DSM: trees, vehicles and houses accurately modeled. Generating accurate 3-D point clouds from UAV imagery paves the way for ASM to navigate robots in urban environments and complex terrain since robotic cameras are non-metric. Figure 17 displays houses, trees, stationary vehicles and even small bushes, accurately modeled. Moving vehicles cannot be extracted because they are in different locations in different stereo images.

Figure 17
3D view generated by DSM and UAV images.

Traditional photogrammetric workstations, such as SOCET GXP are designed to work with images from accurate, expensive metric cameras, not with UAV images. It is a challenge to model and triangulate UAV images accurately in a traditional photogrammetric workstation. One of the main reasons is lens distortion, which can be up to 20 pixels for these non-metric UAV cameras. More investigation is needed to model UAV images accurately.

As noted earlier, ASM assumes that there is no Y-parallax and SOCET GXP triangulation should be run to achieve images free of Y-parallax. However, SOCET GXP triangulation may not be able to generate sensor models that guarantee UAV images free of Y-parallax. As long as there is no significant Y-parallax after SOCET GXP triangulation, ASM should generate an accurate and dense DSM from UAV images. More research is needed in ASM to work with images with significant Y-parallax.

In Figure 14, 124 ground truth points were manually measured using the stereo images. The points were evenly spaced 30 m apart to cover all types of terrain, as shown in Figure 18. The fidelity of the orthorectified image on houses (especially edges and corners) and trees indicates that the DSM is extremely dense and accurate. A few points in occluded areas were excluded since they could not be manually measured. The orthorectified image in the lower part of Figure 18 is very accurate even on houses due to the high accuracy of the DSM.

Figure 18
Manually measured ground points, 124 (red dots) and an orthorectified image generated from the DSM and UAV images.

The SOCET GXP Quality Statistics module was used to compare the measured heights with those interpolated from the ASM DSM: the RMSE and standard deviation were 0.052 m and 0.053 m respectively (Figure 19).

Comparison of two DTM files

Master DTM File: `EDIT_MASTER.dth`
Slave DTM File: `horizontal_strip_6_pairs.dth`

num_pts = 124, rms = .0532, std = .0533, bias = -.0038
percent blunders = .0000

After two outlier removal
num_pts = 121, rms = .0366, std = .0367, bias = .0022
percent blunders = 2.4793

After three outlier removal
num_pts = 120, rms = .0352, std = .0352, bias = .0032
percent blunders = 2.5000

NOTE: bias = (Z from Master) - (Z interpolated from Slave)

Figure 19
Output from SOCET GXP Quality Statistics module for the 124 ground-truth points.

Case Study 3: ADS40 images

The Leica ADS40 is a pushbroom sensor, very different from regular aerial frame cameras. This case study consists of six images, 12,135 lines x 102,725 samples, 50 cm GSD, covering a very steep mountainous area. Auto DTED should be used to provide good initial elevations for ASM due to large elevation difference.

ASM determines at which RSET to stop using elevation values from the Seed DTM by comparing the precision of the Seed DTM with the precision from stereo image matching.

Generally, two stereo ADS40 images are selected for ASM due to the unique ADS40 stereo image formation geometry. This case study used two strips with three images per strip (forward, backward, and nadir). There is significant overlap between the two strips as shown in Figure 20.

