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Aerial Image Acquisition Considerations for Phodar Forestry Applications

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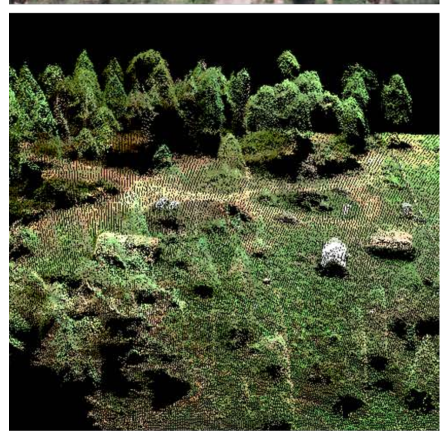

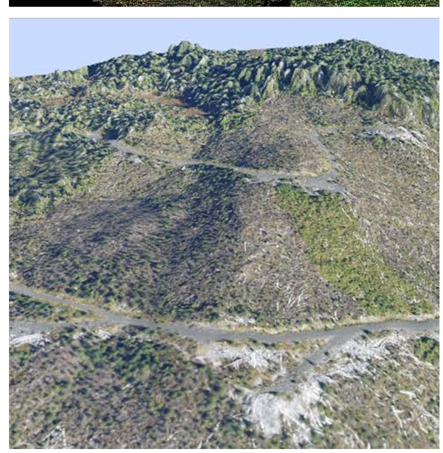

Forest Service

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Table of Contents

Introduction

Aerial imagery has long been used by the Forest Service to help map, inventory, and monitor the national forests. Resource aerial imagery is typically collected for the national forests on a cycle of every five to ten years, and is used primarily as a 2-D dataset for image interpretation, feature mapping, image segmentation, land use planning, as well as a host of other applications. Before the imagery is flown, acquisition specifications are determined to ensure that the aerial imagery meets project needs. During the last decade, new softcopy photogrammetry tools have emerged that enable users to generate dense 3-D point clouds from stereo aerial imagery, also known as phodar. In the past, acquisition specifications were largely driven by the requirements of 2-D products (e.g., orthophotos and orthomosaics). However, these new tools have opened up new opportunities of using aerial imagery to derive 3-D products.

Since this technology is fairly new, methods and tools for creating phodar products are still being researched and developed. However, studies performed thus far have provided valuable insight into the key acquisition specifications and other considerations for obtaining valuable phodar products. The recommended specifications vary depending on project requirements and landscape type. The goal of this document is to provide basic guidelines and considerations for selecting acquisition specifications for projects that aim to create phodar products for forestry applications. This document focuses primarily on digital frame cameras. Imagery acquired by other sensors, such as pushbroom aerial or satellite sensors, can be used to create phodar products, but are outside of the scope of this document.

Project Considerations

Before getting started, it is important to assess project objectives and make sure that the data being collected meets those needs. The main product from phodar is a digital surface model (DSM), which is a raster product that includes elevations representing the earth's surface and all objects on it (i.e., ground surface, vegetation and buildings). If there are minimal objects on the surface or spacing is adequate between objects, then it may be possible to filter out the object elevations and create a phodar digital terrain model (DTM), which is a raster product that only includes elevations representing the terrain (figure 1). Both a DTM and DSM are needed to create a canopy height model (CHM), which is made by subtracting the DTM from the DSM, thus only leaving the heights of objects above ground. One of the main limitations of phodar is that it becomes increasingly difficult to create a phodar DTM as vegetation cover increases. As such, phodar may not be the best method for obtaining vegetation height information for forested sites that lack a high spatial resolution DTM – such as one derived from lidar; For densely forested areas, a lidar data collection would likely be better fit.

