Manual

RPC Stereo Processor (RSP) – Building 3D with 2D Satellite Images!

Version 1.

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Contents

Chapter 0

0 Preface

In my PhD work I am looking into 3D change detection problems, one of the most important cases is to use satellite stereo images to detect the geometric differences of the ground. However, by the time there are no handy tools for generating good quality DSM (Digital Surface Models), some of the commercial software packages do not really offer good results. In 2013, I begin to write this package by implementing a modified version of SGM (Semi-global Matching) as its core matching method, the development and enrichment of the functionality of this package is still ongoing.

This tool is designed to be easy-to-use, while flexible enough to handle different dataset. The memory management and implementation have been carefully considered and designed, theoretically allowing to you compute images with very large dimension. However, to keep the maximal flexibility to handle different case, (multi-spectral availability, Level-1 image, Level-2 image, availability of control points), I tend to keep the control file open and modularize each essential steps to make sure you can handle your dataset, but this also means you may also need to specify the file name for each module. But the good thing is, you can store your control file for processing the same type of data (data organization), which is very convenient to build workflows.

Up to now, I am the sole developer of this software package; hopefully, my team will have more contributors on this for more exciting functions!

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Chapter 1

1. Introduction

1.1. Background

For a very long time, the research on remote sensing are mainly performed on a 2D basis. Researchers have been thinking on using 3D data to enhance the remote sensing analysis. However, the traditional way of using LiDAR (Light Detection and Ranging) is expensive and it also requires image-LiDAR registration. Reconstruction 3D based on spaceborne stereo images has been a key issue to retrieve low cost topographical information of the ground, wherein the quality of dense matching is the major source of concern.

With the advanced dense image matching algorithms developed by the computer vision and photogrammetry community, higher quality data can be generated from the stereo matching procedure. However, figuring out and implementing the basic geometric model of the spaceborne images, as well as the consideration of efficient memory management is quite a big effort. This blocks the way of remote sensing scientists to use this technique. The ISPRS DEM benchmark matching contest have been released since 2010, but until now only a few researchers have participated this challenge, mainly due to the complication of implementing the basic geometric model and handling of large format satellite data.

1.1.What does the software do

The RPC Stereo Processor is a standalone software package that performs stereo matching based on the very common RPC (rational polynomial coefficient) model used by spaceborne images. Taking two space-borne images as well as their associated RPC parameters as the input, it generates pixel-wise color/grey point clouds, obj meshes, DSM (digital surface models) raster and true orthophotos, where the DSM is pixel-wisely overlaid with the orthophoto, meaning each pixel of the orthophoto will have an additional height attribute. The following graph (Figure 1.1) gives you a general idea of what the current functions are.

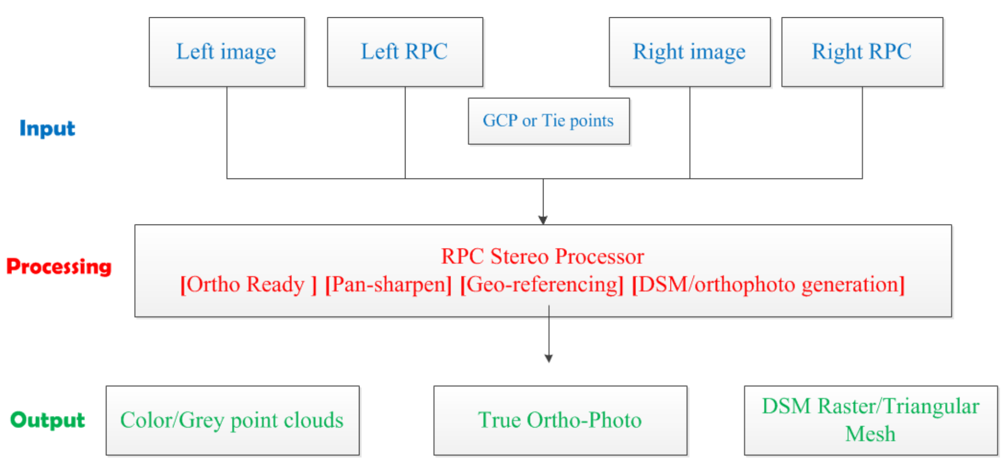

Figure 1.1. The input-output functioning diagram of the RSP.

1.2. Prerequisite and installation

It is recommended to have a powerful computer, with good CPU processor, as well as sufficient memory (16GB+), although RSP could work with very old computer with very little memory (it will just be very slow!!). The software is somewhat memory expensive, thus I only provide the 64-bit binary to allocate large memory.

1.2.1. Asking for a license.

1.2.2. Installation

Unzip the file and keep all the associated libarary (*.dll) in the same directory as the binary (exe), and then you are ready to use it through the windows command window.

1.3. Working philosophy

The software follows a "function" + "control file" fashion. "Function" are components (e.g. geo-referencing using control points) which will be introduces in each chapters later on, and control files are supposed to provide input for the component (e.g. image paths, and GCP, or tie points). For example, if you want to perform a relative orientation between two images, navigate your working path of (through "cd") to the "exe" folder, and then type the following in your command window:

```
RSP geo_ref "C:\xml_path\geo_ref.xml"
```

Or type the full path:

```
"C:\exepath\RSP.exe" geo_ref "C\xml_path\geo_ref.xml"
```

If the "geo_ref.xml" does not exist in the given path, RSP will automatically generate a template xml file at the given path for you to fill in your parameters. Alternatively, you can simply type:

```
RSP geo_ref
```

Currently the software offers the following functions:

Table 1.1. Currently Supported Functions

Name	Function
ortho_ready	Based on a given plane (usually take the parameter directly from the RPC file), it computes the corresponding level-2 image, or so-called ortho-ready image
Pan_Sharpen	This performs pan-sharpening of the images, given a panchromatic and a multi-spectral image.
geo_ref	1. Given GCPs, it performs 1-order, 2-order bias-correction, and generates corrected RPC file 2. Given tie points, it takes the left image as the reference image, and compute relative orientation between two images. 3. Given 6-parameter affine transformations, it compute a new RPC file.
DSM_Ortho	1. Performance stereo dense matching and generate color/grey point clouds.

	2. Re-projecting the point clouds to a DSM and performance interpolation 3. Ortho-photo rectification considering the ray visibility.

