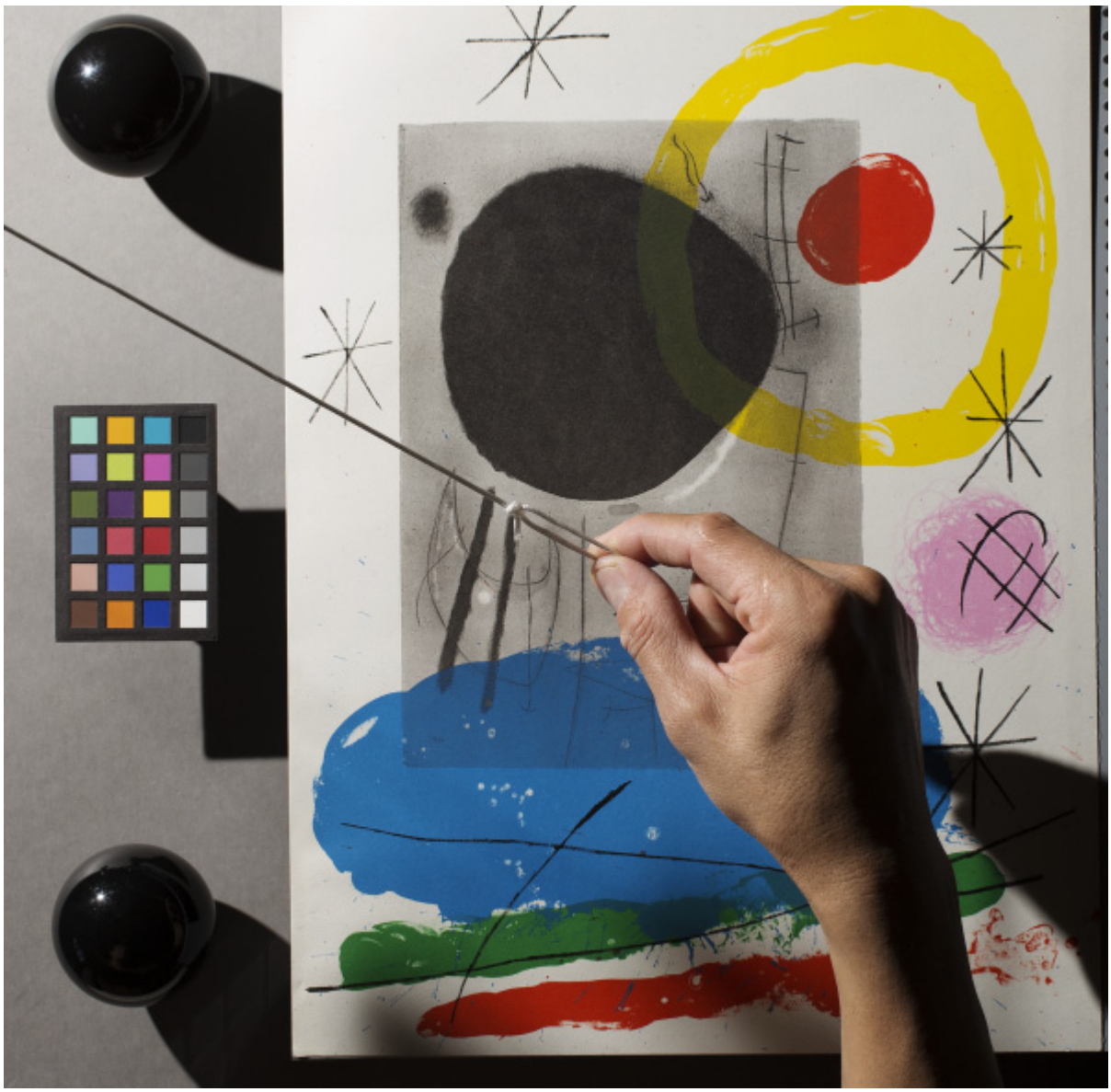
REFLECTANCE TRANSFORMATION IMAGING

GUIDE TO HIGHLIGHT IMAGE CAPTURE

Document version 2.0

Find updates and related materials at http://CulturalHeritageImaging.org/downloads/



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Reflectance Transformation Imaging: Guide to Highlight Image Capture v2.0

Documents are also available in Spanish translation; see http://CulturalHeritageImaging.org/downloads/.

Acknowledgments:

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The contents are solely the responsibility of the authors and do not necessarily represent the official position or policies of the National Park Service or of the National Center for Preservation Technology and Training or of the Institute of Museum and Library Services.

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Setting up for Highlight RTI Image Capture

Overview

Highlight RTI image capture is a technique for obtaining the original digital image data from which you can produce reflectance transformation images (RTIs). An RTI, in addition to storing the color data for each pixel, stores a *normal* value for each pixel that records its surface shape. The processing software calculates this value using data about the position of the light in each image, relative to the camera.

In highlight RTI image-capture technique, you include one or (preferably) two reflective spheres in each shot. The reflection of the light source on the spheres enables the processing software to calculate the light direction for that image. This allows you great flexibility in subject size and location.

Physical setup summary

It is very important that the camera, the target object, and the reflective spheres do not move at all during the capture sequence; only the light moves.

You need to set up the following elements:

- Camera

  You must set the digital camera on a tripod or camera stand for stability, and to eliminate vibration during image capture. Sandbags or other weights can help you to further stabilize tripods and supports.

  We use Canon digital SLRs for illustration and demonstration, but many different camera types have produced high-quality RTIs. You must be able to set exposure and aperture manually, and turn off autofocus in order to keep a fixed focus on the subject.

  The recommended method is to connect the camera to the computer, and use the computer to control it for testing your setup, and when shooting the images. This way, you can trigger the camera and flash directly from the computer and download and name your images at the time of capture. Alternatively, you can use a remote triggering device for the camera, such as a trigger release cable or radio trigger.

  For details, see "Camera setup" on page 6.

- Target object with reflecting spheres

  Depending on the size and portability of the target object, you must compose the camera's field of view so it can encompass both the object and two reflecting spheres of an appropriate size. The spheres should have a diameter of at least 250 pixels in the resulting photograph.