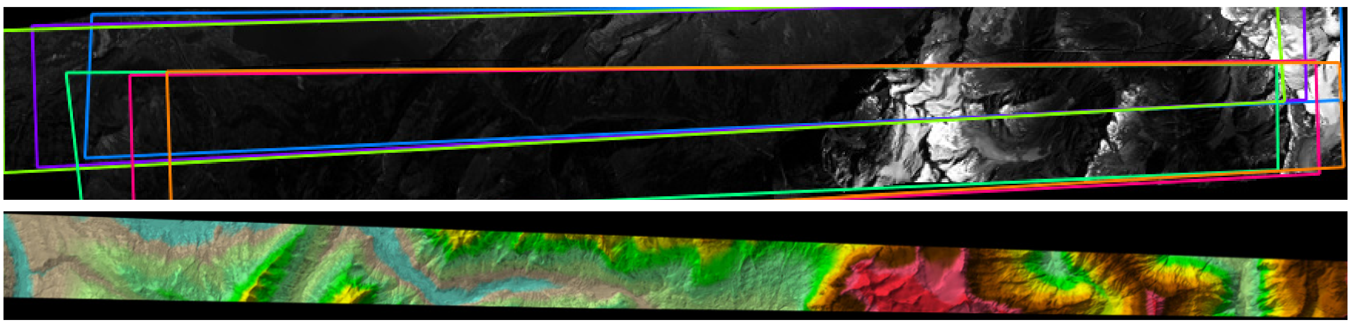


Figure 20
Six ADS40 images.

Imagery courtesy of Swisstopo, geodaten©swisstopo.

A DSM of 845 million posts with post spacing of 50 cm was generated by ASM. The lower image is the TSR of the DSM. The three images within each strip can form three stereo pairs (forward and nadir, backward and nadir, forward and backward). As ASM is currently configured, each image from the first strip can form stereo pairs with two different images from the second strip. For example, the forward looking image from the first strip can form a stereo pair with the nadir image from the second strip and another stereo pair with the backward looking image from the second strip.

A total of 12 stereo pairs are available in the overlapping area between the two strips when the three stereo models formed within the first strip, and the three within the second strip are included. A value of 6 was defined for Maximum Number of Image Pairs field for this case study. ASM has special logic to form stereo image pairs for matching ADS40 imagery.

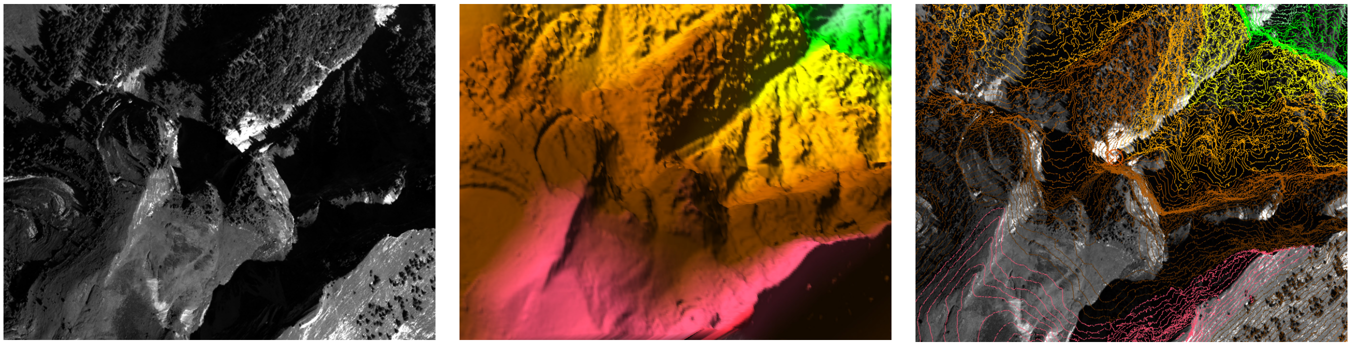


Figure 21
DSM on steep slopes with dark shadows.

The left-hand panel shows the imagery with dark shadows on steep slopes, the center panel, the TSR, and the right-hand panel, 10 m contours.

Dark shadows in steep mountains pose challenges for stereo image matching. Image signal-to-noise ratio becomes poor. To compensate for this, increase the window size so there is enough image information for matching. When the dark shadows are on steep slopes, a smaller window size is used since X-parallax within the image matching window will be less variable. These two contradictory conditions make dark shadow on steep slopes a difficult problem for stereo image matching. As shown in Figure 21, ASM generated an accurate DSM in areas with steep slopes covered by dark shadows. ASM generated an accurate DSM in the challenging areas due to its advanced image matching algorithms and the ADS40 sensor's signal-to noise-ratio.