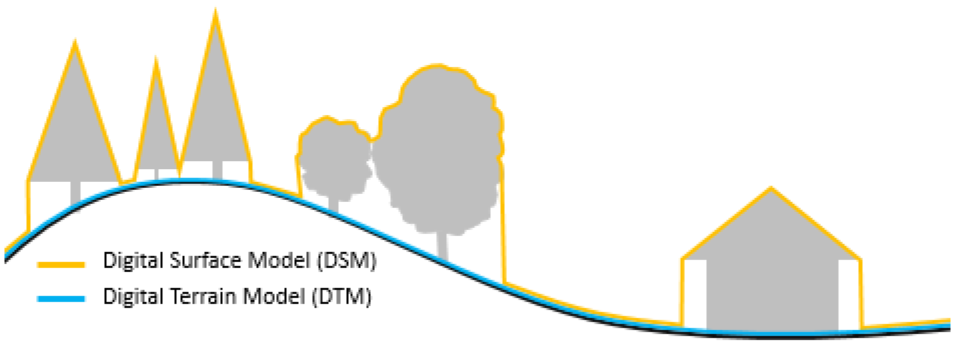

Figure 1: A DTM includes only elevations of the terrain, whereas a DSM includes elevations of the earth surface and all objects on it.

One application that does not necessarily require a DTM is change detection. The DSMs from different acquisitions could be compared to one another and used to identify areas of change. For most phodar products, this would likely be for large changes that involve the removal or loss of vegetation, such as timber harvest and fire. Subtle changes, such as vegetation growth may be possible if the accuracy of the phodar products is adequate for the magnitude of change.

The Forest Service has thousands of aerial images dating back to as early as the 1930s. These images are a valuable resource that allows us to get a glimpse of what the landscape looked like years ago. These images were usually collected with enough overlap to ensure complete coverage and to produce stereo image-pairs. As such, these images can be scanned, orthocorrected, and processed to produce phodar products and may be most useful in change detection efforts. However, it is important to recognize limitations that these datasets might have. This document may be useful for identifying such limitations of past image collections before attempting to create phodar products.

Acquisition Specifications

Below are some of the main specifications to consider when planning an aerial image acquisition for phodar products.

Overlap

There are two types of overlap: endlap and sidelap. Endlap is the amount of overlap between adjacent images within the same flightline; whereas, sidelap is the amount of overlap between images from adjacent flightlines. Image overlap is critical in producing phodar products since at least two viewpoints of a feature are needed to calculate its horizontal and vertical location. Traditional image acquisitions of 60% endlap and 30% sidelap may be adequate for capturing the ground and other fairly flat features in non-forest conditions. However, due to the complexity of vegetation and the obstruction of view that it causes when not at nadir in the image, it is recommended to increase the overlap for forest conditions to at least 80% endlap and 60% sidelap. Doing so allows for a higher probability of successful matches since the change in viewpoints is reduced and the features appear more similarly in the adjacent images (Gobakken 2015; Lemaire 2008). Increasing image overlap also reduces occlusion areas (i.e., gaps between trees that are missed), as shown in figure 2, and improves geometric accuracy by increasing the redundancy of image information. The result is a more rigid model with fewer blunders and gross errors, higher level of automation, and a more accurate representation of the vegetation (Leberl 2010).

Figure 2: Some of the lower vegetation cannot be seen in both images with the 60% endlap (left and center). With 80% overlap, the circled vegetation can be seen and heights can be derived using phodar (bottom).

One caveat of increasing the amount of overlap is that it reduces the base-to-height (B/H) ratio of the stereo image pair, which has a negative effect on the vertical accuracy of the model. Some photogrammetric software applications have the ability to calculate the elevations from several images using a multi-ray approach. Doing so improves the vertical accuracy of the model by including stereo image-pairs with greater B/H ratios while still using the higher overlaps to reduce occlusions (Hohle 2011).

Increasing the amount of endlap increases the amount of data collected, but should not increase the cost of the acquisition since the flight plan remains the same (Nurminen 2013; Hohle 2011; Leberl 2010). However, increasing the amount of sidelap does add to acquisition costs since additional flightlines are needed, which increase flight time.

Spatial Resolution

The spatial resolution of aerial imagery, or ground sample distance (GSD), varies depending on project needs and funding. Resource aerial imagery is typically collected at a GSD of 30cm or less. A smaller GSD can improve homogeneity of the pixel and interpretability of features in the imagery. This typically results in more detail in the phodar products when compared to products created from coarser imagery. However, a smaller GSD comes at the cost of more data to store and added processing time for creating phodar products.

