Guidelines for Images to be used for Photogrammetry

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Disclaimer: First let me say we are also in a learning mode and there are a million combinations of variables that affect the QOR, quality of results. We have gone down a path that works but that is not to say there aren't many other paths that work and may work better. Hopefully by collaborating with other contributors we can evolve a more robust set of guidelines.

Software: The archaeology industry seemed to standardize on the Agisoft Photoscan probably because it was first to market. Our experiments show it is very capable of doing quality underwater models. The NPS SRC started with Agisoft, but is using Reality Capture now also. In our tests we have found Reality Capture to be much faster, but less able to reliably knit together all of our less than optimal underwater images leaving many components or pieces of the model that must be manually aligned. Jerry Eliason and I have been using 3D Flow's 3D Zephyr software. It also does a good job of assembling less than optimal underwater images.

Background: Our GLSPS team has been experimenting with photogrammetry for four years shooting with three different cameras and multiple lighting configurations. We have used a Jerry Eliason Sony surveillance drop camera which shoots 1080x1920 HD images (Manasoo and J.H. Jones, Hesper). I shot with an older Sony Z1U camcorder 1080x1440 (Strathmore) and later a Canon 5D Mark IV at 1080x1920 video (Strathmore, Hopkins) then later 6720x4480 30megapixel images (Hopkins). Brett Seymour with the NPS shoots 40 megapixel images for the parks models. Imaging expert Evan Kovak has a multiple camera imaging system mounted on a scooter which records images from multiple angles. He shoots Nikon mirrorless cameras. Tim Pranke has been using a two-camera rig with GoPro4's shooting HD video with success. All configurations have worked to some extent. We have also tried processing older standard definition photomosaic video with varied results (Sophie's Wreck, Chisholm Cumberland Site).

Video or Stills: The software can handle either but basically it picks individual frames at a rate you select out of the video. The software varies on the video formats they can handle, but formats can usually be converted. Agisoft is very limited on which video formats it can process but Reality Capture does multiple video formats. When using video we have used .mp4. When using stills we have used .jpg. We have evolved to use 30 megapixel jpegs. Brett Seymour of the NPS Submerged Resource Center uses RAW stills which can be color adjusted better before processing. It takes either very fast storage media or multiple cards to keep up with the write speed for storing high resolution RAWs at more than one per second. My Canon shoots 3 images per second with jpeg and I swim at a normal rate. Brett shoots at one image per second and swims slowly. If you choose to adjust color or exposure in Photoshop or other software you will probably want to be able to apply the same corrections to all images in a batch process. I have batch adjusted exposure in Photoshop and it seemed to work well. When I adjusted exposure on underexposed individual frames to get the software to use them, it had the opposite affect rejecting those frames and the subsequent frames.

Resolution: What we learned was HD 1080x1920 does work well but when the models are compared to models shot with higher resolution cameras the difference is obvious like any time you compare two images shot at different resolutions. The lower resolution image looks good until you look at it side by side with a higher resolution image. We were originally concerned about added processing time for the higher resolution images but it turned out not to be a problem. It did use more memory when processing the 30 megapixel images vs. the HD images but the surprisingly the processing time in the software we are using 3D Zephyr did not increase significantly. The relative insensitivity to the higher resolution images may be to the fact that at least Agisoft downgrades the resolution before aligning the images. The user does have control over the amount it downgrades the images. I would recommend at least shooting 4k images but HD does work.

Depth of Field: Good depth of field is important as it gives the software more edges to align so using a smaller aperature will help.

Lighting: Even soft lighting is best. Shadows will make the model look like the light is coming from one point even though in the tool you place the lighting somewhere else. Try to make your artificial light as soft and evenly distributed across the image plane. Either natural or artificial lighting work but if you are shooting a shallow wreck with a large gradient of lighting across the wreck site or plan to shoot on multiple days and conditions using artificial light will give you more control over the lighting. Shooting on a night dive can solve those problems.