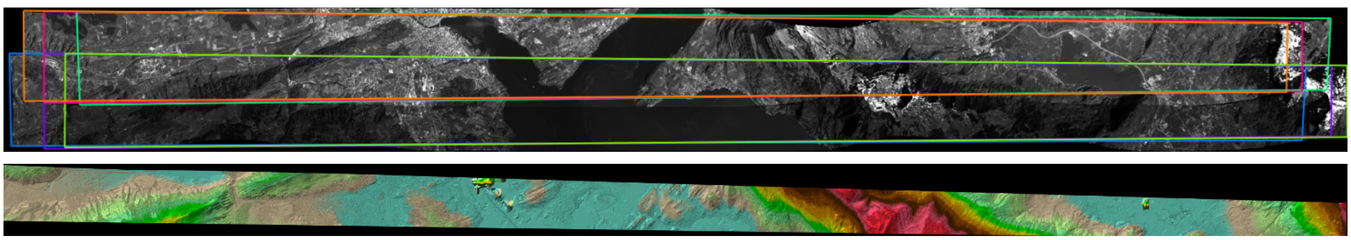


Figure 22
Six 25 cm ADS40 images and the TSR image of a DSM generated by ASM.

A second set of ADS40 images with 25 cm GSD were used in Figure 22, consisting of six images in two strips. ASM generated a DSM with 1478 million posts at 25 cm post spacing or the same size as a pixel. About one third of the DSM covers water, which cannot be matched in theory, and ASM could not match pixels on water in practice. About one fifth of the DSM is in urban areas with highways, houses, and buildings. A very accurate DSM was generated, due to the ADS40 sensor's dynamic range, the advanced stereo image matching algorithms in ASM, and accurate ADS40 sensor modeling in SOCET GXP (Figures 23 and 24).

The resemblance between the TSR image and the ADS40 image indicates the high accuracy of the DSM. The image GSD is too large to generate houses accurately, but it is small enough for large buildings. The ADS40 sensor's unique image formation geometry prevents building corners and edges in the DSM from being as sharp as regular aerial frame cameras such as DMC and UltraCAM. Stereo pairs that cover vertical building facades are needed to generate sharp and accurate building edges and corners. It is difficult for ADS40 sensors to achieve this because of the forward, backward, and nadir line-scans.

Figure 23
ADS40 image covering highways,
buildings and trees.