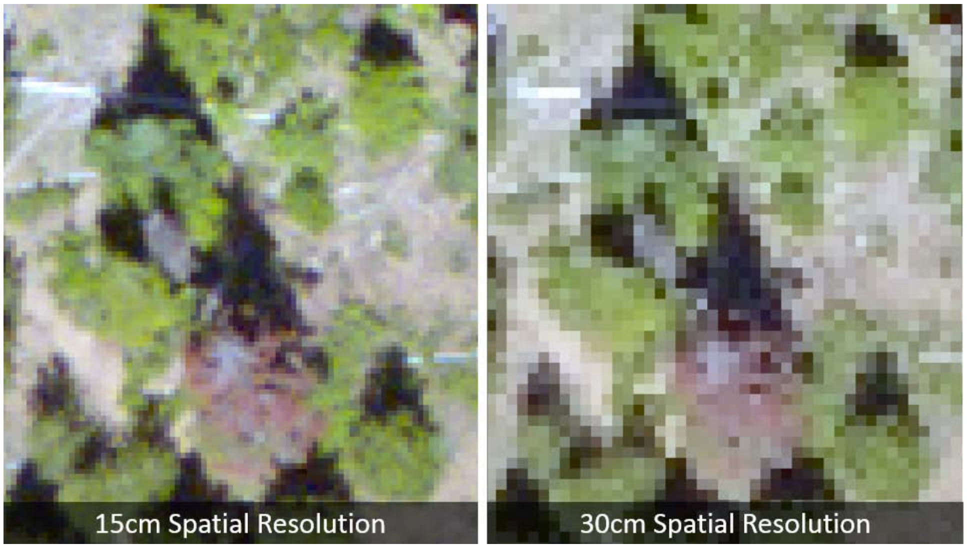

Figure 3: The 15cm image (left) contains 4 times the resolution as the 30cm image (right). The higher spatial resolution image contains more detail and more pixels that can ultimately be captured in the phodar products.

The focal length of the camera and flying height are the main variables in calculating the GSD. Higher flying heights will result in a larger GSD and a larger area being captured in the image. As such, acquisition costs go up as GSD decreases since additional flight lines are required to maintain the desired amount of overlap (Gobakken 2015). For creating phodar products of trees, a 15cm GSD should be adequate for most applications. However, if information about shrubs, saplings/seedlings, down-woody material, or interpretation of plant species is desired then it may be necessary to reduce the GSD. The challenge is to select a GSD that provides the information desired, but with the least amount of data. To do this, it may be helpful to compare images of varying GSDs and evaluate how clearly the target features can be seen. If the target features are difficult to distinguish in the image, it is unlikely that phodar software will be able to accurately model it in the 3D point cloud.

Radiometric Resolution

Radiometric resolution, or the sensors ability to discriminate between differences in electromagnetic energy and record those values, is another key acquisition specification for phodar products. Radiometric resolution is typically specified as bit depth, or the maximum number of brightness levels available for each image band. Digital frame cameras typically record either 12-bit or 14-bit data for each band. The imagery is later processed into either 8-bit or 16-bit TIFFs for delivery. An 8-bit image is only able to store a maximum of 256 values, whereas a 16-bit image stores a maximum of 65,536 values. The increase in radiometric resolution improves the interpretability and matching of features in shadows and highlights, which is needed in forested conditions (Hohle 2011). The result is a more complete phodar product since the software is able to match more points.

Figure 4: The 8-bit image (left) contains less detail in the shadows and bright areas when compared to the 16-bit image. This reduced detail makes it more challenging for phodar software to correctly match points.

Although higher bit-depths result in increased file size and processing time, it should not significantly increase the acquisition cost since the sensors are natively recording at the higher bit depth rate. If, for some reason, 8-bit imagery is desired at a later time then the imagery can be resampled to the lower bit depth. However, it is not possible to regain the radiometric resolution once converted to a lower bit depth. Whenever possible, request 16-bit imagery for projects that aim to create phodar products.