1.4. XML control file

To Note: It is advised to read the special notes in section 6.2 before you first write your own xml files.

Each function is associated with an xml file as the control file, which follows a tree structure standard. The syntax of xml files is easily to understand and very popular. You can find many of instructions in the internet (e.g. Tutorial in W3School, http://www.w3schools.com/xml/), but here I will still give a very brief introduction of the content organization.

A typical xml file will look like this (Figure 1.2):

```xml
<?xml version="v 1.0, control file for stereo geo_referencing" ?>
<GEO_REF>
    <Parameters>
        <GEO_REF_MODE Mode="TIE">
            <!--the mode could be: GCP or TIE or AFFINE-->
        </GEO_REF_MODE>
        <Height_Plane_FROMRPC value="1" />
        <Height_Plane value="-9999" />
        <Height_Range value="-9999">
            <!--this can be estimated from the height scale-->
        </Height_Range>
        <GCP_RECORDS>
            <!--Do replicate with more measurement-->
            <GCP_Rec X="0" Y="0" Z="0" />
        </GCP_RECORDS>
    </Parameters>
    <Image_Files>
        <!--For TIE geo-referencing, only two images are allowed, the first is left, the second is right-->
        <Image_object>
            <Image_Name>C:\Users\testsamples\left_img\left_img_PS_or.tif</Image_Name>
            <RPC_Name>C:\Users\testsamples\left_img\left_img_PS_or_rpc.txt</RPC_Name>
            <Output_RPC_Name />
            <Image_measurements>
                <img_pt x="21463.95" y="12421.06" />
                <img_pt x="13266.16" y="4980.25" />
            </Image_measurements>
            <Affine_parameter CL0="0" CLL="0" CLS="0" CS0="0" CSL="0" CSS="0" />
        </Image_object>
        <Image_object>
            <Image_Name>C:\Users\testsamples\right_img\right_img_PS_or.tif</Image_Name>
            <RPC_Name>C:\Users\testsamples\right_img\right_img_PS_or_rpc.txt</RPC_Name>
            <Output_RPC_Name>C:\Users\testsamples\right_img\right_img_PS_or_krct_rpc.txt</Output_RPC_Name>
            <Image_measurements>
                <img_pt x="21467.02" y="12422.99" />
                <img_pt x="13268.08" y="4985.21" />
            </Image_measurements>
            <Affine_parameter CL0="0" CLL="0" CLS="0" CS0="0" CSL="0" CSS="0" />
        </Image_object>
    </Image_Files>
</GEO_REF>
```

Figure 1.2. A typical xml file.

It looks very complicated at the first glance, but the file always follows a tree structure, where each node is described in “<name> </name> ” tag, where each node is associated with attributes and contents, such as parameter values or tasks. Nodes described inside a session, such as:

```
<name>

        <name1>
```

</name1>

</name>

is a child node (name1). In Figure 1, <GEO_REF> is the root node describing the task, being the control file of the geo-referencing task. It has two child nodes, being <parameters> and <Image_Files>. Inside the <Parameter> session, a couple of parameters regarding to this task will be used as the input. Regarding to <Image_Files>, it contains images to be processed in an iterative form, where each image is represented as an <Image_object>, with its associated parameters and values. The detailed description of these parameters and inputs will be introduced in each of the following Chapters.

Chapter 2

2. Ortho-Ready Image Generation

Ortho-ready image is a projected raster image to a mean-height level (map projection). Many of the data companies provide ortho-ready images, which can be used directly for stereo and measurement purpose (coarse). However, sometimes you also get the Level 1 images (in the flying direction). For this reason the ortho-ready generation is needed for the subsequent process. In the meantime, the pan-sharpen module in this package will also need the input from this module. However, it is always recommended that you go through this step to avoid unexpected errors.

To start from scratch, type:

"RSP ortho_ready"

to get the control file in the folder where the RSP binary. You will get something like this (Figure 2.1):

```
<?xml version="v 1.0, control file for ortho ready image generation" ?>
<Ortho_Ready_Gen>
    <Parameters>
        <Region_Ortho Mode="COMMON_REGION">
            <!--this can be FROM_RPC, COMMON_REGION, CUSTOMIZED_REGION-->
            <Region Max_X="0" Max_Y="0" Min_X="0" Min_Y="0" />
        </Region_Ortho>
        <Tile_Options Tile_X="15000" Tile_Y="15000" Extra_X="10" Extra_Y="10" />
        <Plane_options Mode="FROM_RPC">
            <!--this can be FROM_RPC or CUSTOMIZED-->
            <Cell_Size x="-1" y="-1" />
            <Height_Plane value="-9999" />
        </Plane_options>
    </Parameters>
    <ImageFiles>
        <Image_object>
            <Image_Name />
            <RPC_Name />
            <Ortho_Ready_Image_Name />
            <Ortho_Ready_RPC_Name />
            <is_for_Height_plane value="1" />
        </Image_object>
    </ImageFiles>
</Ortho_Ready_Gen>
```

Figure 2.1. The default ortho-ready control file.

The <Parameters> tag controls the projection options such as the region (footprint) and the projected height plane. <ImageFiles> lists images that will be computed to ortho-ready image. Note that each <Image_object> corresponds to an image, with associated input output name and associated parameters.

2.1 Parameters

This session contains the necessary parameters performing the ortho-ready image generation. An ortho-ready process is to project the image to a specific height plane, where by the following parameters needs to be known:

<Region_Ortho>: The footprint in a specific plane, the X-Y plane, it has three modes:

1) FROM_RPC: this projects the images as it is, without any truncation.
2) COMMON_REGION: this projects the images listed in the Images Files, and find their maximal overlapped regions for truncation.
3) CUSTOMIZED_REGION: sometimes we are only interested in a small part of the image. This mode helps you to cut out that area by specifying their UTM coordinates as being maximal and minimal X,Y. The specified tags “MAX_X,MAX_Y,MIN_X,MINY” will only take effect if the CUSTOMIZED_REGION mode is used.

<Plane_Options>: Since we need to project the image onto a plane, therefore we need to know that height value of the plane. There are two modes being used here:

1) FROM_RPC: this extract the height plane value directly from the RPC file, unless you have a particular plane that you want to projected, otherwise it is recommended to use this mode
2) CUSTOMIZED: being contrary to the above, where the <Height_plane value=””> takes effect.