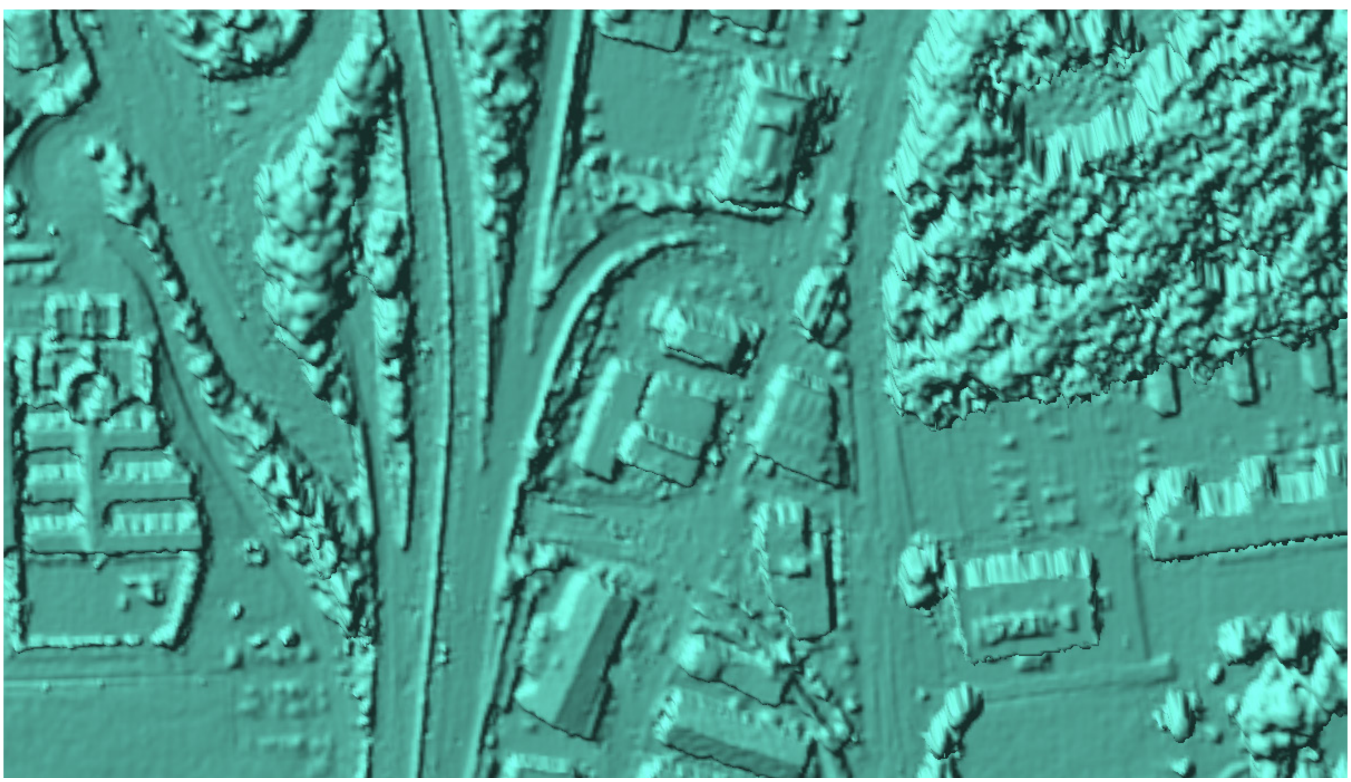


Figure 24
TSR image of an accurate
DSM generated by ASM.

Case Study 4: Satellite (WorldView-1) images

GXP has invested heavily in satellite image processing since many SOCET GXP customers use satellite images. A stereo pair of DigitalGlobe WorldView-1 images covering an area of the Rocky Mountains in Colorado was used for this case study; the `asm_rural_steep.strategy` file and 60 cm post spacing. In NGATE, a post spacing of at least three times image GSD is recommended. For ASM, a new logic utilizes post spacing as small as the image GSD.

The image GSD and the DSM post spacing are almost the same in this case study. There are a total of 1.7 billion posts in the DSM generated by ASM (Figure 25). Auto DTED is used to provide good initial elevations to Seed ASM due to huge elevation differences (over 2000 m).

ASM processed on a desktop workstation with an Intel Xeon CPU running at 3.2 GHz (2 processors), 24 GB RAM and a Geforce GTX Titan GPU. Two processes and ASM took 10 hours and 40 minutes to generate the DSM. ASM achieved a success rate of 91% i.e., 91% of image pixels were successfully matched. The other 9% were on lakes, extremely dark shadows where the signal-to-noise ratio was so poor that they could not be matched in theory. This does not mean that the 9% needed to be manually edited; their elevations could be interpolated from adjacent matched posts. Most of the interpolated elevations were accurate and did not need to be manually edited. Posts on lakes were manually edited since the adjacent matched posts could not be used to interpolate their elevations.

