

Relief Visualization Toolbox, ver. 2.2.1

Manual

By Žiga Kokalj, Klemen Zakšek, Krištof Oštir, Peter Pehani, Klemen Čotar and Maja Somrak
Research Centre of the Slovenian Academy of Sciences and Arts
Contact: ziga.kokalj@zrc-sazu.si

When using the toolbox, please cite:

Kokalj, Žiga and Maja Somrak 2019. Why not a single image? Combining visualizations to facilitate fieldwork and on-screen mapping. *Remote Sensing* 11 (7): 747.

Klemen Zakšek, Krištof Oštir and Žiga Kokalj. 2011. Sky-View Factor as a Relief Visualization Technique. *Remote Sensing* 3(2): 398-415.

General information

This software was developed to help scientists visualize raster elevation model datasets. We narrowed down the selection to include techniques that have proven to be effective for the identification of small-scale features. Default settings therefore assume working with high resolution digital elevation models, derived from airborne laser scanning missions (lidar). Despite this, the techniques can also be used for different other purposes. Sky-view factor, for example, can be efficiently used in numerous studies where digital elevation model visualizations and automatic feature extraction techniques are indispensable, e.g. in geography, geomorphology, cartography, hydrology, glaciology, forestry and disaster management. It can be used even in engineering applications, such as predicting the availability of the GPS signal in urban areas.

For a more detailed description of the visualization methods see the references given at each method, and a comparative paper describing them (e.g. Kokalj et al. 2013; Kokalj and Hesse 2017).

The tool also supports elevation raster file data conversion. It is possible to convert all frequently used single band raster formats into GeoTIFF, ASCII gridded XYZ, Erdas Imagine file and ENVI file formats.