  There are various ways to mount the reflecting spheres. In general, you can set the spheres on stands in the target area, or mount them on light stands or tripods to get them into the desired positions.

  For details, see "Subject and reflective sphere setup" on page 11.

- Lighting

  You must have a portable lighting unit of a type and intensity appropriate to the location and environmental conditions. For this technique, you can attach the lighting unit to a pole or monopod, and move it by hand into the general positions required for a complete set of images, in an imaginary hemisphere around the subject.

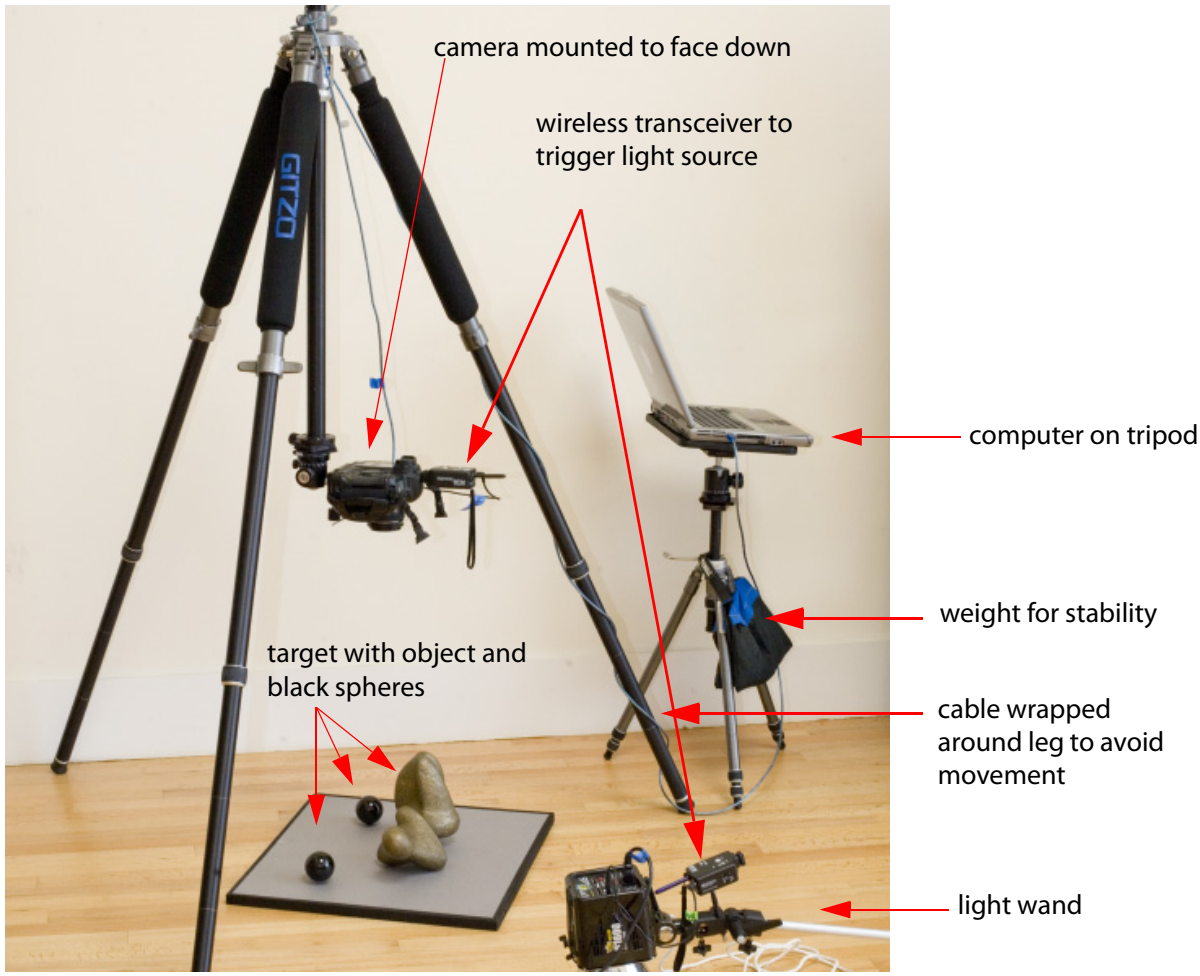
  The distance of the light from the object must be the same for all shots; you can easily measure it with a string.

  For details, see "Lighting setup" on page 17.

- Computer

  If you are using a computer to control the camera, it must be near enough to connect and be easily accessible, but it must be placed out of the way of the object, camera, and lighting area. You can mount it on any stable surface. In outdoor field situations, it is useful to mount it on another tripod stabilized by weights or sandbags.

  Connect the camera to the computer through a USB cable, as shown in "Camera setup" on page 6, and install the camera-control application for your camera; see "Computer software setup (optional)" on page 22. You must also install the capture and post-processing software that we provide, and the viewer application that allows you to view your RTI images. See "Computer software setup (optional)" on page 22.



Starter Kit

For convenience, Cultural Heritage Imaging offers an RTI Highlight Capture Starter Kit that is designed to get you up and running quickly. It contains all the parts you need to capture images for RTI using the highlight method.

For complete details, see http://culturalheritageimaging.org/rti-kit.

CHI Forums

As a public service, Cultural Heritage Imaging hosts and maintains a set of online forums, intended for the community of users, developers and others interested in Reflectance Transformation Imaging (RTI), Algorithmic Rendering, and related computational photography techniques.

In order to post in the forums, you must sign up for and verify an account, but there are no fees or other requirements for membership. Except for the Announcements section, posts are not moderated, but CHI staff monitors the forums and warns users who post inappropriately.

You can see a short description of the existing topic areas here:

http://forums.culturalheritageimaging.org/

We welcome suggestions for additional topic areas. If you have private comments or suggestions, send e-mail to: `forums@c-h-i.org`

Camera setup

You must set the digital camera on a tripod or camera stand for stability; it is very important that there be no movement or vibration of either the camera or subject. You can mount the camera directly on the ball head (mounted on the top of the tripod or at the bottom of the central column).