<Cell_Size>: being part of the <Plane_Options>, this is to specify the value of Cell size of the projected raster (ortho-ready), if it is specified as -1, the program will estimate the cell size according to the footprint, otherwise it resamples to the given value. In practice, it is always recommend to specify the value as you know the pixel-footprint of a particular sensor, and this can be used to unify all the images in the <Image_Files> list to the same pixel-footprint (also called GSD (ground sampling distance)), for the subsequent dense matching.

In <Tile_Options> , “Tile_X, Tile_Y” specified the tile size in the x,y direction of the image, with a unit in pixels. “Extra_X, Extra_Y” specifies the overlapping pixels to avoid boundary inconsistencies. “Tile_X = -1, Tile_Y = -1” means everything will be loaded into the memory. Increasing “Tile_X, Tile_Y” will result in more memory consumption, but less I/O, which is of course faster, otherwise slower. You should adjust the tiles accordingly based on the memory amount in your hardware. **Note this will be widely used in controls files of other modules.**

2.2 Image files

This session maybe used quite often in other control files. It generally includes the input path of the images being processed, as well as the output paths.

<Image_Name>: full path of the image. It supports various image format, as well as the digital

<RPC_Name>: full path of the associated RPC file, it supports the general rpc formulation, as well as the worldview RPB file format.

<Ortho_Ready_Image_Name> and M< Ortho_Ready_RPC_Name >: this specifies the output ortho-ready images as well as the recomputed RPC files.

<is_for_Height_plane>: this will take effect if the mode of the <Plane_Options> in the parameter session is FROM_RPC, whereby the height value will be extract from this RPC file if the value is 1. In theory this should only appear once at all the images, otherwise the value takes the last one with this tag (with a value of 1).

2.3 An example

Figure 2.2 shows an example of the file in an ortho-ready generation task:

```xml
<?xml version="v 1.0, control file for ortho ready image generation" ?>
<Ortho_Ready_Gen>
    <Parameters>
        <Region_Ortho Mode="COMMON_REGION">
            <!--this can be FROM_RPC, COMMON_REGION, CUSTOMIZED_REGION-->
            <Region Max_X="0" Max_Y="0" Min_X="0" Min_Y="0" />
        </Region_Ortho>
        <Tile_Options Tile_X="20000" Tile_Y="20000" Extra_X="5" Extra_Y="5" />
        <Plane_options Mode="FROM_RPC">
            <!--this can be FROM_RPC or CUSTOMIZED-->
            <Cell_Size x="0.5" y="0.5" />
            <Height_Plane value="-9999" />
        </Plane_options>
    </Parameters>
    <ImageFiles>
        <Image_object>
            <Image_Name>C:\Users\testsamples\054460862010_01_P001_PAN-1\leftimg\leftimg_pan.tif</Image_Name>
            <RPC_Name>C:\Users\testsamples\054460862010_01_P001_PAN-1\leftimg\leftimg_pan_rpc.txt</RPC_Name>
            <Ortho_Ready_Image_Name>C:\Users\testsamples\left_img\left_img_pan_or.tif</Ortho_Ready_Image_Name>
            <Ortho_Ready_RPC_Name>C:\Users\testsamples\left_img\left_img_pan_or_rpc.txt</Ortho_Ready_RPC_Name>
            <is_for_Height_plane value="1" />
        </Image_object>
        <Image_object>
            <Image_Name>C:\Users\testsamples\054460862010_01_P001_PAN-1\rightimg\rightimg_pan.tif</Image_Name>
            <RPC_Name>C:\Users\testsamples\054460862010_01_P001_PAN-1\rightimg\rightimg_pan_rpc.txt</RPC_Name>
            <Ortho_Ready_Image_Name>C:\Users\testsamples\right_img\right_img_pan_or.tif</Ortho_Ready_Image_Name>
            <Ortho_Ready_RPC_Name>C:\Users\testsamples\right_img\right_img_pan_or_rpc.txt</Ortho_Ready_RPC_Name>
            <is_for_Height_plane value="0" />
        </Image_object>
        <Image_object>
            <Image_Name>C:\Users\testsamples\054460862010_01_P001_MUL\leftimg\leftimg_MS.tif</Image_Name>
            <RPC_Name>C:\Users\testsamples\054460862010_01_P001_MUL\leftimg\leftimg_MS_rpc.txt</RPC_Name>
            <Ortho_Ready_Image_Name>C:\Users\testsamples\left_img\left_img_MS_or.tif</Ortho_Ready_Image_Name>
            <Ortho_Ready_RPC_Name>C:\Users\testsamples\left_img\left_img_or_MS_rpc.txt</Ortho_Ready_RPC_Name>
            <is_for_Height_plane value="0" />
        </Image_object>
        <Image_object>
            <Image_Name>C:\Users\testsamples\054460862010_01_P001_MUL\rightimg\rightimg_MS.TIL</Image_Name>
            <RPC_Name>C:\Users\testsamples\054460862010_01_P001_MUL\rightimg\rightimg_MS.RPB</RPC_Name>
            <Ortho_Ready_Image_Name>C:\Users\testsamples\right_img\right_img_MS_or.tif</Ortho_Ready_Image_Name>
            <Ortho_Ready_RPC_Name>C:\Users\testsamples\right_img\right_img_MS_or_rpc.txt</Ortho_Ready_RPC_Name>
            <is_for_Height_plane value="0" />
        </Image_object>
    </ImageFiles>
</Ortho_Ready_Gen>
```

Figure 2.2. An exemplar ortho-ready generation control file.

This example shows an ortho-ready generation task with four images, being panchromatic and multispectral images for both left and right images of a stereo pair. The GSD (cell size) is specified as 0.5 meters to unify the GSD for all the images, which is prepared for the subsequent pan-sharpening procedure. This example cuts each image their common area, so that all the resulting images will have the same dimension. The height value is picked in the first rpc file.

After the computation, the ortho-ready xml control file will have one more output session, as shown in below (Figure 2.3):

```xml
<Output>
    <Output_Plane_options Cell_X="0.5" Cell_Y="0.5" height_plane="14" ZONE="18S"/>
    <Output_Region Max_X="248982.115498473" Max_Y="3393415.57252589" Min_X="235702.654029128" Min_Y="3370937.82853497" />
</Output>
```

Figure 2.3.The output session after the ortho-ready generation process.

