DASOS - User Guide

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Disclaimer

DASOS was developed to support an EngD thesis and as a research software could be file format and CPU dependant.

Identified bugs and a list of potential improvements can be found here: `<https://docs.google.com/spreadsheets/d/10yE5p463cLA_GtKkyiaWEzScW7N9cVxbPs5y0muXuZY/edit?usp=sharing>`

Contents

1 Introduction

Full-waveform LiDAR data have great potential in forestry due to the increased amount of information they contain in comparison to discrete LiDAR data. But increased information implies bigger datasets, which are more difficult to handle. Even though scientists understand the concepts and potentials of full-waveform, there are very few applications/usages of full-waveform LiDAR due to a low amount of open and available easy to use software that are able to handle FW LiDAR data. For that reason, DASOS is created to fill this gap between understanding and using the data. DASOS can handle FW LiDAR data, generate metrics and produce polygon representations.

DASOS after the Greek word "$\delta\acute{\alpha}\sigma o\varsigma$" (=forest) was first introduced at the 36th International Symposium of Remote Sensing of the Enviroment, 2015. It's an easy to install software with a friendly command line user interface that handles FW LiDAR data in a volumetric approach. For information about the algorithms used, please refer to the corresponding paper about DASOS: `<https://www.researchgate.net/publication/277347868_Alignment_of_hyperspectral_imagery_and_full-waveform_LIDAR_data_for_visualisation_and_classification purposes>`

DASOS can also handle hyperspectral Imagery and aligns the hyperspectral data with the full-waveform. Aligned metrics and coloured polygon representations can also be generated.

This user guide aims to give an in depth understanding of DASOS's functionalities and help scientists to further use the FW LiDAR data in forestry.

2 License

The following paper must be cited in any publications, software or other media using DASOS:
Miltiadou M., Warren M. A., Grant M., Brown M., 2015, Alignment of Hyperspectral Imagery and full-waveform LiDAR data for visualisation and classification purposes, ISPRS Archives 36th International Symposium of Remote Sensing of the enviroment.
Paper available at:`<https://www.researchgate.net/publication/277347868_Alignment_of_hyperspectral_imagery_and_full-waveform_LIDAR_data_for_visualisation_and_classification_purposes>`

The source code is released under the GNU General Public Licence, Version 3. The full description of the usage licence is available here:`<https://github.com/Art-n-MathS/DASOS/blob/master/License.txt>`

The 1^{st} sample dataset provided for testing was collected by the NERC Airborne Research and Survey Facility (ARSF). Copyright is held by the UK Natural Environment Research Council (NERC). The data are free for non-commercial use, but NERC-ARSF must be acknowledged in any publications, software or other media that make use of these data.

The 2^{nd} sample dataset provided by Interpine Group Ltd. Copyright is held by Interpine Group Ltd and the data are free for non-commercial use, but Interpine Group Ltd must be acknowledged for any publications, software or other media that make use of these data.

3 Installation Guide

3.1 Windows

The windows binaries have not been officially published yet, but for this workshop they are provided on the hard drive. It is suggested to copy the folder `"DASOS_userGuide"` into the `C:\ directory.`
You can then run DASOS from the Command Prompt.
i.e. cd `C:\DASOS_userGuide` :: go to the directory DASOS
DASOS –help :: run the help guide
If you would like to use a different directory, use that directory in all the examples instead of `"C:\"`.

3.2 Linux

Download the source code from: <https://github.com/Art-n-MathS/DASOS>.

For compiling DASOS on linux, there are three dependancies:

1. qmake-qt4 (or later release) / qtcreator
2. gmtl library - please make surethat .pro file points to the correct directory
3. -std=c++11

Once those are installed compile DASOS as shown below:
```
$: qmake-qt4
$: make
```

4 Sample Data

There are two datasets provided for this workshop. The 1^{st} dataset is available at: <https://rsg.pml.ac.uk/shared_files/arsf/DASOS/> and the second is to be included there soon.
For this workshop both datasets are provided on the USB. Please check that all the files are included in the directory `C:\DASOS_userGuide\SampleDATA\`