There are many possible configurations, depending on the size, portability, and positioning of the target object. Some possibilities are shown in these illustrations.

Mounting the camera

Before you mount the camera, attach the lens and any filters you are planning to use.

You can mount the camera directly on a ball head on the tripod, or you can attach a plate to the camera and attach that to a clamp that you mount on the ball head, as shown here. The plate-and-clamp setup can make it easier to mount and unmount the camera, and it can also make the camera more stable.

You can attach the camera to a ball head on top of the tripod, for a vertical capture position (for paintings hanging on a wall, for instance), or you can attach the ball head and camera to the lower end of the tripod central column; see "Choosing a configuration" on page 8.

Here, the camera is mounted on the ball head on top of the tripod.

- The radio transmitter shown here is optional; see "Flash lighting options" on page 18.
- The USB cable attaches the camera to the computer; see "Connecting the computer and lights" on page 10.

Choosing a configuration

Configuring the camera and tripod depends on the size and portability of the target object, as well as what equipment you have available. Line up the plane of the camera to be parallel with the plane of the subject or subject detail you wish to photograph.

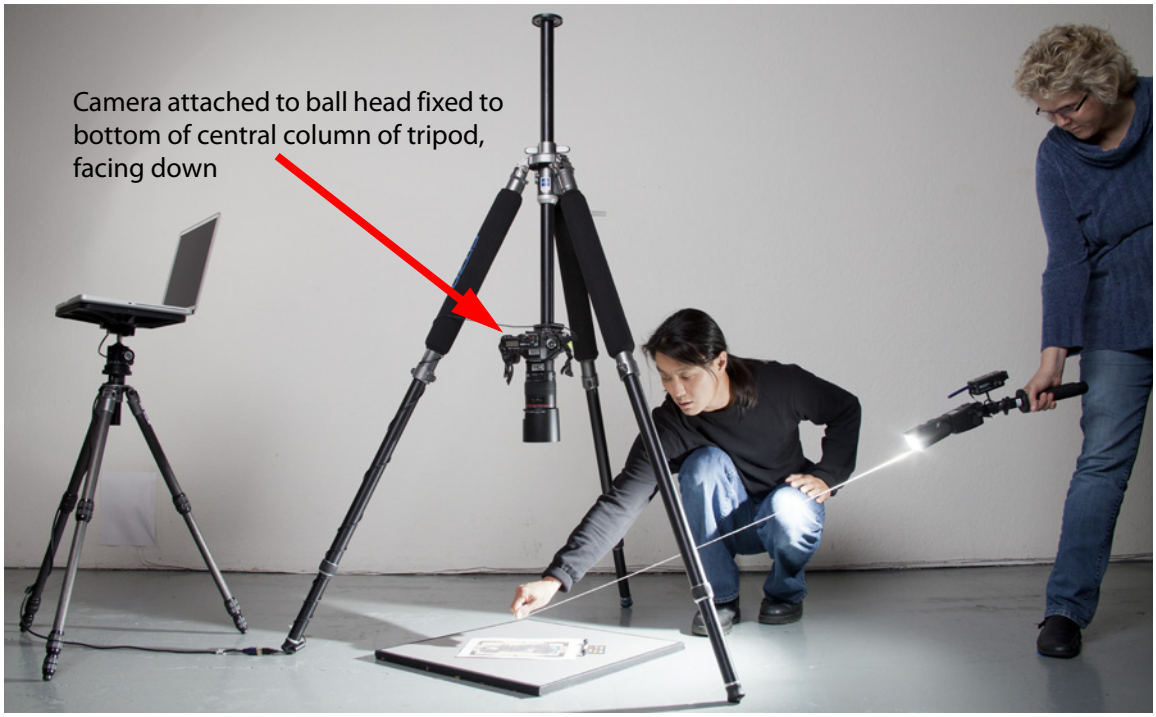
Vertical subject

To shoot a vertical subject, such as rock art or a painting hanging on a wall, mount the camera on a ball head on top of the tripod facing the subject.

Horizontal subject

To shoot a subject that is on a horizontal surface, mount the camera so that it views the subject from directly above.

Generally, the best choice for a horizontal subject is to mount a ball head upside down on the bottom of the tripod's central column, and rotate it so that the lens faces straight down. This creates the fewest shadows and makes positioning easier.



For larger objects, use a larger tripod. If the subject is too large for available tripods, you may need an alternative camera support, such as a cross bar, supported at both ends, with an attached camera clamp or ball head. The crossbar must be long enough so that the shadows from the cross bar supports are not a problem.

These cameras are mounted facing directly down onto the target object and spheres.

Always choose a configuration and position that minimizes any shadows cast from the tripod legs onto the subject, at any of the lighting angles.

If you find that you cannot avoid shadows at some lighting angles, do not shoot at those angles. If you get shadows on areas of interest in any of the images (from objects outside the target object such as tripod legs or spheres), discard those images during post-processing. Be careful to distinguish such shadows from those that a sculptural object might cast on itself.

Connecting the computer and lights

When the camera is approximately positioned, set the computer near the camera, and connect the camera to the computer with the USB computer-control cable. We recommend using the computer to control the camera settings and trigger the shutter and lights, in order to prevent any camera movement. Alternatively, you can use a remote trigger; see "Triggering trade-offs" on page 30.

If you are using a flash, configure the camera to make sure that the camera's shutter synchronizes with the flash; see "Lighting setup" on page 17.

To finalize the camera position, you must adjust the relative positions of camera and subject in order to frame the subject correctly in the camera's view, as discussed in "Setting up the capture session" on page 23.

Stabilizing the camera assembly

It is essential that the camera not move at all during shooting. Set the tripod legs as wide apart as necessary to prevent shadows, but make every effort to maximize stability. When you have framed the subject correctly in the camera's view, tighten all the clamps and mounting screws. Once everything is correctly framed, you should adjust nothing but the camera focus.