Horizontal and Vertical Accuracies

Horizontal and vertical accuracies are usually measured by using accurate check points to calculate the root-mean-square-error (RMSE) of the model and products. The accuracy of the model and the orientation parameters produced by the model greatly affect the accuracy of the phodar products. Horizontal accuracies for traditional resource image acquisitions are typically specified at 6 meters from true ground at a 95% confidence level and vertical accuracies are usually not specified. Slight errors in the model can be destructive for the phodar outputs. Therefore, both the horizontal and vertical accuracies need to be tightened from traditional specifications in order to produce acceptable results.

Most aerial systems now are able to perform direct georeferencing with the GPS and IMU data collected during the image acquisition. However, direct georeferencing does not typically produce the level of accuracy needed for creating phodar products unless if it involves Real Time Kinematic (RTK). For most acquisitions involving phodar, it is recommended that a full aerial triangulation be performed using survey grade ground control points (GCPs) (Lemaire 2008; Gobakken 2015). Collecting GCPs can be expensive, especially for remote sites. Aerial triangulation can be performed with a minimum of 3 GCPs; however, for best results, at least 10 evenly distributed GCPs are recommended for the acquisition site (PhotoScan user guide). Nevertheless, the exact number of GCPs can be determined by the vendor to achieve the specified accuracies. For projects involving phodar, the horizontal and vertical accuracies should be approximately double the GSD (e.g., 30cm vertical and horizontal accuracy for 15cm GSD imagery).

Other Considerations

There are several other items that can influence the quality and accuracy of the phodar products. Some of following items could be included in the contract in order to obtain best results.

- **Wind**: Windy conditions can cause the tops of trees to sway and move horizontally from one image to the next. Even a slight horizontal discrepancy caused by wind can cause meters of height errors for trees in the phodar products. For areas with trees more susceptible to movement in the wind, a max wind speed for the acquisition should be specified in the contract. Something similar to the following statement could be included: "Image acquisition shall be conducted during wind speeds that minimize tree movement and maximize data quality; in no case greater than 10 mph", or whatever wind speed is considered unacceptable.
- **Clouds**: A minimum amount of cloud cover is usually specified in the contract and is very important when it comes to creating phodar products. Any clouds, cloud shadows, or hazy conditions that exist in the imagery will likely prevent the software from accurately matching the pixels, resulting in holes or noise in the dataset.
- **Snow and Water**: Image matching algorithms struggle to create matches for homogenous features, such as snow and water. Of course, some sites will contain permanent bodies of water that are unavoidable. However, acquisition timing should attempt to avoid periods when seasonal snow or flooding is obscuring vegetation or other features on the ground.
- **Sun Angle**: Current contracts usually specify the sun angle. This is very important because low sun angles create excessive shadowing in vegetated areas and steep terrain. Deep shadows in imagery can result in voids and erroneous values in the phodar products. Something similar to the following statement could be included: "imagery should only be collected during the portion of the day when the minimum sun angle exceeds 45 degrees."
- **Coverage**: Be sure to specify stereo-image pairs for the entire acquisition area. At least two viewpoints are needed to create phodar products and so if the imagery only goes to the boundary then the outer rim will not have the necessary overlap. To avoid this, either apply a buffer to the acquisition area or specify complete stereo-image coverage in the contract.
- **Image Format**: The images should be delivered in a non-compressed format, such as a TIFF. Compressing the file using JPG or other compressed formats can lead to a loss of information and affect the phodar products.

Summary

Aerial imagery and the use of phodar products can provide valuable information to various forestry applications. In order to achieve optimal results, it is necessary to modify the specifications from traditional aerial image acquisitions. Increasing the amount of overlap is likely the most important modification for improving phodar products in forested conditions. However, more research is needed to determine how each of these components affects the end products.

The following table provides a summary of the recommended specifications as they relate to traditional acquisitions. These are only recommendations and would need to be refined for individual project needs. Keep in mind that some of these recommended phodar specifications will increase acquisition costs considerably and so both project objectives and acquisition costs need to be considered in selecting the final specifications.

	Traditional Specs	Phodar Specs
Endlap	60%	80%
Sidelap	30%	60%
Bit Depth	8 bit	16 bit
Spatial Resolution	30 cm	15 cm
Horizontal Accuracy	< 6 m	30 cm (2x GSD)
***Vertical Accuracy**	None	30 cm (2x GSD)

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