It outputs all the necessary parameters associated with this task (in case you choose the option of estimating the cell size, as well as extracting height planes from the RPC). This also includes the output region of the image files, as well as the UTM zone. The purpose of having this output session is to record these parameters for the consistency in the subsequent processing.

Chapter 3

3. Pan Sharpen

Very often you get the panchromatic and multispectral images as separated file from the data provider, where resolution of multispectral image is much coarser than the panchromatic images. In this case you want the multispectral images to have the same spatial resolution as the panchromatic images by merging them into one. This process is called pan-sharpen. RSP provides such a module to generate pan-sharpen images.

3.1. The xml control file

To get the default xml control file, type:

```
RSP Pan_Sharpen
```

You will get the default xml control file as follows (Figure 3.1):

```xml
<?xml version="v 1.0, control file for Pan-sharpened image generation" ?>
<Pan_Sharpen_Gen>
    <Tile_Options Tile_X="15000" Tile_Y="15000" Extra_X="10" Extra_Y="10" />
    <Processing_Unit>
        <Image_Shift Unit="MAP">
            <Correponding_Point X_pan="0" Y_pan="0" X_ms="0" Y_ms="0" />
            <!--The unit can be either 'MAP' (meters) or 'PIXEL', deleting the image-shift section means that no correction will be applied-->
        </Image_Shift>
        <PAN_Image_File />
        <PAN_Image_RPC_File />
        <MS_Image_File />
        <PS_Image_File_Output />
    </Processing_Unit>
</Pan_Sharpen_Gen>
```

Figure 3.1. The xml control file for pan-sharpen processing.

<Pan_Shapren_Gen> is the root node of this pan-sharpen task. There is only one global parameter option under the root node, being <Tile_Options>, which controls the memory consumption of the task by given the tile size of the images. It has the same meaning as the M<Tile_Options> being introduced in section 2.1.

3.2. The processing unit

The <Processing_Unit> as its name, is a place to specify the input pan-mul pair (Panchromatic-multispectral), as well as their output. With batch-processing concept, you can specify multiple processing units as needed.

The tags <PAN_Image_File>, <PAN_Image_RPC_File>, <MS_Image_File>, <PS_Image_File_Output> are self-explanatory. The resulting RPC file of the pan-sharpen image will be a copy of the panchromatic image RPC file, but this is not mandatory, however recommended.

A big note for this process is **that the panchromatic and multispectral image should have exactly the same dimension**, which should be the output of the ortho-ready image generation, by specifying the same GSD for both images, as this module will not inherently perform an interpolation process.

<Image_Shift>: Sometimes there exists a misalignment between the panchromatic and multispectral images in terms of the image content. For each <Processing_Unit>, <Image_Shift> offers an optional

chance to correct this, by giving two corresponding points, with units either in MAP (UTM coordinates), or in PIXEL (pixels), deleting this tag means on misalignment correction will be applied (see the green comments in Figure 3.1).

Eventually the following example would work (Figure 3.2.)

```xml
<?xml version="v 1.0, control file for Pan-sharpened image generation" ?>
<Pan_Sharpen_Gen>
    <Tile_Options Tile_X="10000" Tile_Y="10000" Extra_X="10" Extra_Y="10" />
    <Processing_Unit>
        <Image_Shift Unit="MAP">
            <Correponding_Point X_pan="333700.50" Y_pan="4318850.83" X_ms="333700.08" Y_ms="4318880.76" />
        <!--The unit can be either 'MAP' (meters) or 'PIXEL', deleting the image-shift section means that no correction will be applied-->
        </Image_Shift>
        <PAN_Image_File>C:\Users\testsamples\left_img\left_img_pan_or.tif</PAN_Image_File>
        <PAN_Image_RPC_File>C:\Users\testsamples\left_img\left_img_pan_or_rpc.txt</PAN_Image_RPC_File>
        <MS_Image_File>C:\Users\testsamples\left_img\left_img_MS_or.tif</MS_Image_File>
        <PS_Image_File_Output>C:\Users\testsamples\left_img\left_img_PS_or.tif</PS_Image_File_Output>
    </Processing_Unit>
    <Processing_Unit>
        <PAN_Image_File>C:\Users\testsamples\right_img\right_img_pan_or.tif</PAN_Image_File>
        <PAN_Image_RPC_File>C:\Users\testsamples\right_img\right_img_pan_or_rpc.txt</PAN_Image_RPC_File>
        <MS_Image_File>C:\Users\testsamples\right_img\right_img_MS_or.tif</MS_Image_File>
        <PS_Image_File_Output>C:\Users\testsamples\right_img\right_img_PS_or.tif</PS_Image_File_Output>
    </Processing_Unit>
</Pan_Sharpen_Gen>
```

Figure 3.2 An example of the pan-sharpen xml control file

Chapter 4

4. Geo-referencing

Due to the positioning errors of satellite system, geo-referencing is a step that referencing two images in the stereo pairs to the same coordinate frame, so that to perform accurate spatial resection. Most of the time the geo-referencing of the RPC modeled images are done via a process called bias-correction, using ground control points. This bias-correction with GCP is done independently for each image, referencing the identical points in two images with their 3D coordinates. When GCP is not available, the referencing procedure can be done with identical points (image measurement), by means of relative orientation. The geo-referencing module (geo_ref) of RSP provides a full solution of geo-referencing in a stereo case.

To get the default xml control file, type:

```
RSP geo_ref
```

You will get the following default xml file (Figure 4.1):

```xml
<?xml version="v 1.0, control file for stereo geo_referencing,if a TIE mode is idenfied with no points in the image field, it runs an auto_TIE" ?>
<GEO_REF>
    <Parameters>
        <GEO_REF_MODE Mode="AUTO_TIE">
            <!--the mode could be: GCP or TIE or AUTO_TIE or AFFINE-->
        </GEO_REF_MODE>
        <Height_Plane_FROMRPC value="1" />
        <Height_Plane value="-9999" />
        <Height_Range value="-9999">
            <!--this can be estimated from the height scale-->
        </Height_Range>
        <GCP_RECORDS>
            <!--Do replicate with more measurement-->
            <GCP_Rec X="0" Y="0" Z="0" />
        </GCP_RECORDS>
    </Parameters>
    <Image_Files>
        <!--For TIE geo-referencing, only two images are allowed, the first is left, the second is right-->
        <Image_object>
            <Image_Name />
            <RPC_Name />
            <Output_RPC_Name />
            <Image_measurements>
                <img_pt x="0" y="0" />
            </Image_measurements>
            <Affine_parameter CL0="0" CLL="0" CLS="0" CS0="0" CSL="0" CSS="0" />
        </Image_object>
    </Image_Files>
</GEO_REF>
```