1. 1^{st} sample dataset:
   (a) `DATASET_1\LDR-FW-FW10_01-201009821.LAS`
   (b) `DATASET_1\e098211b_FODIS.bil`
   (c) `DATASET_1\e098211b_FODIS.bil.hdr`
   (d) `DATASET_1\e098211b_masked.bil`
   (e) `DATASET_1\e098211b_masked.bil.hdr`
   (f) `DATASET_1\e098211b_osgn.igm`
   (g) `e098211b_osgn.igm.hdr`
   (h) `Readme.txt`
2. 2^{nd} sample dataset:
   (a) `DATASET_2\Australia_1.pls`
   (b) `DATASET_2\Australia_1.wvs`
   (c) `DATASET_2\Australia_1_dtm.bil`
   (d) `DATASET_2\Australia_1_dtm.hdr`
   (e) `DATASET_2\Australia_2.las`
   (f) `DATASET_2\Australia_2.wdp`
   (g) `DATASET_2\Australia_2_dtm.bil`
   (h) `DATASET_2\Australia_2_dtm.hdr`
   (i) `DATASET_2\Australia_3.las`
   (j) `DATASET_2\Australia_3.wdp`

   Information about data usage and related license are given in Section 2.

5 Instructions

DASOS is a command line software and can either be used in Command Prompt on windows or a linux shell. At first change directory (cd) to go to the directory DASOS is saved or compiled in. Then for windows run:
`$: DASOS <arg1> <arg2> ... <argN>`
or `$: DASOS.exe <arg1> <arg2> ... <argN>`
On Linux run:
`$: ./DASOS <ar1> <ar2> ... <argN>`

For consistency in this guide we will be using the 1^{st} windows example since all of the inputs, parameters and output arguments are the same for both windows and linux.

The tags of DASOS are divided into three groups:

1. Inputs
2. Parameters
3. Outputs

Even though many tags are optional or contain default values, it's essential to follow the order <inputs> <parameters> <outputs> because if the outputs are defined first unexpected results may occur, due to adding outputs to the stack before parameters are initialised.

Furthermore, all the parameters have default values, but you need to have at least one input and one output for the program to run. The only exception for this rule is when the help menu is requested. The following command will give you a full guide about DASOS commands:
`$: DASOS --help`

The following subsections 5.1, 5.2 and 5.3 give you a list of all the possible tags of DASOS. These tags are classified into inputs, parameters and outputs. It also gives you an insight of DASOS's limitations and the dependencies between inputs and outputs.

5.1 Inputs

The inputs are divided into compulsory and optional. It is essential to load only one full-waveform LiDAR file format. The options for loading files is given in Table 1 :

Tags	**Instructions**
-las <file1> <file2> ... <fileN>	The name/directory of a number of LAS files. If spaces exist in the file names or directories it is recommended to use double quotation marks at the beginning and end of the file name (i.e. `"C:\Dir Las\LAS1.las"`). It is also suggested to manually define the boundaries of the area of interest when more than one files are loaded. Otherwise the boundaries of the first LAS file loaded is used. Furthermore DASOS only supports LAS1.3 with waveform packet format 4.
-pw <file1> <file2> ... <fileN>	loads a number of pulsewave files (*.pls). Same rules apply as the -las tag
-volume <file>	loads an exported volume instead of reading a LAS or pulsewave file. This volume file must be a file exported from DASOS

Table 1: DASOS File Inputs

The optional loaded files depend on the extra functionalities of DASOS. There are two extra/optional functionalities:

1. Alignment with Hyperspectral Imagery: in order for DASOS to use that functionality 3 bil files have to be loaded and their header files have to be in the same directory.
2. Subtracting a pre-computed Digital Terrain Model to normalise the surface.

For example for aligning the FW LiDAR data with hyperspectral imagery, the related hyperspectral files should be loaded. The following Table 2 gives a list of all the possible files that can be imported and explains their usage.

5.2 Parameters

Pre-defined parameters exist, therefore all the parameters are optional. But parameters are advised to be adjusted for each project. Table 3 contains information about all the parameters that can be modified: how they can be modified and what they represent.

Some of the parameters are hyperspectral related and if hyperspectral images are not loaded then those parameters are ignored.

Tags	Instructions
-igm <igmFileName>	The name/directory of the .igm file that defines the geolocaiton of the hyperspectral pixels.
-bil <bilFileName>	The name/directory of the .bil file that contains the hyperspectral cube.
-fodis <fodisFile>	The name/directory of the fodis .bil file for hyperspectral imagery
-dtm <dtmFileName>	loads a pre-calculated DTM and subtracts it from the position of each waveform sample before importing it to the volume. Please note that the DTM file format must be .bil and saved into float pointing numbers. Potential further file format limitations may exist.