Always use remote triggering of the camera shutter. You can use the camera control software to trigger the shutter (see "Computer software setup (optional)" on page 22), or you can use a remote shutter release. If you use a remote shutter release, it can be wireless or wired. Wireless is preferred, but if you must use a wire or cable release, make sure the wire or cable is securely attached to something stable and out of the way, so that shutter release causes no movement or vibration.

Use weights to stabilize the camera assembly and eliminate all movement and vibration.

- Drape sandbags over the tripod legs when they are widely separated.
- If the camera is mounted on top of the tripod, you can hang a weight from a center-column hook inserted in the bottom of the tripod shaft. This is very good for stabilizing the weight of a large camera.
- You can also use weights around the feet of the tripod, particularly in an outdoor environment.

stabilizing sandbag on tripod leg

sandbags mounted on center column of tripods to stabilize both camera and computer

Subject and reflective sphere setup

Use a neutral background; colored backgrounds can reflect their color onto the subject. Try to use a white, black, or gray neutral background (as appropriate for contrast with the target object). If the subject is suitable for placement on a flat surface, you can set it on a neutrally colored cloth or surface. Similarly, if it is upright, try to create a neutral background if possible, by hanging it on a neutrally colored wall or setting up a sheet or board behind it.

A neutral *gray card* (18% gray), or photographic reference card that includes a scale of neutral grays with known values, is essential for proper color balancing, and it can also be used as a valuable reference for determining proper exposure. You must include a gray card or scale in at least one image shot during the session. You can shoot it separately from the RTI sequence; see "White balance" on page 28 for suggested gray targets and their use.

You must set up the subject area so that the camera's field of view contains both the target subject and the two reflective spheres. The reflections of the light source on each sphere in each image tell the processing software the exact angle of the light for that image. The size and position of the spheres depends on the size and shape of the subject. The diameter of each sphere should be at least 250 pixels in the image.

You will need some or all of this equipment to set up the target area:

- Reflective black spheres in several sizes (such as snooker ball or ball bearing). You may need to modify the spheres so that they can be attached to holders. See "Mounting the spheres" on page 12.
- For larger spheres, use a tripod or light stand, with a ball head and clamp or umbrella clamp light holder, and a boom arm of adjustable length. You must be able to attach a sphere to one end of the arm or rod, and attach the other end to the light stand or tripod. Be very careful, especially if you use weights for stabilization, that the sphere setup cannot tip over and damage the subject.

The size of the spheres you use depends on the size of the subject. The sphere diameter in an image should be at least 250 pixels wide. It can be smaller and still work, but the resulting light-direction data is less precise. The pixel size of the sphere in the image depends on the resolution of your camera.

Any pixel size larger than 250 is fine for RTI calculation, but if your spheres are too large, they can take up more of the image area than is necessary, requiring you to crop more data out of the images, and also increase the size of the shadows that you will need to keep off the target area.

For small objects, you might use ceramic ball bearings (like those included in the RTI starter kit). For larger objects, you can use billiard balls or larger spheres. The spheres should be reflective black.

Mounting the spheres

The way in which you mount the black spheres depends on their size and where they must be positioned to be near the subject. There are two general ways to mount them; you can set them on a small, stable stand near the subject, or you can extend them into the camera's field of view on a pole or rod. Various kinds of mounting hardware are included in the RTI starter kit available from Cultural Heritage Imaging (see "Starter Kit" on page 5).

- You can place small spheres and ball bearings on washers, brass studs, or other small discs to support them during the capture sequence. However you choose to mount them, make sure they are stable and never move at all during the capture sequence.

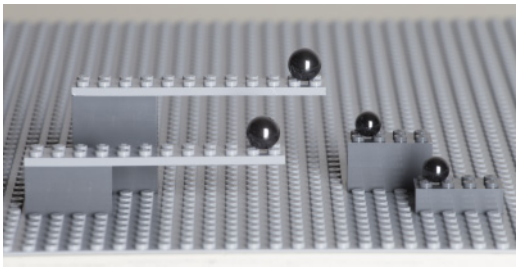
Here, 2.25" and 1" spheres are sitting on finish washers.

A pair of spheres in each of these sizes, as well as the finish washers, are included in the RTI starter kit.

- You can glue small spheres and ball bearings directly to small sticks or rods (such as chopsticks or skewers), and mount these to clamps on tripods or other structures.

These spheres are hot-glued to the ends of wooden dowels and mounted on a device called a Grip-It.

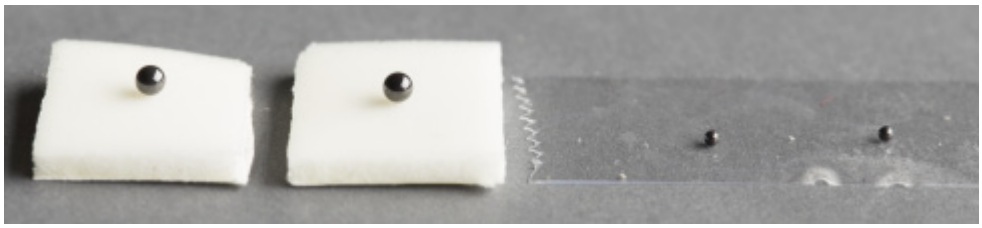
- You can use Lego blocks to place small spheres for horizontal subjects.



You can use additional blocks to raise the spheres to the required height. These mounts are snapped to a Lego board, but they can also be free standing.

Use all gray, black, or white blocks. Do *not* use colored blocks; they can produce a color cast onto your subject.

- For small spheres, you can use double-sided sticky tape.

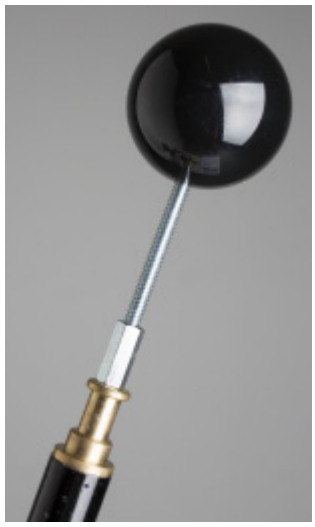


These tiny spheres are held in place with double-sided tape.
These sphere pairs from the RTI starter kit are 1/16" (1.588mm) and 1/32" (0.79375mm).