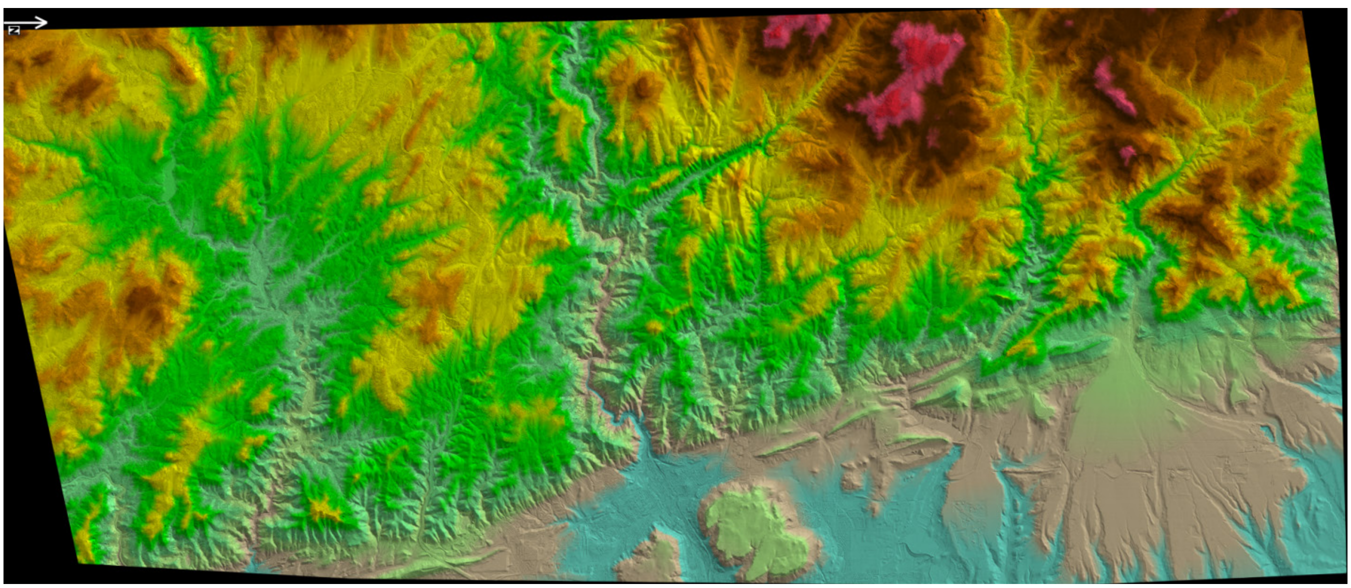


Figure 25
TSR image of the DSM generated from WorldView-1 satellite images.