Lens Length: Frankly we have not experimented much with this variable. The software recommends not getting too wide angle. We have stuck to about equivalent 20mm with dome port. It is important to be consistent for the whole model. Pick one lens and stick to it. While this requirement may vary from software to software, sticking to it will make your images more likely to be usable in any software used to process the data.

Shutter Speed: Since we have used video for a number of our models, this is one parameter we have experimented with. Normally video shutter speed is twice the frame rate which for normal 24 to 30 fps is $1/50^{th}$ or $1/60^{th}$ of a second. The slow shutter speeds in video allows a certain amount of motion blur which our eyes and brains associate with the speed of motion. For photogrammetry we use individual frames which need to be sharp with no motion blur and in focus. When I shot video with the normal $1/50^{th}$ second shutter speed and I am fairly steady shooting video we had spotty results. When I increased to $1/125^{th}$ second shutter speed our results were much better but it is a function of how fast you move the camera and how close to the subject you are. With Jerry's drop camera which is on a long tether and makes smooth slow passes at a farther distance from the subject we get by with $1/50^{th}$ of a second.

Lighting: This is an ongoing experiment. We have experimented with this a lot with variable results so I can give our current thinking. Both natural lighting and artificial lighting work and frankly we can't say which is better. When you shoot with both and the distance to the camera changes it does create a color shift which shows up on the model. We haven't tried to adjust individual images for that. As far as artificial lighting the goal should be to have flat even lighting across the image side to side and top to

bottom which is another reason very wide angle lenses are a challenge. Normal surface lighting rule of thumb is to mimic daylight with one bright light (the sun) and a fill to mimic bright sky. Of course we never do that under water, but typically we do carry our lights above and far apart to minimize back scatter. Eliminating back scatter is important because if the software sees it in multiple images it will add it to the model. Lighting from above tends to make the bottom of the image darker than the top which becomes more obvious when you are shooting a flat surface like the side of a ship. It may not be obvious when we are shooting a normal photograph of a diver or artifact in the center of the frame as the fade to dark around the edges just helps to vignette the subject. What I tried and appeared to work is to mount two lights above and two lights below so the entire frame was evenly lighted. Since we like to shoot with the camera pointed forward slightly maybe 10 degrees I put the brightest lights above the camera since the top of the image is typically farther from the light source than the bottom. This seemed to achieve the goal but obviously many variables and room for experimentation. The key is to illuminate the frame evenly top to bottom and side to side and minimize backscatter.

Now that we have talked about the camera and lighting settings let's talk about swim patterns and camera angles.

Overlap: The software would like about a 60% overlap between images. Every point on the wreck should be visible in at least three frames. This applies to both horizontal and vertical directions. We typically swim the length of the wreck multiple times trying to achieve 60% overlap between passes. This works but generally pass to pass needs some manual alignment in the software to get the pass to pass alignment. The one time the software managed to knit everything together without manual intervention was when we shot one day with the drop camera doing passes stem to stern then the next day when the wind shifted we shot passes side to side. I attribute this to the fact that between a series of images we have better than 60% overlap but between passes we have 60% or less of overlap. When we shot in both directions we had plenty of overlap in both directions. We haven't tried and I'm not suggesting you need to shoot in both directions which would take a lot of dives but the point is to emphasize the importance of having plenty of overlap. Too much is better than not enough. We found shooting in a vertical format worked better if you are moving in a horizontal direction. You get good overlap image to image but it is more difficult to control your overlap vertically between passes so getting the widest angle of coverage vertically in the frame improves the vertical overlap.