- For larger spheres, you can drill and tap into the spheres in order to insert 1/4 by 20 inch threaded metal rods, which you can then attach to extendable booms, mounting plates, and other structures.

A sphere that has been tapped can be screwed onto a brass fitting and attached to an extendable arm or rod.

For a very inexpensive rod that can be easily attached to the sphere, you can use 1/4 by 20" *threaded stock,* found in most hardware stores.



This 3" threaded rod and coupler bolt are part of the RTI starter kit. The coupler bolt can attach to any 1/4 by 20" threaded photographic fitting.

A good choice for attaching a rod to a light stand is an inexpensive *umbrella adapter*, found in photography supply stores. Attach a threaded rod or extendable arm to one end of the umbrella adapter, and clamp the other end to the light stand or other positioning device.

This elbow is made from a Manfrotto Super Clamp and umbrella adapter for a light stand.

You can insert a simple threaded rod or extendable arm to make a boom arm for holding a sphere in position.

spheres mounted on extendable arms allow for flexible sphere placement

Both spheres are attached to the arms using a coupler bolt and 3" threaded rod that are included in the RTI starter kit.

The upper arm is attached directly to the ball head on top of the tripod.

The clamp and umbrella adapter are used to attach the extendable arm to the tripod leg for the lower sphere.

Placing the spheres

As with the various camera setups, you must adjust the sphere configuration according to the circumstances of the subject and environment. Look through the camera lens to determine a suitable position for the spheres.

During post-processing, you will crop out the reflective spheres from the images; this is something to keep in mind when positioning them. They must be close enough to the subject so that the camera can focus on both the spheres and the subject with sufficient depth of field, but far enough away so that you can crop them out of the image without losing any image data for the subject itself. All of each sphere must appear in the image; make sure the edge of the image does not cut off any part of the spheres.

If you use a light stand and extending pole to support a black sphere in the camera frame:

- Adjust the stand's legs to make it stable. As with the camera, it is important that the spheres not move at all while you are capturing the images.
- You can slide the extendable pole's mounting plate into the stand's ball head clamp, or if there is no mounting plate, insert it into the top half of the umbrella clamp.
- Attach the black sphere onto the far end of the extendable pole.

Position the entire assembly so that the black sphere extends into the desired area of the image composition, close to the photographic subject.

- Looking at the camera's view, position the sphere in a corner of the shot, where it can be cropped out without losing any of the object data. Keep in mind that the easiest way to crop is to specify a rectangular area around the object, although a "free-hand" crop function is also available in the image-processing tool.
- Consider how the shadows of the spheres will fall on your object with the light source at different angles, and try to minimize these shadows.

The crop rectangle shows how the reflective spheres are cropped out of the captured images.

The black spheres for these shots are glued to wooden dowels.

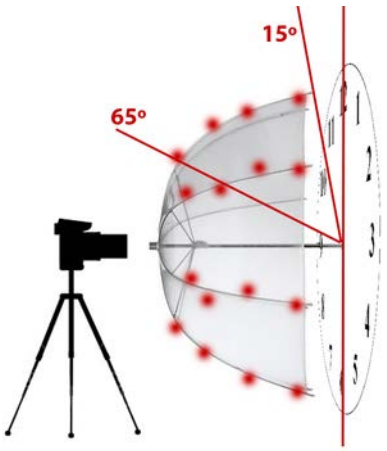
Notice how the spheres are placed so that the shadows cast by the spheres and supporting dowels do not fall on any areas of interest in the subject itself.

- You should also consider the depth of field when placing spheres. The top third of each sphere (that is, the third closest to the camera) must be in focus when the subject is in focus. Take test shots, and adjust the height of the spheres if necessary. You might need to adjust how the spheres are mounted in order to get them at the right height.

After adjusting the placement and angles of all the components, tighten all the clamps or mounting screws to stabilize the setup, and add weight to the light stand to increase stability.

Lighting setup

In order to build an RTI using the highlight method, you move the light source to an approximate position in a flexible sampling pattern before each shot, to create a hemispherical set of lighting samples around your photographic subject.



The lighting samples cover a range of inclination angles from 15 degrees above the horizon to 65 degrees above the horizon, and an even sampling around the subject, all at a fixed distance from the subject (which you can measure simply with a string).

For more about the specific angles, see "Capturing images" on page 29.

To do this, you must have a portable light source. For larger subjects, place the light on an extendable arm. You will have to position it higher than you can reach for some of the shots.

The type and intensity of the lighting you need varies according to whether you are photographing indoors or out, and the size of the subject. Indoors, you can plug the light into the wall or a power strip. In the field, you can use a battery pack or a generator.

There are two basic light source types; continuous lights, and flash or strobe lights. Each type has its own advantages and disadvantages:

- Continuous lights can be aimed quickly and accurately at the center of the subject, permit longer exposures if more light is required, and do not need to be synchronized to the camera shutter.

  Continuous light is easy to work with if you are indoors, have control over ambient illumination, and have appropriate power. It doesn't work well in location settings where you might not have a generator and can run out of batteries. You have to manage a power cord (although this is also required with the larger studio flashes). If you use continuous light, you must ensure that it is completely stable and does not move, especially if you are using longer shutter speeds.

  Continuous lights also tend to get hot, which can make them more difficult to work with. You also have to think about the potential for photonic damage to the target object, and whether a continuous light might damage it due to the amount of time the light is pointing at the subject.

- Flash units are nearly always required in high ambient-light environments (such as outdoors in daylight), and are often better for shooting large objects. The extreme brightness of a flash can overpower the unwanted effects of the ambient illumination, as long as the shutter speed and

aperture combination that you choose does not record an image without flash. See "Setting exposure: shutter and aperture settings" on page 26. Flash units also use less electricity than similarly-powered continuous lights, which can be important when working on location away from the power grid.