Table 2: DASOS Optional File Inputs

Tags	Instructions
-vl <voxelLength>	The voxels length is in meters. Default value is 2.5m
-nl <noiseLevel>	The threshold that separates noise from the actual data in the waveforms. Default value is 25. Please note that the intensity of each wave sample hasn't been transformed to volts yet. According to the LAS file specifications there is a way to do it, but that will be included in future releases of DASOS. It is recommended to use the -exportPulses tag to export the amplitude of a few pulses and use those as sample data to define an appropriate noise threshold.
-iso <isolevel>	The iso-level/iso-surface defines the boundaries of the implicit object. It is a threshold that classifies noise after the volume is created. By default it's zero. Please note that noise level and isosurface level are closely related but only the isolevel can be modified from an exported volume.
-userLimits <maxNorthY> <minNorthY> <maxEastX> <minEastX>	User define boundaries of the area of interest.If not defined then the boundaries of the first file loaded are used (as defined in the header).
-rgb <band1> <band2> <band3>	Defines the 3 bands of the hyperpectral images that will be used for texturing the polygon mesh. If not defined the default values 140, 78 and 23 are used. Only used if a bil and igm file are loaded. Please note that fodis is not used in polygonisation.

Table 3: DASOS Optional File Inputs

5.3 Outputs

DASOS has three potential outputs and at least one of them must be used, unless the user is requesting the help guide (–help). The potential outputs are the following:

1. Metrics: information about the scanned area in .asc format
2. Polygon representation: .obj file with vertices, edges and faces of the polygon generated using the Marching Cubes algorithm. An image is also exported when hyperspectral images are loaded.
3. Volume: is an ASCII file designed to allow quick loading of FW LiDAR data in DASOS. Please note that the file exported cannot be used in any other software, but it is much faster loading a pre-computed volume compared to reading .pls or .las files.

Table 4 gives information about DASOS outputs.

Tags	**Instructions**
-exportPulses <noOfPulses> <fileName.csv>	Method that exports a number of pulses into a .csv file. <noOfPulses> the number of sample pulses to be exported into the <fileName.csv> file. It is used for deciding the noise level threshold for each project.
-exportVolume c <volumeFileName>	Exports the volume into an ASCII file to speed up future interpolation of the data. 'c' refers to compressed and it's an implicit functionality. If 'c' is not included then a non compressed file is exported, which sometimes is too big to be read back into DASOS. Therefore 'c' should always be included.
-map <type> <outputName>	The metrics available are the following and they are not case sensitive: • `NON-EMPTY_VOXELS` • `DENSITY` • `THICKNESS` • `FIRST_PATCH` • `AVERAGE_HEIGHT_DIFFERENCE` • `LAST_PATCH` • `HYPERSPECTRAL_MEAN` • NDVI • `LOWEST_RETURN` • `INTESNSITY_AVG` • `INTENSITY_MAX` • `ALL_FW` All the maps are exported into .asc format and can be loaded into QGIS and other software packages. The `ALL_FW` option generates one metric for each available full-waveform LiDAR related metric and their names are: outputName+metricsType+.asc
-map HYPERSPECTRAL <band> <output-Name>	The hyperspectral map needs an extra parameter defining which band will be output.
-obj <objFileName>	The name of the .obj file where the polygon representation of the LiDAR file will be exported to. A texture is exported when hyperspectral images are loaded. Please note, that a bug has been detected and the polygon may look like a bunch of cones. This bug is under investigation and hopefully it will be fixed in future versions.

Table 4: DASOS Ouput Options

6 Exercises

These exercises will give you an in depth understanding of DASOS, while working with real examples. At first, copy the folder `"DASOS_userGuide"` into your `C:\` drive. To ease typing, all the example commands are given

into the ExerciseCommands.bat file, which can be opened in a text editor.

Once all the files are copied across, open the command Prompt and type:
`$: cd C:\DASOS_userGuide\DASOS`
This will bring you to our working directory. In case you are using a different directory then go to your work directory inside the folder DASOS and the rest of the commands should work OK.

A full guide of all the available tags is given with the following command.
`$: DASOS --help`
The same information can be found inside the Readme.txt file and this User Guide (Section 5).