Figure 4.1. The default xml control file for geo-referencing

4.1. Parameters

The <Parameters> session contains the necessary parameters in building up the referencing conditions:

<GEO_REF_MODE>: This specifies how the stereo images are being referenced:

1) GCP: ground control points are available. This mode will activate the <GCP_RECORDS>, being the 3D coordinates of the GCP. By duplicating the <GCP_Rec></GCP_Rec> session, you can specify multiple GCPs. The “<Image_measurements></Image_measurements>” (in pixels) for each image will correspond to the GCPs in order.
2) TIE: ground control points are not available. In this mode <GCP_RECORDS> will not take effect, and “<Image_measurements></ Image_measurements>” will be identical points, and the referencing will make the left image (the first image_object) as the reference frame.

3) AFFINE: this mode can be used when the bias correction parameters are available, e.g. computed from other software, in this case these parameters can be input in the <Affine_parameter> for each image (image_object).
4) AUTO_TIE: ground control points are not available. In this mode, <GCP_RECORDS> and "<Image_measurements></ Image_measurements>" will not take effect, the identical points will be matched automatically, and the referencing will make the left image (the first image_object) as the reference frame.

!!!Note: all the image measurements should be performed on the images specified in the <Image_Files>. These images should be Ortho-Ready images.

<Height_Plane_FROMRPC> specifies if the following two parameters are extracted from the RPC (it is always recommended to get the parameters from the RPC file).

<Height_Plane>: the approximate average height value of the mapping area.

<Height_Range>: the approximate height range of the mapping area.

4.2. Image files

The <Image_Files> follows the same definition from Chapter 2, where each <Image_object> is associated with one image. <Image_Name> and <RPC_Name> are self-explanatory, where <Output_RPC_Name> specify the corrected RPC after the geo-referencing.

In GCP and AFFINE mode, each image will have a corrected RPC file, which will be used for subsequent DSM and Orthophoto generation. Since in GCP and AFFINE mode, the correction is independent, thus you can attach more than two images in the process. However for the TIE mode, only two images should be used, where the first one defines the frame, and only the second image will have a corrected RPC file.

<img_pt> specifies the image measurements (in pixels) and can have multiple records. In the GCP mode, it corresponds to each GCP, where in the TIE mode corresponds to records across the images, and for each image (image_object), it should have the same number of <img_pt> as the others. In the AUTO_TIE mode, it will not take effect.

Figure 4.2 shows an example of a geo-referencing file with the AUTO_TIE mode, which can automate the process of the tie point measurement. In matching difficult regions (e.g. untextured regions, texture changing regions), it is better to use the TIE mode. Figure 4.3 shows an example of a geo-referencing file with the TIE mode. In principle one point is enough for the referencing, but it is always recommended to measure more points to average the measurement errors.

```xml
<?xml version="v 1.0, control file for stereo geo_referencing,if a TIE mode is idenfied with no points in the image field, it runs an auto_TIE" ?>
<GEO_REF>
    <Parameters>
        <GEO_REF_MODE Mode="AUTO_TIE">
            <!--the mode could be: GCP or TIE or AUTO_TIE or AFFINE-->
        </GEO_REF_MODE>
        <Height_Plane_FROMRPC value="1" />
        <Height_Plane value="-9999" />
        <Height_Range value="-9999">
            <!--this can be estimated from the height scale-->
        </Height_Range>
        <GCP_RECORDS>
            <!--Do replicate with more measurement-->
            <GCP_Rec X="0" Y="0" Z="0" />
        </GCP_RECORDS>
    </Parameters>
    <Image_Files>
        <!--For TIE geo-referencing, only two images are allowed, the first is left, the second is right-->
        <Image_object>
            <Image_Name>C:\Users\testsamples\left_img\left_img_PS_or.tif</Image_Name>
            <RPC_Name>C:\Users\testsamples\left_img\left_img_PS_or_rpc.txt</RPC_Name>
            <Output_RPC_Name />
            <Image_measurements>
                <img_pt x="0" y="0" />
            </Image_measurements>
            <Affine_parameter CL0="0" CLL="0" CLS="0" CS0="0" CSL="0" CSS="0" />
        </Image_object>
        <Image_object>
            <Image_Name>C:\Users\testsamples\right_img\right_img_PS_or.tif</Image_Name>
            <RPC_Name>C:\Users\testsamples\right_img\right_img_PS_or_rpc.txt</RPC_Name>
            <Output_RPC_Name>C:\Users\testsamples\right_img\right_img_PS_or_krct_rpc.txt</Output_RPC_Name>
            <Image_measurements>
                <img_pt x="0" y="0" />
            </Image_measurements>
            <Affine_parameter CL0="0" CLL="0" CLS="0" CS0="0" CSL="0" CSS="0" />
        </Image_object>
    </Image_Files>
</GEO_REF>
```

Figure 4.2. An example of xml control file for geo-referencing using AUTO_TIE mode.

```xml
<?xml version="v 1.0, control file for stereo geo_referencing,if a TIE mode is idenfied with no points in the image field, it runs an auto_TIE" ?>
<GEO_REF>
    <Parameters>
        <GEO_REF_MODE Mode="TIE">
            <!--the mode could be: GCP or TIE or AUTO_TIE or AFFINE-->
        </GEO_REF_MODE>
        <Height_Plane_FROMRPC value="1" />
        <Height_Plane value="-9999" />
        <Height_Range value="-9999">
            <!--this can be estimated from the height scale-->
        </Height_Range>
        <GCP_RECORDS>
            <!--Do replicate with more measurement-->
            <GCP_Rec X="0" Y="0" Z="0" />
        </GCP_RECORDS>
    </Parameters>
    <Image_Files>
        <!--For TIE geo-referencing, only two images are allowed, the first is left, the second is right-->
        <Image_object>
            <Image_Name>C:\Users\testsamples\left_img\left_img_PS_or.tif</Image_Name>
            <RPC_Name>C:\Users\testsamples\left_img\left_img_PS_or_rpc.txt</RPC_Name>
            <Output_RPC_Name />
            <Image_measurements>
                <img_pt x="21463.95" y="12421.06" />
                <img_pt x="13266.16" y="4980.25" />
            </Image_measurements>
            <Affine_parameter CL0="0" CLL="0" CLS="0" CS0="0" CSL="0" CSS="0" />
        </Image_object>
        <Image_object>
            <Image_Name>C:\Users\testsamples\right_img\right_img_PS_or.tif</Image_Name>
            <RPC_Name>C:\Users\testsamples\right_img\right_img_PS_or_rpc.txt</RPC_Name>
            <Output_RPC_Name>C:\Users\testsamples\right_img\right_img_PS_or_rpc.txt</Output_RPC_Name>
            <Image_measurements>
                <img_pt x="21467.02" y="12422.99" />
                <img_pt x="13268.08" y="4985.21" />
            </Image_measurements>
            <Affine_parameter CL0="0" CLL="0" CLS="0" CS0="0" CSL="0" CSS="0" />
        </Image_object>
    </Image_Files>
</GEO_REF>
```