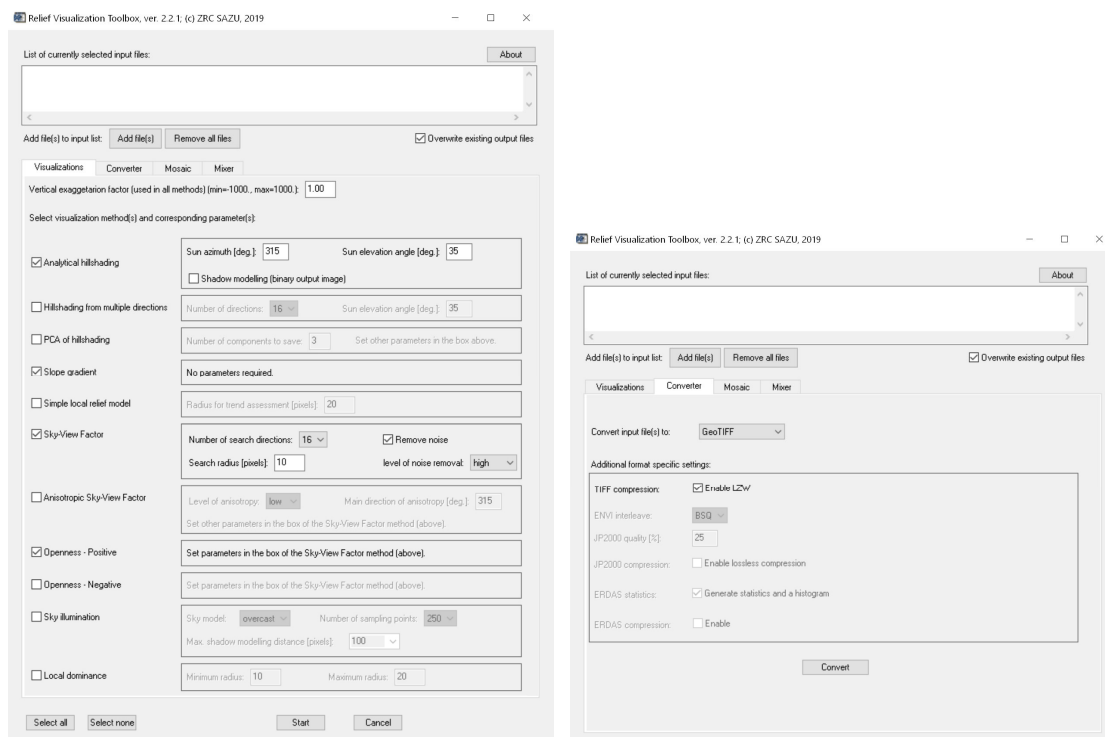
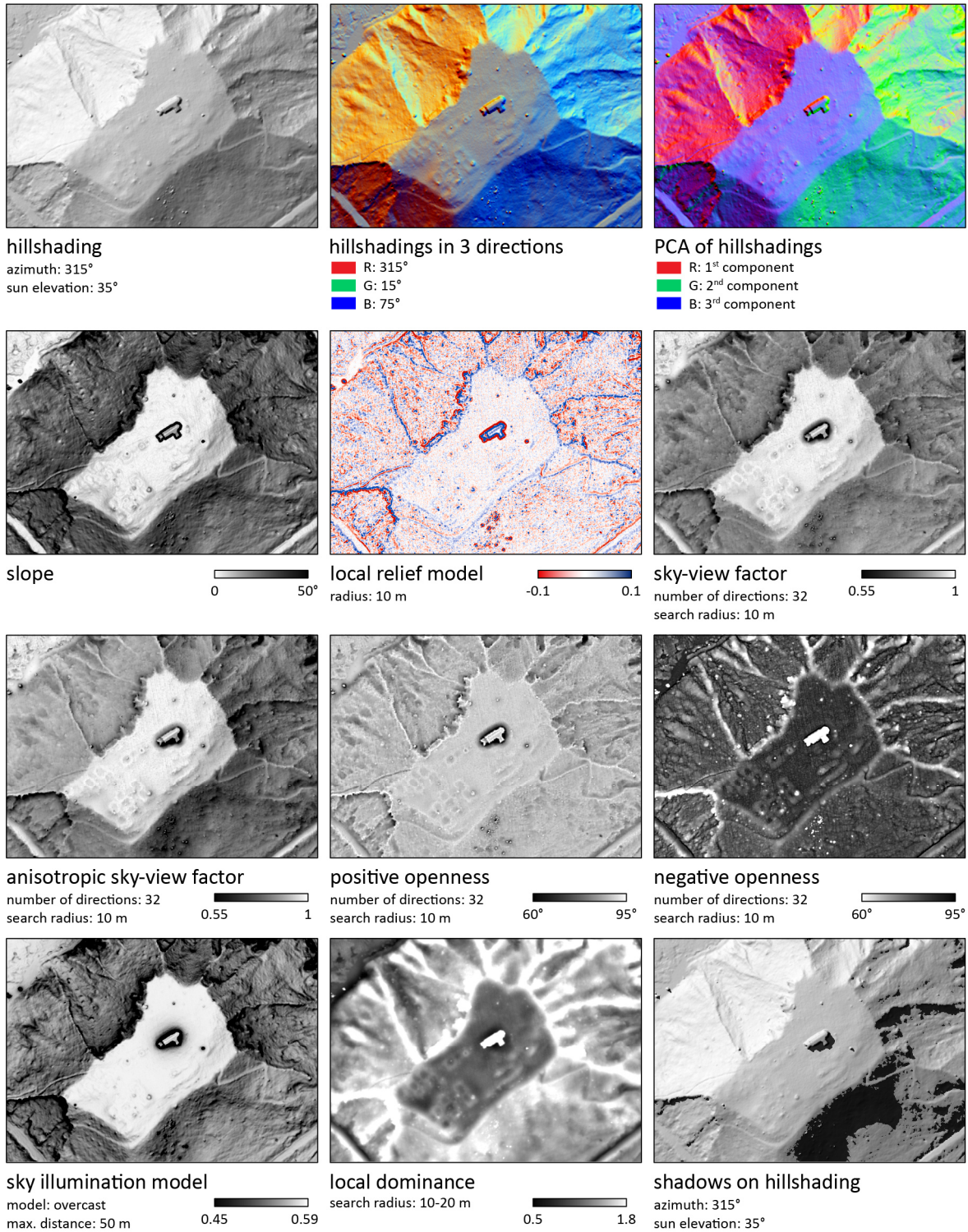


Figure 1: RVT user interface for computation of different visualizations (left) and a single band raster data converter (right).