An advantage of flash units is that they fire a very brief burst of light, which limits the amount of potentially damaging light on the target object. If you are working with paintings or paper objects, this can be an important concern.

The most portable option with the fewest cords is a camera-mountable flash unit (a Canon Speedlite or Nikon Speedlight*)* with an infrared or wireless radio trigger, and a battery pack attached to the flash unit (that is, mounted in an off-camera flash configuration). This is suitable for subjects less than a meter in diameter.

Lighting equipment

You will need some or all of this equipment to set up your lighting assembly:

- A lighting unit, with a battery pack or power cord.
  - For flash lighting, a triggering system. This can be a wireless transmitter and receiver for radio flash triggering, an infrared trigger for a remote camera flash, or a sync cable directly connecting the flash unit to the camera. See "Flash lighting options" below.
- A UV filter for the light, if the subject requires it. This is recommended in most cases. The RTI starter kit includes clear UV filtering Acrylite (OP-3) that has been precut to fit the face of Speedlights.
- An adjustable monopod or minipod (such as the one included in the RTI starter kit).
- A piece of string, rope, or cord approximately 2 to 4 times the diagonal measurement of the object or object detail you wish to image. You will use this to maintain the correct distance from the light to the subject for each shot; see "Setting up light-to-subject distance" on page 23.

Flash lighting options

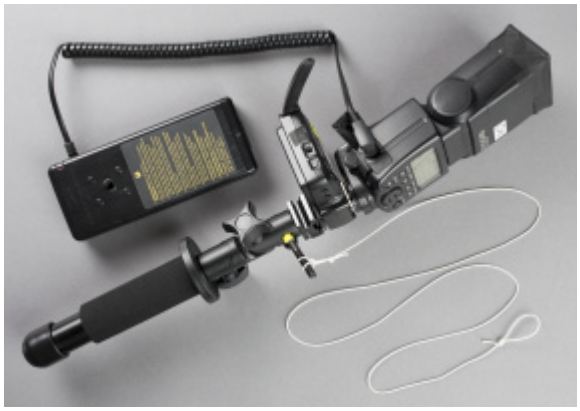
If you use a flash or strobe, you must connect it to the camera so that it flashes when the shutter is open, capturing each image. (You will be triggering the camera remotely; see "Triggering trade-offs" on page 30). The most inexpensive way to do this is to attach the light directly to the camera with a sync cable. Alternatively, you can use a wireless transmitter for radio flash triggering (such as a PocketWizard wireless transmitter and receiver), attached to the light by a sync cable, or using a hot-shoe mount. This works well with a studio light, such as AlienBees B1600 with a 5600° K daylight-balanced flash tube light. (Some newer cameras and flashes are preconfigured to communicate wirelessly, so you don't have to worry about this.)

The sync cable is cheaper than a radio trigger, and you might want to have it as a backup, even if you use a radio trigger. However, it adds an extra cable to keep track of as you move the light into its capture positions. A sync cable should be at least 25 feet in length. You must be very careful to secure the end of the cable near the camera, so that movement in the cable is not transferred to the camera. Any movement will ruin the entire sequence. You can use tape, for example, or BongoTies such as those in the RTI starter kit.

You can use a radio trigger with a flash that would normally be placed in the camera's hot shoe. You can also use a simpler infrared trigger, which is cheaper than a pair of radio triggers. If you are using a flash or strobe unit:

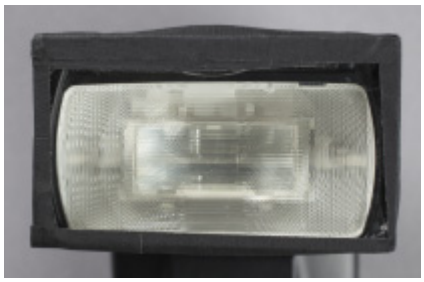
1. Attach the infrared or wireless trigger unit to the hot shoe of the camera.
2. Use the same channel for the transmitter and the receiver.
3. Set the flash to Manual mode and dial in the flash exposure that you establish with a test shot.
4. Set the flash to the widest beam spread, such as the 24mm setting on the Canon Speedlite.

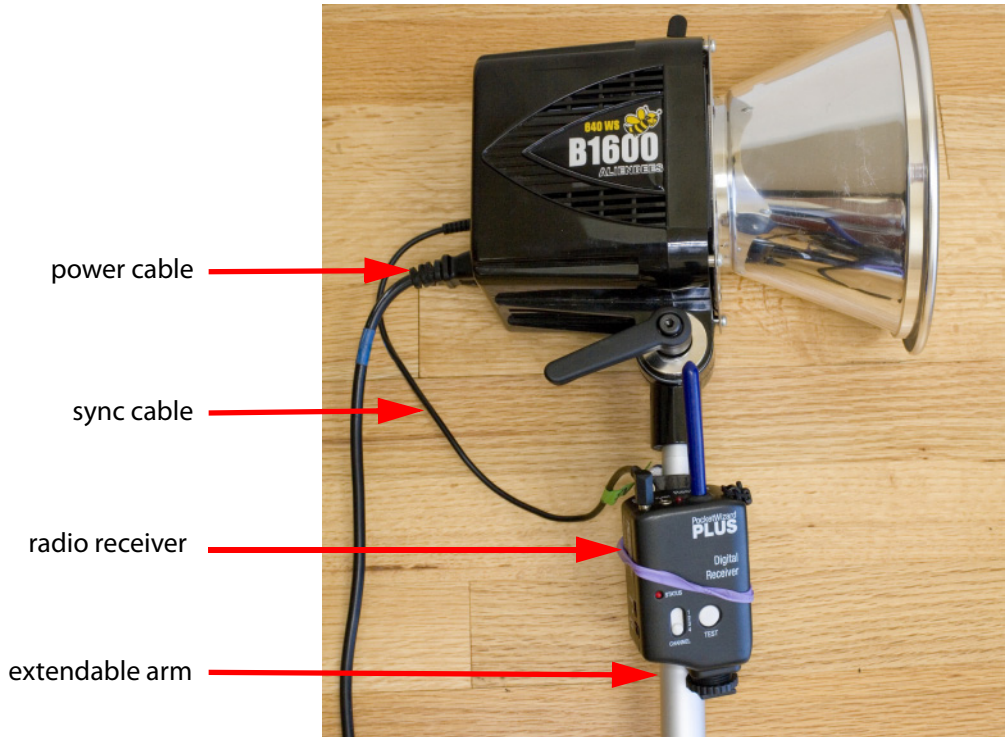
Whichever system you choose, attach the lighting unit and transceiver or sync cable to the monopod or minipod; some options are shown here. When you have connected the power pack to the light unit by whatever system you have decided on, you should test the flash.