6.1 Deciding Noise Threshold

The following examples export the amplitudes of 12 pulses into a .csv file to help us decide what noise threshold to use.

```
$:DASOS -las ..\SampleDATA\DATASET_1\LDR-FW-FW10_01-201009821.LAS -exportPulses 12
   ..\LAS21pulsesSamples.csv

$: DASOS -las ..\SampleDATA\DATASET_2\Australia_2.las -exportPulses 12
   ..\Australia_2_pulsesSamples.csv
```

6.2 Exporting metrics from DASOS

The following commands export a height map into .asc files. These files can be used in QGIS. This will give us the location of the flightlines and the relation between them.

```
$: DASOS -las ..\SampleDATA\DATASET_2\Australia_2.las -nl 6 -vl 2 -map height
   ..\Australia_2_vl2_height

$: DASOS -las ..\SampleDATA\DATASET_2\Australia_3.las -nl 6 -vl 2 -map height
   ..\Australia_3_vl2_height
```

Generating a single map at the beginning is useful for deciding which flightlines lie inside the area of interest.

6.3 Loading Multiple Flightlines

As mentioned before, for loading multiple flightlines it is suggested to manually define the boundaries of the area of interest. The following command loads two flightlines, generates a volume from the area of interest and exports it into the Australia2-3.vol file.

```
$: DASOS -las ..\SampleDATA\DATASET_2\Australia_3.las
   ..\SampleDATA\DATASET_2\Australia_2.las -nl 6 -vl 2 -iso 4 -userLimits 6199990 6199639
   762405 761951 -exportVolume c ..\Australia2-3.vol
```

6.4 Exporting Metrics

The following command loads the pre-computed volume and creates a height map and all the FW related metrics. Please note that height is also a FW related metric, therefore it will be created twice.
`$: DASOS -volume ..\Australia2-3.vol -map height ..\Australia2-3 -map all_fw`
`   ..\Australia2-3`

6.5 Subtracting Pre-computed Digital Terrain Model

The next command loads two LAS files, a pre-computed DTM file is subtracted from the wave samples' positions while the volume is created, the volume is exported into the `Australia2-3_dtm.vol` file and finally it exports a height metric.
Please note that when a DTM is introduced, a new volume must be created. Since the volumetric files are raster data and contain no information about pulses.

```
$: DASOS -las ..\SampleDATA\DATASET_2\Australia_3.las ..\SampleDATA\DATASET_2\Australia_2.las
   -dtm ..\SampleDATA\DATASET_2\Australia_2_dtm.bil -nl 6 -vl 2 -iso 4 -userLimits 6199990
   6199639 762405 761951 -exportVolume c ..\Australia2-3_dtm.vol -map height
   ..\Australia2-3_vl2_dtm_height
```

You may then use the same volume to export more metrics:

```
$: DASOS -volume ..\Australia2-3_dtm.vol -map AVERAGE_HEIGHT_DIFFERENCE
   ..\Australia2-3_dtm_AVG_height_diff
```

6.6 Pulsewave Data

As mentioned before, it is suggested to first export the amplitudes of a few pulses to decide on an appropriate noise threshold.

```
$: DASOS -pw ..\SampleDATA\DATASET_2\Australia_1.pls -exportPulses 15
   ..\PLS_amplitudeSamples.csv
```

And then you can generate the desired metrics:

```
$: DASOS -pw ..\SampleDATA\DATASET_2\Australia_1.pls -nl 5 -dtm
   ..\SampleDATA\DATASET_2\Australia_1_DTM_1m.bil -vl 3 -map thickness PLS_vl3_thickness
   -exportVolume ..\Australia_1_vl3_dtm.vol
```

6.7 Polygon Representation

DASOS create 3D polygon representation using the '-obj' tag. The 3D polygon representations are exported into .obj format, which can be visualised using animation software packages. For this workshop we are using Meshlab because it is a free tool and it can handle millions of triangles.
Meshlab is available to download from here: `<http://meshlab.sourceforge.net/>` and it is also included into our working directory `"DASOS_userGuide"`.
An example of generating polygons is given below:

```
$: DASOS -las ..\SampleDATA\DATASET_1\LDR-FW-FW10_01-201009821.LAS -nl 20 -vl 1.7 -obj
   ..\LAS21.obj -exportVolume c ..\LAS21_vl1.7.vol
```

The generated volume is also saved because we need it for the following exercises.

6.8 Hyperspectral Imagery

One of the key functionalities of DASOS is the alignment with the hyperspectral imagery. DASOS can export 3D coloured polygon representations and aligned metrics between FW LiDAR and hyperspectral data.