Lidar data © Walks of peace in the Soča river foundation
Average last and only returns per m² of a combined dataset: 11.2
Spatial resolution of the DEM: 0.5 m

0 50 100 m



Figure 2: Visualization techniques showing St. Helena church and its immediate surroundings. St. Helena is a known yet un-researched archaeological site west of Kobarid, Slovenia, believed to be a late Roman camp.

Online resource

<http://iaps.zrc-sazu.si/en/rvt>

Please *report* any bugs and suggestions for improvements.

Version

Version: 2.2.1, September 2019

Name of the standalone package: RVT_2.2.1_Win64.zip

For changes, see version history at the bottom.

Installation

No installation is required. Unzip the package RVT_2.2.1 to any folder and run the exe file.

If you intend to process large files, please make sure the hard drive where RVT is located has several tens of gigabytes of free space. RVT stores intermediate results in its own folder, but releases the space after processing is finished.

Input and output files

Input file(s): one or several digital elevation model file(s) in GeoTIFF format or any GDAL (GDAL Development Team 2014) supported format (*e.g.* GeoTIFF, generic binary file, Erdas Imagine file, ENVI file, Arc/Info ASCII Grid, ASCII gridded XYZ, JPEG2000...). If your extension is not listed on the Add files menu, change the format filter to *.*. Input files can come from multiple folders and can be of different formats. You can copy-paste the file list into the input window or manually type in the files. Each path/filename has to be in a separate line. For ASCII gridded XYZ input files the software assumes that units are meters and that coordinates have even spacing, therefore, it will not convert ungridded XYZ data, *e.g.* last return lidar data.

Output file formats for data format conversion: GeoTIFF, ASCII gridded XYZ, Erdas Imagine file or ENVI file.

Output files for visualizations: a pair of GeoTIFFs per each selected visualization:

- a calculated 32-bit result, and
- a simplified 8-bit result, optimized for non-GIS software.

All output files are written into the folder of the input file. Output file names for visualizations are composed of the input file name, and suffixes describing the selected method and processing parameters. Format conversion only changes the file extension. *N.B.* If output files already exist, the tool replaces them without warning! It is possible to disable this if you uncheck the option.

Each execution of the program generates a processing log file per input file that includes a list of performed visualization and blending methods, parameters used, output file names, possible warnings, and other metadata. The log file is named `input_file_name_process_log_yyyy-mm-dd-hh-mm-ss.txt`.

Simplified 8-bit GeoTIFF files are prepared for displaying the results in non-GIS software, *e.g.* by Windows Photo Viewer or by Preview for Mac users. Each 8-bit visualization uses its own histogram stretch, as described in the table below. The histogram stretch with a cut-off does not work when there are more than 2% extreme values such as no-data values or outliers (*e.g.* 0 value borders, "birds", "clouds"...) – the 8-bit image is grey. You can visualize the results by applying a manual stretch (about -0.1 to 0.1 m for SLRM for example) to the original results.

As with all spatial calculations that consider neighbourhood, edge pixels do not have correct values. The size of the incorrect edge depends on the neighbourhood size; *e.g.* when openness is calculated with search radius of 10 pixels, 10 edge pixels have incorrect values.

Table 1: Parameters for conversion of visualizations to 8-bit files.

	name suffix	histogram stretch type	min, max	note
analytical hillshading	HS	linear stretch	0, 1	
hillshading from multiple directions	MULTI-HS	linear stretch	0, 1	Red 315°, Green 15°, Blue 75°.
PCA of hillshading	PCA	histogram equalization	2% cut-off	does not work with large files
slope gradient	SLOPE	linear stretch	0°, 51°	inverted greyscale bar
simple local relief model	SLRM	histogram equalization	2% cut-off	
sky-view factor	SVF	linear stretch	0.6375, 1	
anisotropic sky-view factor	SVF-A	histogram equalization	2% cut-off	
openness – positive	OPEN-POS	linear stretch	60°, 95°	
openness – negative	OPEN-NEG	linear stretch	60°, 95°	
sky illumination model	SIM	linear stretch	0.25% cut-off at minimum	
local dominance	LD	linear stretch	0.5, 1.8	

Visualization methods and parameters

To ease the usage of the toolbox the number of input parameters required for each visualization technique is kept to a minimum.

If you select a parameter beyond the allowed interval (min ... max), the parameter is adjusted (trimmed) to fit into the interval, and a corresponding warning is written in the log text file.