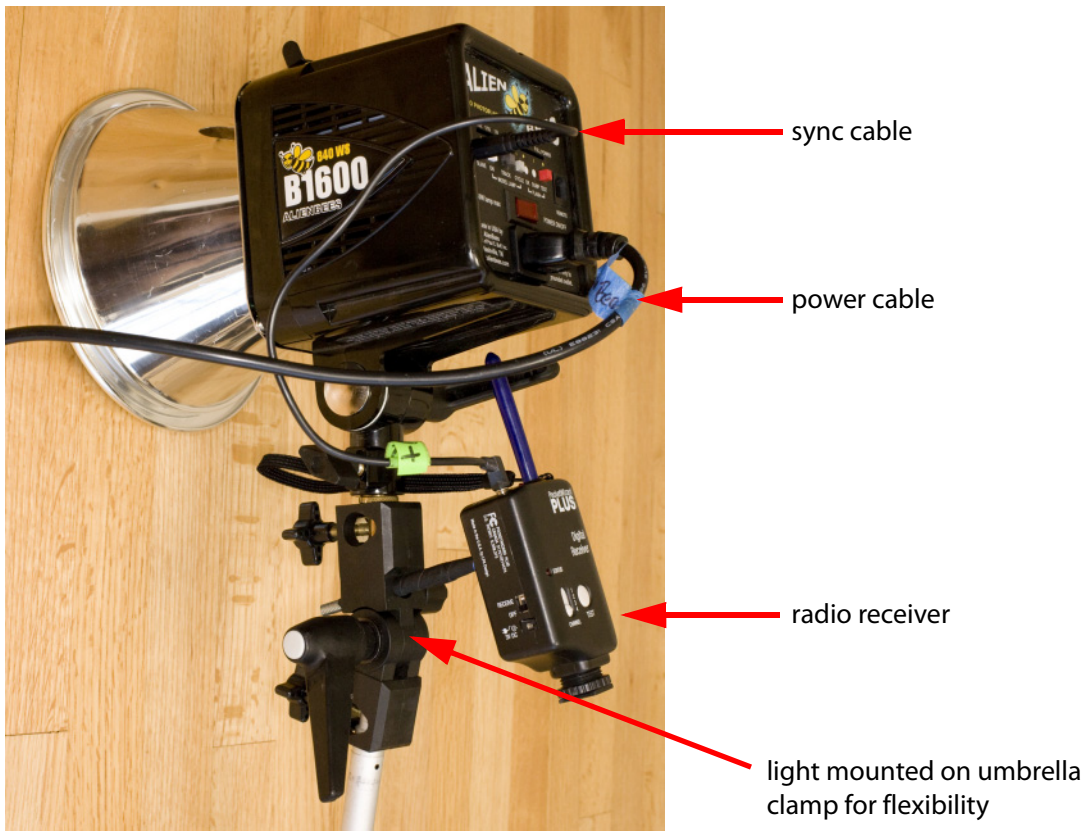


This lighting unit incorporates parts from the RTI starter kit (umbrella adapter, minipod, bolt with distance string) with a Canon 580EX II Speedlite flash unit, a CP-E4 battery pack, and PocketWizard TT5 (which are not included in the kit).

Here, clear pre-cut UV filtering Acrylite (OP-3) has been taped to the front of the flash in order to protect the subject from UV wavelengths. This filter is part of the RTI starter kit.




power cable
sync cable
radio receiver
extendable arm


sync cable
power cable
radio receiver
light mounted on umbrella clamp for flexibility

Testing the light model for shadows

Light stands, tripods, cables, and other tools and equipment can cast shadows on your subject while photographing it. Try to minimize the effects of shadowing by positioning your spheres carefully.

When you have set up and tested the lighting unit, you can test for shadows. Use a bright flashlight to move the light around the subject, looking for angles that create excessive shadowing on the subject. Rearrange the target, camera, or sphere placement to reduce or eliminate these shadows, if possible. If you cannot eliminate them, note these light locations and avoid using them during the image capture and testing sequences.

Shadows can be cast into the target area by the reflective spheres, or by other elements of the setup, such as tripod legs, cables, or easels.

Some objects, such as sculptures, might cast shadows onto themselves, which is fine. Just try to eliminate shadows from outside the subject.

Computer software setup (optional)

We recommend that you perform your RTI capture sequence with the camera tethered to a computer. This allows you to take test shots and look at the results of full size images to check focus and exposure. It also allows you to name the images and set where they are downloaded on your computer.

If you choose to capture your images without a computer, you will need to check everything using the LCD display on the back of the camera. This approach is a bit more error prone, especially if you are just learning RTI. You will need to set up a computer at some point to process the captured images; in either case, we recommend that you create a capture folder to contain all the relevant tools or shortcuts to them.

If you use the computer for image capture, you must install the camera control application for your camera (such as the Canon EOS Utility or Camera Control Pro 2 for Nikon) in order to adjust camera settings and to set the image storage location.

- You can use the camera control application to set up the focus on the target and spheres, the exposure, and the depth of field. The Live View feature in the Canon and Nikon camera-control utilities shows you on the computer screen the same image you would see on the camera's LCD, and shows the effects of settings in real time. See "Performing Highlight Image Capture" on page 23.