Camera Angle: We like to swim horizontal passes the length of the wreck for horizontal wrecks with the camera tilted slightly forward maybe 10 degrees. Since the overlap is generally better in the direction of the camera motion than pass to pass I generally shoot with the camera sideways or with the widest angle of the frame vertically to give the best pass to pass overlap. It doesn't seem to matter to the software. However, if your camera auto-rotates images be sure to turn that off since at least Agisoft complains when it encounters the rotated images. Remember you are trying to get all sides of any relief or protrusions from the side or deck so you may have to slow down and slowly pan back as you swim to get the back side of something protruding from the surface you are shooting. Then take the time to slowly bring the camera back to the normal shooting angle so you don't miss the surface after the object. Generally it is better to hold the camera at a fixed angle but if you do need to pan do it very slowly since it always seems when you are swimming to be slower than it really is. This is important as

you round the bow or stern corner of the ship. Make these pans very very slowly. We typically have had to increase the number of frames grabbed in these areas to make up for the pan speed when we are shooting with video. The idea is you want to shoot from multiple angles with the camera tilted up and down forward and back so each feature is covered from all directions. This can also be achieved consistently with a multi-camera rig. Of course with a multi-camera rig you must also consider your ability to consistently light the full range of the covered area.

Swim Patterns: Like stated earlier we typically cover the horizontal wrecks swimming the length making a very slow turn around the bow and stern. The next pass can then be done above or below with a 60% overlap. Don't forget to include a portion of the bottom around the wreck to include artifacts or wreckage surrounding the wreck. Whenever you make a turn do it very slowly so there are sufficient images to give is a smooth transition from one side to the other. This makes the passes knit together with little or no manual effort. In doing photomosaics quite often we continued the path off the wreck then turned without regard to the direction the camera pointed into the water column. When shooting for photogrammetry it helps to keep the camera pointed toward the wreck as you make a slow turn. This helps the software automatically align the end of the last pass with the start of the next pass. Otherwise quite often we need to manually connect the passes.

When the wreck is on an incline this can create a buoyancy control problem. So be cognizant of this with a safety first mind set. The buoyancy shift at a minimum creates a control problem. Maybe a solution would be to swim at constant depths and not necessarily follow the contour of the hull or deck edge. One thing I learned in shooting a photomosaic of a ship on a fairly steep angle to the bottom in natural light with good visibility and medium distance from the wreck was each image was lighter on the shallow side and darker on the deep side of the frame. Since the camera continually adjusted the exposure for the average or center of the frame the difference was present in all of the images up the length of the hull. When I tried to knit them together into a photomosaic the result was a scalloped light-dark photomosaic. I'm not sure what affect the lighting/exposure shift will have on this software. We haven't done a shipwreck on an incline yet or one with a significant depth and light change from bottom to top. A possible solution might be to shoot the images closer than needed based on visibility to minimize the difference in exposure side to side or top to bottom of the frame or shoot the images on a night dive with artificial light.

Posts, stanchions, and masts create a particular challenge since it is difficult to get all sides of each. On our trials when I was shooting window and door frames of the Hopkins when I didn't get the inner side of the frame the software connected one side of the window with the next frame using the green water in between as a surface. We could manually edit out the green but it left the beams looking hollow with an open side. I tried panning back and forth in the last experiment. Results were better.

Vertical masts pose both an image and buoyancy problem to get sufficient coverage from all sides and not lose control of buoyancy in the process. My current thinking is to spiral around the mast since to me the more important issue is the safety and buoyancy issue. In online instructions for other photogrammetry applications they shoot around the subject. I think it is something we need to make work in a safe way or ignore the masts.

Scaling the Model with Markers: To give the model the most value to any future archaeological studies providing a scale in the area covered by the model is very valuable. This will improve the true dimensional accuracy of the model. Wisconsin Historical has found one-meter markers work well. These are used in terrestrial imaging regularly and they recommend at least three scale markers be used in different locations and orientations on the site. Each marker you add improves the achievable precision of measurements that can be made from the model. These scale markers can range from a simple one-meter stick to a one meter stick with software identifiable targets on the ends with centers one meter apart. Potential designs are shown on our website and can be found at the following website. Cultural Heritage Imaging | 4-Day Photogrammetry Training .

Post Processing Images: Images can be post processed. Tutorials suggest Lightroom for this. It is good to minimize harsh shadows and strong highlights. If you color correct or exposure correct make one macro and apply it to all images so every image looks the same with respect to exposure and color.