Figure 4.3. An example of xml control file for geo-referencing using TIE mode.

Chapter 5

5. DSM Generation and Orthophoto Rectification

This is eventually the final step for generating the ortho-rectified image and Digital Surface Models (DSM), which is also the most complicated one. The input of this step is the geo-referenced (geo_ref) ortho ready images (with GCP or TIE corrected RPC file), and the output will be colored point clouds, DSM raster, obj meshes, as well as orthophoto.

To get the default xml control file, type:

RSP DSM_Ortho

You will get the following file (Figure 5.1):

```xml
<?xml version="v1.0, Control file for Ortho image and DSM generation" ?>
<ORTHO_DSM_GEN>
    <Working_Directory>Put Project Directory here</Working_Directory>
    <Parameters>
        <Height_Plane_FROMRPC value="1" />
        <Height_Plane value="-9999" />
        <Height_Range value="-9999" />
        <Tile_Options Tile_X="15000" Tile_Y="15000" />
        <!--This is to set the default Tile options, adjust it according to match your memory volume-->
    </Parameters>
    <Point_clouds_GEN />
    <DSM_GEN>
        <Cell_size X="1" Y="1" />
        <Interpolation_Radius value="2" />
        <Is_Current_proj value="1">
            <!--The following only take effect when the above value is 0-->
        </Is_Current_proj>
        <Triangulation_based_Interpolation Excute="1" Write_obj_file="0" />
        <Point_Cloud_Folder />
        <Output_DSM_Folder />
    </DSM_GEN>
    <Ortho_GEN>
        <Is_Current_proj value="1">
            <!--The following only take effect when the above value is 0-->
        </Is_Current_proj>
        <Input_DSM />
        <Out_put_file_name />
    </Ortho_GEN>
    <Image_Files>
        <Image_object>
            <Image_Name />
            <RPC_Name />
            <Is_for_ortho value="1" />
        </Image_object>
    </Image_Files>
</ORTHO_DSM_GEN>
```

Figure 5.1 default xml control file for DSM and orthophoto generation

It can be seen that it has three functioning sessions, being <Point_Cloud_Gen>, <DSM_GEN> and <Ortho_GEN>, corresponding to point cloud generation, DSM resampling and orthophoto rectification, respectively, which follows a conventional paradigm. The <Parameters> session specifies the height plane and the basic tile parameters, which follows the same convention as we described before.

You can deactivate any of these three functioning sessions by simply delete them from control files. For example, you can delete the <DSM_GEN> and <Ortho_GEN>, to only generate the point clouds. You can also use this to solely resample your point clouds that obtained from other means such as generating a raster from the mobile laser scanning data by only use the functioning session <DSM_GEN> (in this case you can specify the las file folder in <Point_Cloud_Folder> under <DSM_GEN>). Following the same idea, you can import external DSM other than that generated from RSP in the <Ortho_GEN>.

The <Working_Directory> is indeed the output folder of all the results, e.g. you can put:

< Working_Directory > C:\Users\testsamples\results\</ Working_Directory >

Do end up the folder path with a backslash ("\"), to avoid possible path catenation errors. After the computation you will get something like this (depending on what functioning sessions you activated):

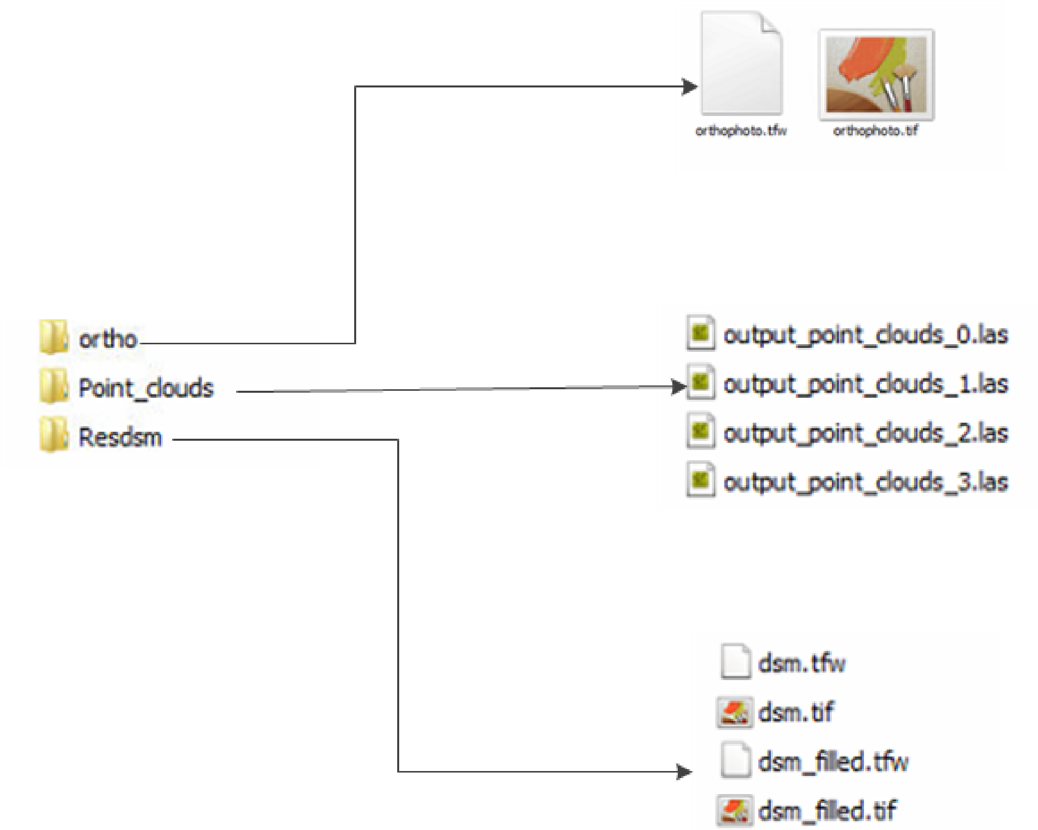

Figure 5.2. An example of the final output (the triangular mesh (obj format) is optional (can be set in the control file), reside in the Resdsm folder if being activated).