Vertical exaggeration is the common parameter that influences all techniques. You can set it higher than the default 1, if you need more contrast in the results; e.g. set it to 3 if the terrain is very flat, or 20 if you use very detailed models, derived with structure-from-motion.

	default value	allowed values min ... max	most useful values	note
vertical exaggeration factor	1	-1000 ... 1000	0.5 ... 3	No exaggeration = 1. For flat relief use > 1. Use < 1 and > 0 if your terrain data has been converted to integer (whole) values (e.g. use 0.001 if units are mm). For calculations on inverted relief use negative values.

Analytical hillshading is straightforward to interpret even by non-experts and without training. However direct illumination restricts the visualization in dark shades and brightly lit areas, where no or very little detail can be perceived. A single light beam also fails to reveal linear structures that lie parallel to it which can be problematic in some applications, especially in archaeology.

	default value	allowed values min ... max	most useful values	note
sun azimuth [°]	315	0 ... 360	0 ... 90, 270 ... 360	0 is North and 90 is East. Values from southern hemisphere (90 ... 270) display inverted shaded relief.
sun elevation angle [°]	35	0 ... 90	5 ... 45	Use small values (5, 10) for flat terrain and higher values (45) for steep terrain.

Analytical hillshading can be calculated in **multiple directions** that are equally distributed between 0° and 360° (Hobbs 1999). 0° is always in band 1, followed by azimuths in clockwise direction, e.g. 45° in band 2, 90° in band 3 ... 315° in band 8, for calculation in 8 directions. The 8-bit image is a result of calculation in three directions, separated by 60° (315° in the red band, 15° in the green band, 75° in the blue band).

	default value	allowed values min ... max	most useful values	note
number of directions	16	4 ... 360	8, 16, 32, 36	The drop down menu is editable, so any number in the allowed range can be inserted. However, it is not very useful to go much beyond 16 directions, due to high autocorrelation.
sun elevation angle [°]	35	0 ... 75	5 ... 45	Use small values (5, 10) for flat terrain and higher values (45) for steep terrain.

Principal Components Analysis (PCA) is a mathematical procedure that summarizes the information of correlated data; hillshaded images from multiple directions in this case (Devereux et al. 2008). The method does not provide consistent results with different datasets. Some common examples of displaying the components are:

- a combination of the first and second principal components, transparently overlaid,
- a false colour composite image (RGB) of the first three components, or
- displaying the third component on its own with high histogram stretch and clipping.

The 8-bit image shows the first three components as an RGB image (1st component in the red band, 2nd in the green band, 3rd in the blue band).

Other parameters are set at the hillshading from multiple directions method box (see above).

	default value	allowed values min ... max	most useful value	note
number of components to save	3	1 ... (number of directions-1)	3	The first three components usually hold more than 99% of the information of the original hillshaded images. The rest is "noise". But sometimes you are interested in it, because it presents something uncommon.

Slope gradient represents the maximum rate of change between each cell and its neighbours and can be calculated either as degree of slope (as in this tool) or as percentage of slope. If presented in an inverted greyscale (steep slopes are darker), slope severity retains a very plastic representation of morphology (Doneus and Briese 2006). However, additional information is needed to distinguish between positive/convex (e.g. banks) and negative/concave (e.g. ditches) features since slopes of the same gradient (regardless of rising or falling) are presented with the same colour. The method requires no parameters.

Local relief modelling removes the large scale morphological elements (hills, valleys...) from data so only small scale features remain (e.g. archaeology). This version of the tool uses a simplified process – the trend is computed by a simple mean filter and a trend removed model is produced directly by subtracting the filtered model from the original. For a more complex method see Hesse (2010) and LiVT (Hesse 2013).

	default value	allowed values min ... max	most useful values	note
radius for trend assessment [px]	20	5 ... 50	10 ... 50	Radius should be a bit more than half the size of the features you are interested in.

Sky-view factor is a proxy for diffuse illumination and measures the proportion of the sky visible from a given point. Locally flat terrain, ridges and earthworks (e.g. building walls, cultivation ridges, burial mounds) which receive more illumination are highlighted and appear in light to white colours on a SVF image, while depressions (e.g. trenches, moats, ploughing furrows, mining pits) are dark because they receive less illumination (Zakšek et al. 2011).