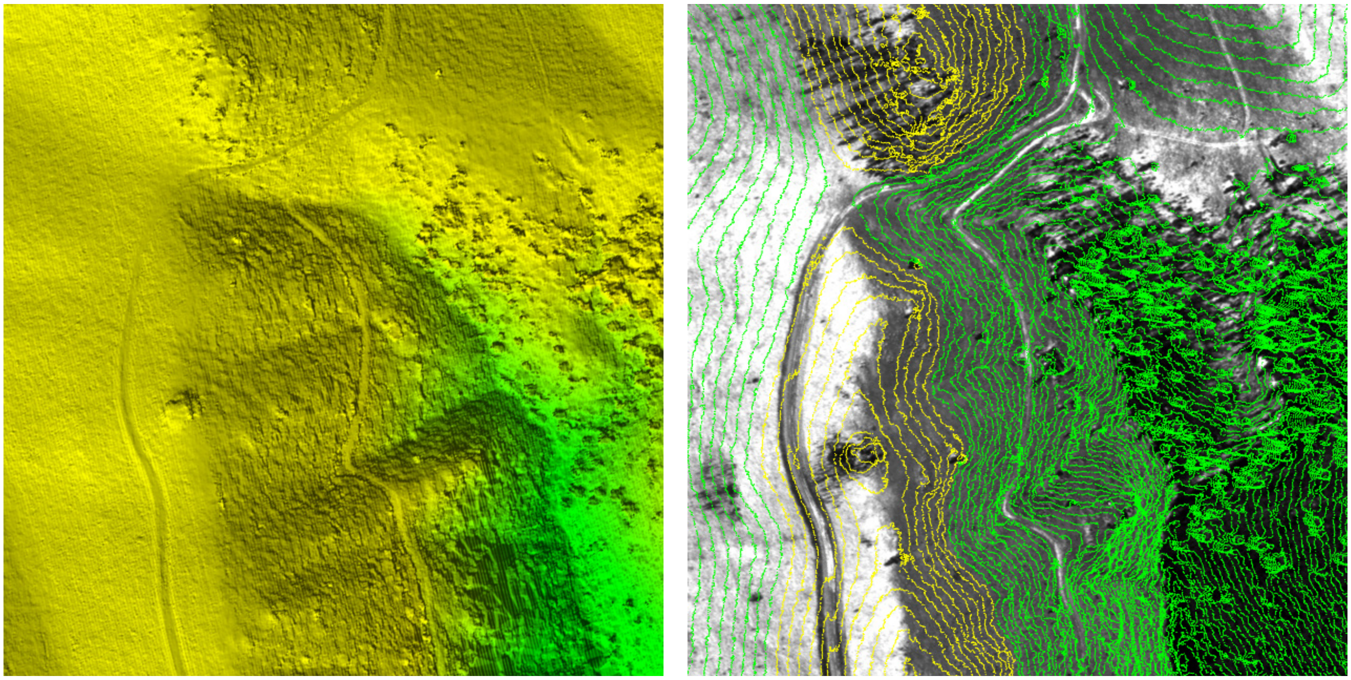


Figure 26
A TSR image of snow, trees, and shadows – smooth in areas covered by snow without trees – bumpy in areas with trees.

SOCET GXP has a large set of terrain editing tools that are easy to use and very productive. Figure 26 shows an area of snow, trees, and shadows where ASM has produced a good result. Two roads are clearly visible and complete in the TSR image. The DSM is accurate even in shadows. Figure 27 displays a 3-D view formed from the WorldView-1 satellite images and the DSM.