5.1. Point cloud generation

The computation and matching parameters are not exposed, therefore <Point_clouds_GEN> is fully parameter-less in the default xml, as for almost all the cases, you do necessarily set anything in this module, but there are several parameters you can actually set, but in terms of file organization. For example, the output tiling, band combination for colorizing the point clouds. These parameters will be introduced in Section 5.4.

If this functioning session is activated, the first image in the <Image_Files > will be the left one and the second image will be the right one. Note the associated RPC files of the images should be those that have been corrected.

5.2. DSM resampling and generation

Under the <DSM_GEN>, the <Cell_size> specifies the resolution of the resulting DSM raster, note that the resolution of the orthophoto will be the same as the DSM, so it will be your choice to set this parameter. Since I use dense matching, I always set it the same as the GSD of the image, which should not make the resulting values in the DSM sparsely distributed.

<Interpolation_Radius>: if you underestimate the cell_size (higher than the original GSD of the image), you will have some gaps between pixels, this is used to help you to filling in these gaps, I suggest you to use a small value if you set the cell_size correctly (equal or larger than the GSD of the image).

<Triangulation_based_Interpolation>: “Excute=1” enable this option, where triangular mesh will be built to fill large DSM gaps (e.g. occlusion). “Write_obj_file=1” will write the mesh in an obj format in the “Resdsm folder”.

<IS_Current_proj>: if the value is 1, it will locate the point cloud folder as the subfolder for point clouds (Figure 5.2), under the path <Working_Directory>. In this case the two tag <Point_Cloud_Folder> and <Output_DSM_Folder> will not take effect. Otherwise if you have the point clouds already and just want to do DSM sampling, set the value of <IS_Current_proj> as 0, and specify the corresponding folders.

5.3. Orthophoto generation

Similar to <DSM_GEN>, a < IS_Current_proj > value of 1 means to get the input DSM directly from the current working directory, otherwise the input DSM and output orthophoto (full filename path) should be provided. The source images and their associated files are under <Image_Files>. A value of 1 in <Is_for_ortho> means this image will be used for the ortho-rectification, and multiple images can be used in the ortho-rectification, but to note that these files should have the same bit depth and band, otherwise use the one you want.

Figure 5.3 gives an example of the xml file to generate point clouds, DSM and orthophoto from two images. A special note is that in this control file, these two images are references using TIE points, therefore the left RPC file is the original one, and the right RPC file is corrected, named as “right_img_PS_or_krct_rpc.txt”.

Note that if you output the obj files, the process will be a bit slower.

```xml
<?xml version="v1.0, Control file for Ortho image and DSM generation" ?>
<ORTHO_DSM_GEN>
    <Working_Directory>C:\Users\testsamples\results\</Working_Directory>
    <Parameters>
        <Height_Plane_FROMRPC value="1" />
        <Height_Plane value="-9999" />
        <Height_Range value="-9999" />
        <Tile_Options Tile_X="10000" Tile_Y="10000" />
    </Parameters>
    <Point_clouds_GEN />
    <DSM_GEN>
        <Cell_size X="0.5" Y="0.5" />
        <Interpolation_Radius value="2" />
        <Is_Current_proj value="1">
            <!--The following only take effect when the above value is 0-->
        </Is_Current_proj>
        <Triangulation_based_Interpolation Excute="1" Write_obj_file="0" />
        <Point_Cloud_Folder />
        <Output_DSM_Folder />
    </DSM_GEN>
    <Ortho_GEN>
        <Is_Current_proj value="1">
            <!--The following only take effect when the above value is 0-->
        </Is_Current_proj>
        <Input_DSM />
        <Out_put_file_name />
    </Ortho_GEN>
    <Image_Files>
        <Image_object>
            <Image_Name>C:\Users\testsamples\left_img\left_img_PS_or.tif</Image_Name>
            <RPC_Name>C:\Users\testsamples\left_img\left_img_PS_or_rpc.txt</RPC_Name>
            <Is_for_ortho value="1" />
        </Image_object>
        <Image_object>
            <Image_Name>C:\Users\testsamples\right_img\right_img_PS_or.tif</Image_Name>
            <RPC_Name>C:\Users\testsamples\right_img\right_img_PS_or_krct_rpc.txt</RPC_Name>
            <Is_for_ortho value="1" />
        </Image_object>
    </Image_Files>
</ORTHO_DSM_GEN>
```

5.4. More functions

Indeed you can do a bit more customization in this session. I put a special command “DSM_Ortho_Pro” to generate the default xml for a more complicated control of the parameters. However, for most of the users, the standard one “DSM_Ortho” is good enough, therefore this section is optional and you can choose to ignore.