The option to remove noise does not consider nearest pixels in the calculation. This diminishes small variations that are usually a result of data collection and processing, and are seen as “salt and pepper effect” on a sky-view factor or openness image.

	default value	allowed values min ... max	most useful values	note
number of search directions	8	4 ... 360	8 ... 36	Computational time increases as a linear function of number of search directions. 16 is optimal for most applications. The drop down menu is editable, so any number in the allowed range can be inserted.
search radius [px]	10	1 ... 100	5 ... 50	Use small search radius (5-10 m; i.e. 5-20 pixels) if you are interested in small features, e.g. archaeology.
remove noise	none	low ... high	low	low: first 10% pixels (1 pixel if $r \leq 10$) medium: first 20% pixels (2 pixels if $5 < r \leq 10$) high: first 40% pixels (4 pixels if $r \leq 10$)

Anisotropic sky-view factor assumes that the sky is brighter in some directions than in others. The weights are based on the cosine function of half angle (Zakšek et al. 2012). There are three parameters that typically have to be set – the azimuth of the highest weight, the exponent defining the gradient from maximal to minimal weight, and the minimal possible weight. The exponent and minimal weight define the level of anisotropy – the greater the exponent and the smaller the minimal weight – the stronger the effect. This has been simplified to the low and high anisotropy levels where the minimal possible weights are 0.4 and 0.1, and the exponents are 4 and 8 respectively.

Other parameters are set at the sky-view factor method box (see above).

	default value	allowed values min ... max	most useful value	note
anisotropy level	low	low, high	low	“How much the relief perception is enhanced.”
main direction of anisotropy [°]	315	0 ... 360	315	0 is North and 90 is East. 315 presents usual direction for shaded relief.

Openness is also a proxy for diffuse illumination and is based on an estimation of a mean horizon elevation angle within a defined search radius. The mean value of all zenith angles gives **positive openness**, while the mean nadir value gives **negative openness**. Positive openness is similar to sky-view factor, with a more ‘flattened feel’, while negative openness gives additional information on convex features (Yokoyama et al. 2002). Because it is direction and shading independent and removes general topography, it is useful for automatic feature recognition.

Parameters are set at sky-view factor method box (see above).

Sky illumination models quantitatively represent natural luminance of the sky under various atmospheric conditions (Kennelly and Stewart 2014). Uniform and overcast sky models are implemented as they both disregard directional shadowing effects. More details in shadows can be seen using the overcast sky model. Calculations last much longer than for other visualizations, especially with large maximum shadow modelling distances.

	default value	allowed values min ... max	most useful values	note
sky model	overcast	overcast, uniform	overcast	Different weights are assigned to calculation points. All weights are equal for uniform sky model while weights increase towards the zenith for the overcast model.
number of sampling points	250	250 or 500	250	Defines how smooth is the resulting image. The difference is minimal.
maximum shadow modelling distance [px]	100	5 ... unlimited	100 ... 500	The maximum distance to which shadows of objects are calculated.

Local dominance visualization of a DEM shows how dominant an observer standing above a certain pixel would be for a local surrounding area (Hesse 2016). Dominance is higher for points on local protrusions as well as on slopes, and lower for points in local depressions. It is well suited for very subtle positive relief features such as former field boundaries or heavily eroded burial mounds, but also delivers very good results for topographic depressions such as dolines, mining traces, and hollow ways.

	default value	allowed values min ... max	most useful values	note
minimum radius [px]	10	2	5 ... 20	Minimum radius should be a bit more than half the size of the features you are interested in.
maximum radius [px]	20		10 ... 50	Maximum radius should be a bit more than the size of the features you are interested in.

Mosaicking

RVT supports mosaicking of multiple files, *e.g.* tiled lidar elevation models. The method is simple and not many checks are performed, but works well if data are reasonable, *i.e.* if all the files have the same projection, resolution, square pixels *etc.* The result is written in the same location and has the same name as the first input file with a `_mosaic` suffix. All the input files are converted to GeoTIFFs.

Blending modes

Blending (combining, fusing) various visualizations allows for a simultaneous display of distinct topographical features in a single (enhanced) image. RVT supports five different blend modes, which can be used to improve the visibility (recognition) of small topographical features.