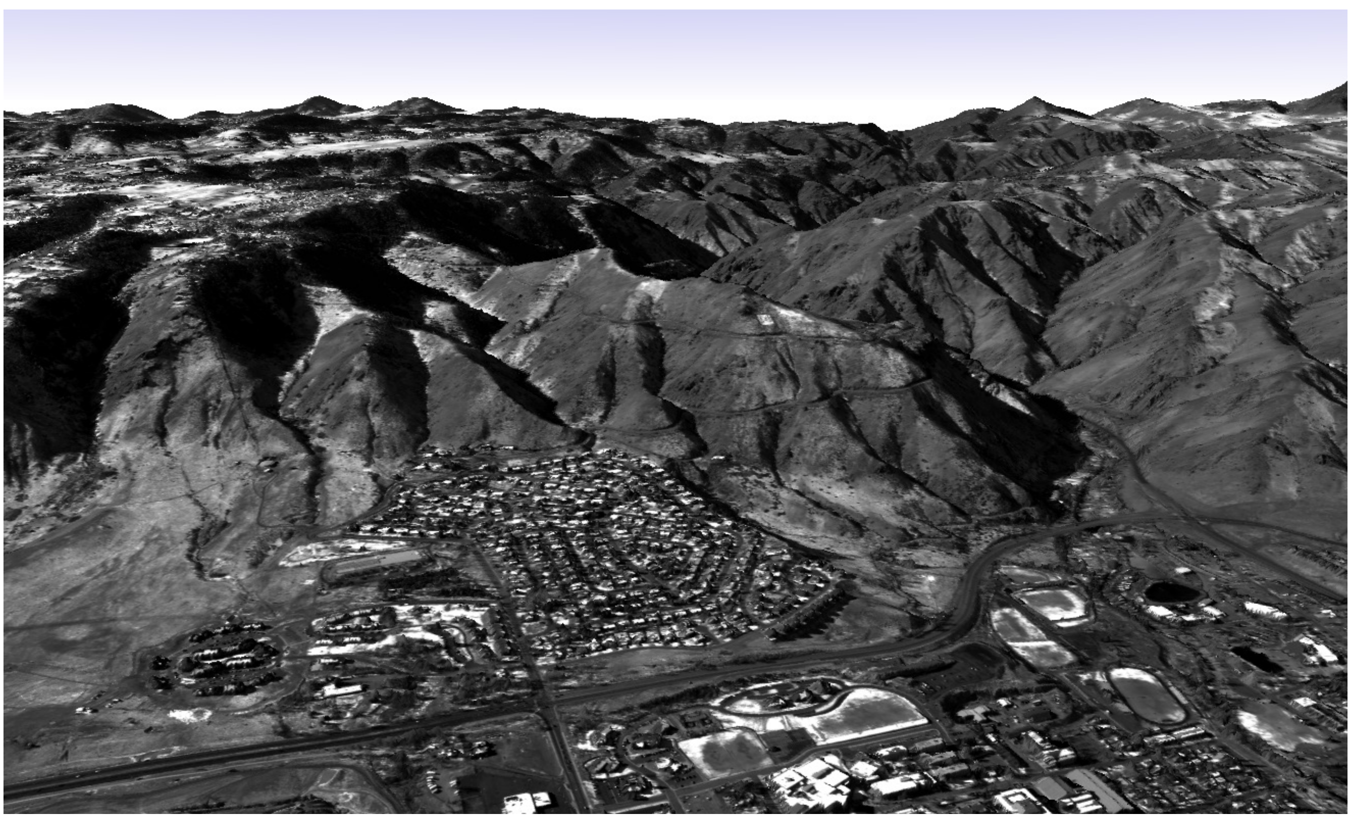


Figure 27
3-D view of stereo WorldView-1 satellite images and DSM.

ASM Accuracy Enhancement

The main objective of ASM is to generate sharp, accurate edges, and corners of buildings and houses in a DSM so SOCET GXP AFE can extract accurate buildings and houses automatically.

The examples in Figure 28 display four highlighted areas where ASM generated sharper and more accurate building edges and corners than NGATE. Using the same images, the same number of stereo pairs per post, and the same post spacing, NGATE generated a DSM as shown in the top TSR image, and ASM generated a DSM as shown in the lower TSR image.

From left to right, the first highlighted area of the figure displays the fence between the two buildings as clearly visible in the DSM generated by ASM. This fence separates the two buildings, which is important for AFE to extract these buildings correctly. The same fence in the DSM generated by NGATE is broken and the two buildings are connected. This connection will cause difficulty for AFE.

The second highlighted area displays a tree well separated from the adjacent building in the DSM generated by ASM, while the same tree is connected to the building in the DSM generated by NGATE. Separating trees from buildings is the most difficult problem in AFE.

The third highlighted area displays two buildings clearly separated in the DSM generated by ASM, while they are loosely connected in the DSM from NGATE. The last highlighted area, shown enlarged in the small panels in the lower part of the figure, displays a house with sharper edges in the DSM generated by ASM: the image is shown in the left-hand panel, the DSM from ASM in the central panel, and the DSM from NGATE is shown in the right-hand panel.