If you type:

RSP DSM_Ortho_Pro:

You will get the following default xml control file:

```xml
<?xml version="v1.0, Control file for Ortho image and DSM generation" ?>
<ORTHO_DSM_GEN>
    <Working_Directory>Put Project Directory here</Working_Directory>
    <Parameters>
        <Height_Plane_FROMRPC value="1" />
        <Height_Plane value="-9999" />
        <Height_Range value="-9999" />
        <Tile_Options Tile_X="15000" Tile_Y="15000" />
        <!--This is to set the default Tile options, adjust it according to match your memory volume-->
    </Parameters>
    <Point_clouds_GEN>
        <Band_RGB Band_R="1" Band_G="1" Band_B="1" />
        <IS_Using_Original_Depth IS_ORIGINAL="1" />
        <Disparity_Range MIN="-1000" MAX="1000" />
        <Point_Sampling x="1" y="1" />
        <Output_Blocks NumX="1" NumY="1" />
        <Tile_Options Tile_X="15000" Tile_Y="15000" Extra_X="500" Extra_Y="500">
            <!--Customized Tile set up, force the process to use these parameters-->
        </Tile_Options>
    </Point_clouds_GEN>
    <DSM_GEN>
        <Cell_size X="1" Y="1" />
        <Interpolation_Radius value="2" />
        <Is_Current_proj value="1">
            <!--The following only take effect when the above value is 0-->
        </Is_Current_proj>
        <Tile_Options Tile_X="15000" Tile_Y="15000" Extra_X="10" Extra_Y="10" />
        <Triangulation_based_Interpolation Excute="1" Write_obj_file="0" Grid_point_interval_X="100" Grid_point_interval_Y="100" />
        <Point_Cloud_Folder />
        <Output_DSM_Folder />
    </DSM_GEN>
    <Ortho_GEN>
        <Is_Current_proj value="1">
            <!--The following only take effect when the above value is 0-->
        </Is_Current_proj>
        <Input_DSM />
        <Out_put_file_name />
        <Tile_Options Tile_X="15000" Tile_Y="15000" Extra_X="10" Extra_Y="10" />
    </Ortho_GEN>
    <Image_Files>
        <Image_object>
            <Image_Name />
            <RPC_Name />
            <Is_for_ortho value="1" />
            <Is_for_Point_cloud value="1" />
            <Is_for_Base_Disp value="1" />
        </Image_object>
    </Image_Files>
</ORTHO_DSM_GEN>
```

Figure 5.4 default xml file for more complicated control of the DSM & orthophoto generation process.

There are not many changes for <DSM_GEN> and <Ortho_GEN>, except an alternative control of the tiles, since you might need to control the tile size for each procedure to make an optimal use of your memory (I will make an automatic control of the memory in later versions). This is because for different steps with the same tile size, they may consume different memory. However, a tile of 10000 – 15000 pixels is good enough to gain the balance between memory and speed for a 16 GB memory computer. Therefore I hide these parameters. If you delete the <Tile_Options > for the three functioning sessions (<Point_Cloud_GEN>, <DSM_GEN> and <Ortho_GEN>), it will read the tile from the <Tile_Options> from the <Parameters> session.

In <Triangulation_based_Interpolation> under the <DSM_GEN>, there are attributes "Grid_point_interval_X" and "Grid_point_interval_Y". This is used to generate more detailed triangular meshes. By default it is set as 100, and you can reduce this number to get more detailed ones, however it is also slower.

In <Point_clouds_GEN>: there are more options available.

<Band_RGB> : this is to tell RSP which band of the multispectral image will be used to colorize the output point cloud (the band is indexed from 1). In default, I set (R=1,G=1,B=1) for the panchromatic images, (R=4,G=3,B=2) (false color) for 4-band multispectral image and (R=8, G=3,B=2) for 8-band

multispectral images. You can set this as (R=3, G=2, B=1) for the original RGB information. Accessing a band which does not exist will produce an error.

<IS_Using_Original_Depth>, it will take the original 16 bit image for computation, otherwise convert them to 8-bit image for matching. I always set “1” for this.

<Disparity_Range>: this is the searching range for matching, and the default value (-1000,1000) is good enough for most of the cases, however I offer this option so that you can modify for extreme cases, such as very deep mountains (where you might have very large parallax).

<Point_Sampling>: sometimes for you might not want per-pixel output of the point clouds, therefore you can set the pixel-intervals, the larger, the more sparse point clouds you will have.

<Output_Blocks>: if you work with a tile size of 10000-15000 to gain speed, you might consequently have a point cloud file (*.las) for each tile with a size of 2-4 GB, which is not portable for demonstration. This allows you to divide your output point cloud file into smaller blocks for quick assessment of the resulting point clouds.

In <Image_Files>, under each <Image_object>, you can set to use which image as the base for matching <Is_for_Base_Disp> and which to use for colorization (<Is_for_Point_cloud>), these two options should be uniquely determined among the images. Note it is quite common that sometimes you only have one multispectral image in the stereo pair, therefore you need to specify the multispectral one to obtain the colorized point clouds, and otherwise you get grey image intensities in the resulting point clouds.

Chapter 6

6. Summary

6.1. Workflow

In most of the cases, you will start with two images with the associated RPC files from the image provider. You might get some more meta files, but these are not needed by RSP.

I suggest the following work follow to obtain your final project (point clouds, DSM, orthophoto).

Step 1: ortho-ready generation, cut the common region of the two images (using COMMON mode), if you have multispectral images, put them in as well. Cutting the common region is very useful for the pansharpen process.

Step 2: pan-sharpen: this is optional if you only have panchromatic image. Pan-sharpen the images in order to use them in the ortho-rectification and point cloud colorization.

Step 3: Geo-referencing: use TIE points or GCP to get the corrected RPC, note in this step the image files will not be changed, only the RPC files. In case of using TIE, only an output of the right image is needed. For AFFINE and GCP, it will produce a new RPC file for each of the image.

Step 4: DSM and orthophoto generation: the input RPC files should be corrected (unless it has already been corrected by other programs, like in the case of the ISPRS benchmark dataset).

6.2. Special notes and what to do if errors occur

I have tried to test this software (RSP) with many different dataset, however these is no guarantee that it will work perfect in your dataset, since it is still a beta version, and will undergo continuous development. There are several criteria to make sure that you do not make basic mistakes when preparing the control files.

- For file organization, always make sure there is no blank and other Unicode characters other than ascii. That is to name your path and file name in English. Avoid complicated and deep paths.
- For folder path input, always end with a backslash “\”.
- When you type the paths in things like <Image_Name /> in the default xml, remember to close it <Image_Name>something</Image_Name>
- When you copy the rpc file name to the corresponding tag, remember it ends up with .txt or RPB (not tif!).
- The output RPC file can only be txt, not RPB.
- Make sure all the file paths are correct, they have to be the absolute path.
- Check in your xml file if any bracket is not close.

Regarding to the tile sizes, I would recommend 15000 pixels for 16GB-memory machine and 5000 pixels for 8 GB-memory, 20000 pixels for a 32GB memory machine. You can use a trial-and-error approach to understand the memory consumption and set your project.

For troubleshooting, write to me via rongjun.qin.eth@gmail.com .