The selected visualizations are blended in a consecutive order from bottom to top.

Normal blend mode is the default mode, where no special blending takes place – it keeps the top layer and hides the bottom layer. It makes the foreground transparent.

Screen lightens the image. Black is neutral, white is opaque.

Multiply multiplies the luminance levels of the top layer's pixels with the pixels in the layers below. The result is always a darker image. Black is opaque, white is transparent.

Overlay applies multiply to darker colours and screen to lighter colours to increase the contrast. 50% grey is neutral.

Luminosity keeps the luminance (the perceived brightness based on the spectral sensitivity of a human eye) of the top layer and blends it with hue and saturation components of the bottom layer. This results in colours of the underlying layer replacing the colours on the top layer, while shadows and texture of the top layer stay the same.

Opacity defines the ‘strength’ of blending – to what degree the blend mode is considered. The lower the opacity, the more we allow the bottom layer to uniformly show through. When the top layer is fully opaque, the bottom layer is invisible.

Normalization method is linear between **minimum** and **maximum** cut-off values or percentages.

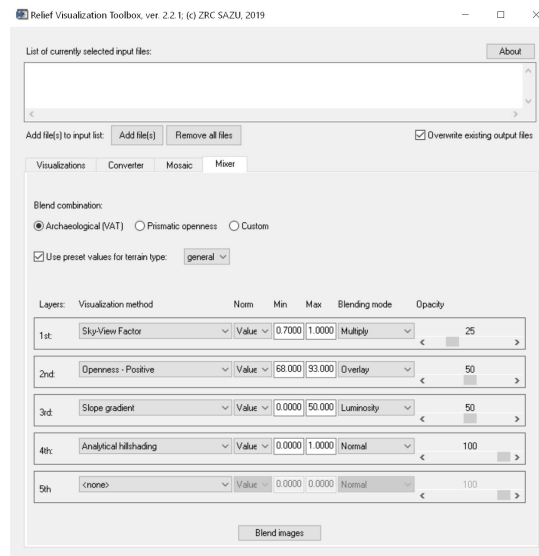


Figure 3: RVT user interface for mixing (combining, blending, fusion) of visualizations.

Terrain settings

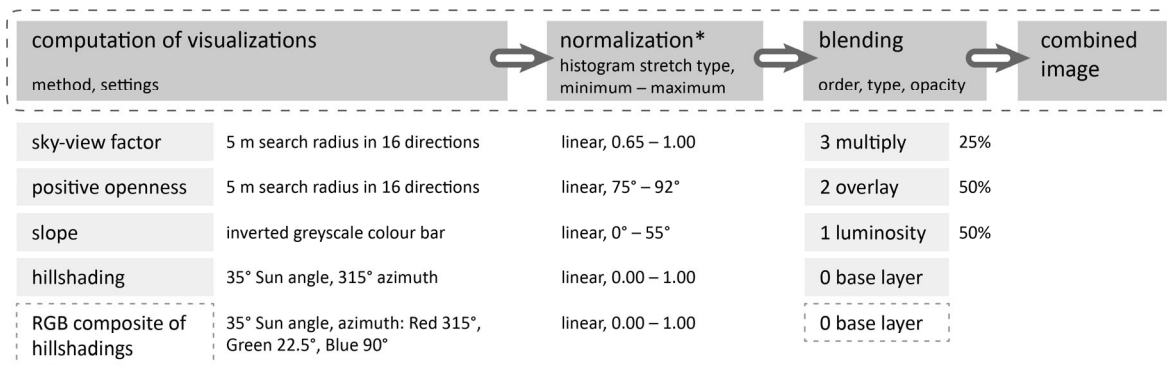
Blending of visualizations can be adjusted for *flat*, *steep* or *general* (normal, mixed) terrain type. The *Use preset values for terrain type* checkbox has to be selected and the type of terrain represented in input file(s) chosen in the drop-down menu. Terrain settings also adjust the:

- normalization minimum and maximum cut-off values for individual visualization layers,
- sun elevation angle for hillshadings,
- pixel radius for sky-view factor, openness and local relief, and
- noise removal for sky-view factor and openness.

These additional parameter changes can be seen if you switch back to the Visualizations tab. The terrain type selected will be included in the output file name.