For the 3D coloured polygon representations you must not use any directory for the exported .obj file Analysisname because the link between the texture and the .obj file will not work. Here is an example:

```
$: DASOS -volume ..\LAS21_vl1.7.vol -bil ..\SampleDATA\DATASET_1\e098211b_masked.bil -igm
   ..\SampleDATA\DATASET_1\e098211b_osgn.igm -fodis
   ..\SampleDATA\DATASET_1\e098211b_FODIS.bil -rgb 240 78 23 -obj
   LAS21_coloured.obj
```

The LAS21.obj file will be saved into the current directory, which in our case is `C:\DASOS_userGuide\DASOS`.

Please note that the following command should give the same results, but as mentioned before importing an exported volume is faster than generating from scratch.

```
$: DASOS -las ..\SampleDATA\DATASET_1\LDR-FW-FW10_01-201009821.LAS -nl 20 -vl 1.7 -bil
   ..\SampleDATA\DATASET_1\e098211b_masked.bil -igm
   ..\SampleDATA\DATASET_1\e098211b_osgn.igm -fodis
   ..\SampleDATA\DATASET_1\e098211b_FODIS.bil -rgb 240 78 23 -obj LAS21_coloured.obj
```

An examplre of generating aligned metrics is given below. The NDVI map is quite slow, so we may need to wait a bit for that.

```
$: DASOS -volume ..\LAS21_vl1.7.vol -bil ..\SampleDATA\DATASET_1\e098211b_masked.bil -igm
   ..\SampleDATA\DATASET_1\e098211b_osgn.igm -fodis
   ..\SampleDATA\DATASET_1\e098211b_FODIS.bil -map hyperspectral 140 ..\LAS21_band140 -map
   height ..\LAS21_height -map NDVI ..\LAS21_ndvi
```

6.9 All Commands Together

Of course, we are able to use multiple outputs into a single command, even though that's not suggested due to the big processing time. An example of merging previous commands into one is given below:

```
$: DASOS -las ..\SampleDATA\DATASET_1\LDR-FW-FW10_01-201009821.LAS -nl 20 -vl 1.7 -bil
   ..\SampleDATA\DATASET_1\e098211b_masked.bil -igm
   ..\SampleDATA\DATASET_1\e098211b_osgn.igm -fodis
   ..\SampleDATA\DATASET_1\e098211b_FODIS.bil -rgb 240 78 23 -obj LAS21_coloured.obj -map
   hyperspectral 140 ..\LAS21_band140 -map  height ..\LAS21_height -map NDVI ..\LAS21_ndvi
   -exportVolume ..\LAS21_vl1.7.vol
```

7 Limitations

Limitation and bugs have been reported throughout the report, but here is a short summary of them.

- Exporting polygon representation could end up generating a punch of cones instead of a nice smooth surface.
- Subtracting DTM depends on the input file format and by subtracting the height the input data may end up outside the boundary of the volume.
- DASOS may be Hardware/CPU dependant since development and testing was done on two computers only.
- The raw waveform amplitude is used as intensity and it hasn't been converted to an absolute digitizer voltage.
- Intensities also have not been calibrated.
- Sometimes memory allocation exceptions occur.

For full bug reports and under development improvements please check the following link:
<https://docs.google.com/spreadsheets/d/10yE5p463cLA_GtKkyiaWEzScW7N9cVxbPs5y0muXuZY/edit?usp=sharing>

8 Related Forums and Social Media

Online social media are used for sharing DASOS updates and discussing issues or potential improvements. Information about DASOS can be found in the following:

- Google Groups: DASOS - the native full-waveform (FW) LiDAR software
  <https://groups.google.com/forum/#!forum/dasos---the-native-full-waveform-fw-lidar-software>
  This group is used for bringing potential issues and possible improvements up in discussion.
- Blogger: ART & M@thS
  <http://miltomiltiadou.blogspot.co.nz/2015/03/las13vis.html>
  This blog is more general. The blog contains updates and explanation of DASOS but usually the code used in DASOS is broken down into small projects and explained how they can be used in general.
- Twitter: @_DASOS_
  Milto Miltiadou's twitter, where all the updates and news of DASOS are posted.
- Twitter: @ARSF_DAN
  NERC Airborne Research & Survey Facility Data Analysis Node, based at PML.