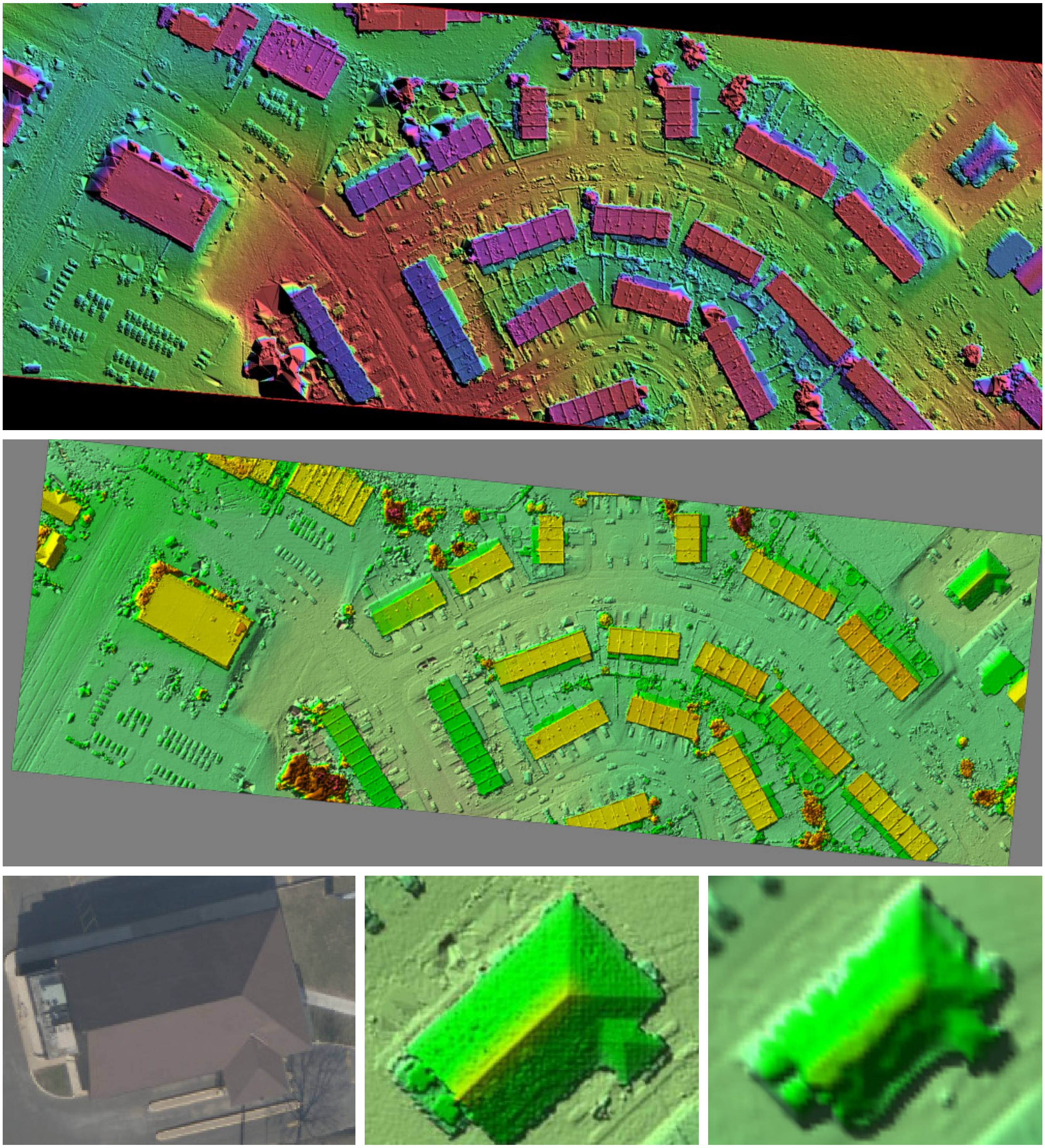


Figure 28
DSM accuracy comparison
between ASM and NGATE.

Summary

There are several new algorithms in ASM to extract sharp building edges and corners. BAE Systems has experimented with several computer vision algorithms from Hirschmüller (2005, 2008), Samsung Research America and Stanford. Our algorithms are significantly different and work more accurately and reliably than the ones we have tried using typical aerial images and satellite images. For this reason, BAE Systems holds its ASM algorithms proprietary.

There are two versions of ASM. One runs on GPUs and the other on CPUs. The GPU version uses Microsoft C++ AMP and is Windows only. The CPU version takes advantages of multi-cores and uses multi-threads to achieve desirable performance. The GPU version is about 30% faster on a K5000 card than the CPU version on an eight-core computer. GPU capacity may double every 1.5 years. The GPU version of ASM may speed up by 50% per year just by taking advantage of new graphic cards.

ASM has two options. Option 1, designed for non-urban areas, uses very similar algorithms to NGATE with a speed increase up to four times. Option 1 is for customers who like NGATE accuracy, but not its speed. With a four times speed increase, these customers can enjoy both accuracy and speed. Option 2 is specifically designed for urban areas with high buildings and houses. It has several new algorithms. This option produces much sharper building edges and corners than NGATE, and is about twice as fast as NGATE. Customers enjoy this speed increase as well as much sharper building edges and corners. In short, Option 2 is significantly more accurate than NGATE in urban areas.

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