Visualization combinations

Visualization for archaeological topography (VAT) combines hillshading (or hillshading from three directions), slope, positive openness and sky-view factor with predetermined calculation and blending settings for ‘normal’ (complex) and very flat terrain. We have selected the visualization methods based on their complementary positive characteristics and the specific blending modes because they amplify these particular characteristics. They also work uniformly with varied data and the visualizations of different areas are therefore directly comparable (Kokalj and Somrak 2019). Figure 4 gives calculation settings for visualizations, histogram stretch minimum and maximum, and opacity values for normal terrain. If the terrain is very flat, sun angle for hillshading can be lowered to 15° (or less), and sky-view factor and openness calculated with remove noise setting set to high. Minimum and maximum cut-off values are modified to 0.9 – 1.0 for sky-view factor, 85°-93° for openness and 0°-15° for slope.



*values between minimum and maximum are linearly transformed to the scale 0 – 1 before blending

Figure 4: A schematic workflow illustrating the steps, variables and their settings (for normal terrain) in producing the visualization for archaeological topography. Either hillshading or an RGB composite of hillshading from three directions can be used as a base layer.



Visualization for archaeological topography (VAT)

calculation settings as in Figure 4

Flatt terrain VAT

remove noise for SVF and openness: High
normalisation: SVF 0.9–1; openness 85°–93°;
slope 0°–15°

Visualization for archaeological topography (VAT)

calculation settings as in Figure 4, RGB of hillshading from three directions as a base layer

Lidar data © Walks of peace in the Soča river foundation
Average last and only returns per m² of a combined dataset: 11.2
Spatial resolution of the DEM: 0.5 m

0 50 100 m



Figure 5: Visualization for archaeological topography calculated with setting for normal terrain (left), with settings for flat terrain (centre), and with settings for normal terrain, but with an RGB composite of hillshadings from three directions as a base layer (right).

Settings file

Default visualization settings can be changed in the default_settings.txt file in the RVT_2.2.1_Win64/settings directory. Computation of a visualization is turned on if its name is followed by 1 and off if it is followed by 0, e.g. hillshading = 1, multiple_hillshading = 0. For the meaning of other settings see descriptions and tables at individual visualizations above.

Default blending settings are stored in the default_mixer_combinations.txt file in the same directory. While parameters in the file can be changed, combination names and parameter values of VAT blending combinations should remain the same. However, advanced users can modify the file to add a few custom pre-set blending combinations to RVT. The structure of the file has to be preserved; it will produce a runtime error otherwise.

Processing without a GUI

RVT checks for filenames with paths in the process_files.txt file in the RVT_2.2.1_Win64/settings directory. If any filenames are found, the GUI does not show, and all the files are processed with visualization (and blending) settings, which were last used in GUI. The filenames should be listed in rows; see below for example.

D:\Podatki\Lidar\Rence\rence_DEM_05m.tif
D:\Podatki\Lidar\Germany\Hugelsheim_DTM_1m.asc

D:\Documents\Papers\2016 Lidar visualization guidelines\data\Maiden_castle_DSM_05m.tif
D:\Documents\Papers\2016 Lidar visualization guidelines\data\Odolina_dem_1m.tif
C:\Test\Manhattan_DSM_1m_avg.xyz

When processing without GUI, there is no special notification when process is finished. The resulting output files will appear in the same folders as their inputs.

License agreement

This software is distributed without any warranty and without even the implied warranty of merchantability or fitness for a particular purpose.

RVT is open source. The code is available at GitHub (<https://github.com/EarthObservation/RVT>), with an Apache License 2.0.

Known issues

IDL running on Windows can encounter problems with large arrays (depending on the amount of physical RAM, limitations of the operating system and memory fragmentation; see documentation on Exelis VIS web pages). To help overcome this issue the SVF and openness based methods use tiling. The tiles are maximum 5 megapixels large (e.g. 2500 by 2000 pixels). A buffer size is determined from selected visualization parameters.

The software can crash when processing large DEMs on a lot of shading directions because of a limitation of GeoTIFF file size.

RVT can only process single band files.

Version history

Version 2.2.1, September 2019

- Support for visualization blending without GUI.
- Bug fixes.

Version 2.2, August 2019

- Terrain type presets.
- Improved processing and tiling of large files for Mixer.
- Added support for input files of higher resolution.

Version 2.0, March 2019

- Added support for fusion of visualization techniques (Mixer).
- Bug fixes.

Version 1.3, September 2016

- Added support for automatic processing without GUI.
- Local dominance modelling.

Version 1.2, August 2015

- Added support for overcast and uniform sky illumination modelling.
- Settings can be read from a txt file and last used settings are saved temporarily.
- It is now possible to mosaic multiple files.
- SLRM calculation was changed from Gaussian averaging to a simple mean.

Version: 1.1, October 2014

- Added support for processing of multiple files.

- The tool now reads different file formats and can convert them to GeoTIFF, ASCII gridded XYZ, Erdas Imagine file or ENVI file.

Version: 1.0, November 2013

- Nine relief visualization methods implemented: hillshading, hillshading from multiple directions, PCA of hillshading, slope gradient, simple local relief model, sky-view factor, anisotropic sky-view factor, positive and negative openness implemented.

References

- Devereux, B. J., G. S. Amable and P. Crow. 2008. Visualisation of LiDAR terrain models for archaeological feature detection. *Antiquity* 82 (316): 470–479.
- Doneus, M. and C. Briese. 2006. Full-waveform airborne laser scanning as a tool for archaeological reconnaissance. In *From space to place: 2nd International Conference on Remote Sensing in Archaeology : proceedings of the 2nd international workshop, CNR, Rome, Italy, December 4-7, 2006*, edited by S. Campana and M. Forte, 99–105. BAR international series, 1568. Oxford: Archaeopress.
- GDAL Development Team. 2014. *GDAL - Geospatial Data Abstraction Library*. Windows (version 1.11.0). Open Source Geospatial Foundation.
- Hesse, R. 2010. LiDAR-derived Local Relief Models - a new tool for archaeological prospection. *Archaeological Prospection* 17 (2): 67–72.
- . 2013. *Lidar Visualization Toolbox*. Visual Basic .NET (version 1.0.0.20). <http://sourceforge.net/projects/livt/?source=navbar>.
- . 2016. Visualisierung hochauflösender Digitaler Geländemodelle mit LiVT. In *Computeranwendungen und Quantitative Methoden in der Archäologie. 4. Workshop der AG CAA 2013*, edited by U. Lieberwirth and I. Herzog, Edition Topoi, 109–128. Berlin Studies of the Ancient World. Berlin: Topoi.
- Hobbs, K. F. 1999. An investigation of RGB multi-band shading for relief visualisation. *International Journal of Applied Earth Observation and Geoinformation* 1 (3–4): 181–186.
- Kennelly, P. J. and A. J. Stewart. 2014. General sky models for illuminating terrains. *International Journal of Geographical Information Science* 28 (2): 383–406.
- Kokalj, Ž. and R. Hesse. 2017. *Airborne laser scanning raster data visualization: A guide to good practice*. Prostor, kraj, čas 14. Ljubljana: Založba ZRC.
- Kokalj, Ž. and M. Somrak. 2019. Why Not a Single Image? Combining Visualizations to Facilitate Fieldwork and On-Screen Mapping. *Remote Sensing* 11 (7): 747.
- Kokalj, Ž., K. Zakšek and K. Oštir. 2013. Visualizations of lidar derived relief models. In *Interpreting archaeological topography – airborne laser scanning, aerial photographs and ground observation*, edited by R. Opitz and C. D. Cowley, 100–114. Oxford: Oxbow Books.
- Yokoyama, R., M. Shlrasawa and R. J. Pike. 2002. Visualizing topography by openness: A new application of image processing to digital elevation models. *Photogrammetric Engineering and Remote Sensing* 68: 251–266.
- Zakšek, K., K. Oštir and Ž. Kokalj. 2011. Sky-view factor as a relief visualization technique. *Remote Sensing* 3: 398–415.
- Zakšek, K., K. Oštir, P. Pehani, Ž. Kokalj and E. Polert. 2012. Hill shading based on anisotropic diffuse illumination. In *Symposium GIS Ostrava 2012*, 1–10. Ostrava: Technical University of Ostrava.

~~~~~

Copyright © 2019 Research Centre of the Slovenian Academy of Sciences and Arts (ZRC SAZU)

6/9/2019