- You can also use the camera control application to trigger shutter release when capturing images. Alternatively, you can use a remote shutter release, which can be wireless or wired. If you use a wired remote shutter release, you must be very careful to set it up in a way that avoids any movement or vibration. See "Stabilizing the camera assembly" on page 10.

You will also need software that allows you to review the test images on your computer. If you shoot in the camera's RAW format (which we recommend), you need software that can read your camera's RAW format (such as `.cr2` for Canon and `.nef` for Nikon). The application you use should allow you to adjust factors such as brightness, although you do not apply any image processing tools until after image capture is completed. When preparing for image capture, you use the software to review test images (with no processing) to make sure you have the best possible focus and exposure to start with.

For more information on how to use your software tools for setting up and performing image capture, see "Performing Highlight Image Capture" on page 23.

Computer setup for post-processing

You will need the following tools for post-processing. They do not need to be installed for image capture, and they do not necessarily have to be installed on the same computer:

- Tools for converting RAW files to the recommended Digital Negative Converter (DNG) format. Adobe products such as Photoshop, Lightroom and Adobe Bridge include Adobe Camera Raw, which is an environment for doing this conversion, as well as for making adjustments to images.

  If you do not have these products, there is a free DNG converter which can be used to convert your camera RAW files to DNG. This tool does not include support for adjusting images or creating the JPEG files that you need for later processing. Download the converter from: http://www.adobe.com/support/downloads/detail.jsp?ftpID=5486

- RTIBuilder, used to process images to produce RTIs.

- RTIViewer or another PTM or RTI viewing program, used to view the result.

For more information on these tools and how to use them, see: http://culturalheritageimaging.org/What_We_Offer/Downloads/Process/index.html

Performing Highlight Image Capture

You should establish a naming convention for the folders in which initial images are stored, and for the file names of the captured images. Choose names that unambiguously identify the subject and circumstances. For the image name template, specify a file name postfix of an underscore and a 2-digit serial number. Do not use spaces or special characters (other than underscores or dashes) in file or folder names.

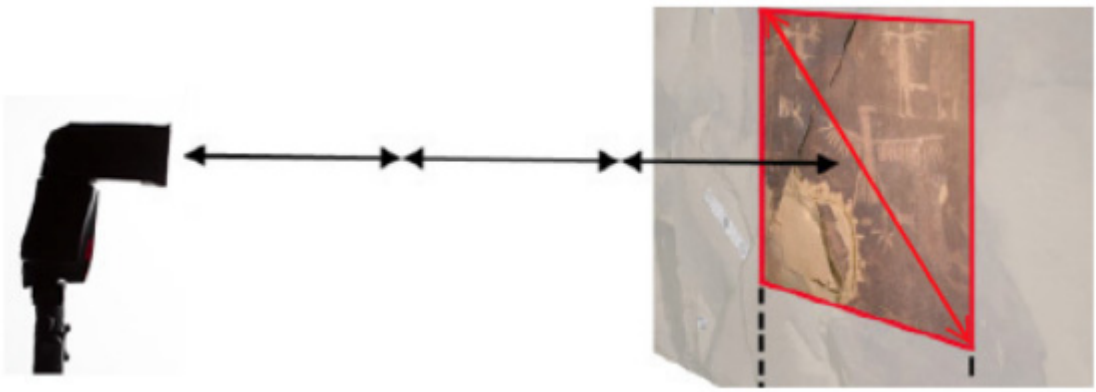
Setting up the capture session

Some preparation applies to all situations, while other actions only apply when you are running tethered to a computer. In all cases:

1. Check that the camera battery is fully charged, or use an AC adapter plugged into a power outlet.
2. Turn the camera on.
3. Set the camera to never turn itself off.
4. Set the camera to Manual mode.
5. We highly recommend that you set the camera to capture RAW files (for both the test shots and the capture sequence). For more information, see "Quality trade-offs" on page 31.
6. Make sure the subject area is properly framed in the camera's view.
7. Determine and mark the optimal subject-to-light distance on the string; see "Setting up light-to-subject distance" below.
8. Take test shots to adjust the focus and exposure. See "Taking test shots for focus and exposure" on page 25.

Setting up light-to-subject distance

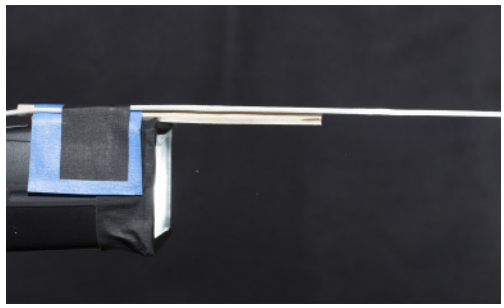
Set the light distance at 2 to 4 times the diagonal size of the target object (or portion of the object being shot). If it is impossible to set the object at this distance, try to set it as far away from the light as possible. The minimum distance is twice the diagonal size of the object.

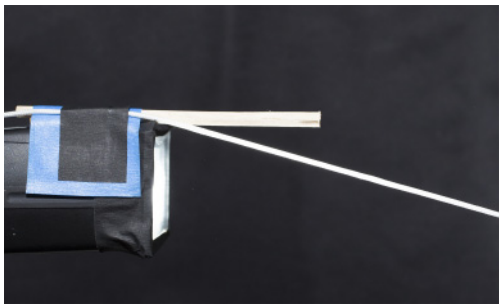


Many high-tech distance measuring methods have been evaluated, including lasers and image processing methods determining light intensity. A string (affectionately called "the Egyptian Method") has proved to be the most efficient. If you are using a string or rope, tie it or tape it to an area near the front of the flash. You can tape a short, straight stick to the front of the flash to use as an aiming guide.

Here, a guide stick is taped to the front of the flash, along with the string. This makes it much easier to see the angle of the string with respect to the direction of the light.

Notice how the string goes straight out along the guide, without making an angle to it.





Here, you can see that the string is at an angle to the guide, which shows that the light is not pointing directly at the target.

During your test shots, when you are setting the focus and depth of field, extend the string to an area safely above the center of photographic subject, and mark the distance. You can, for instance, tie a knot in a small string, or mark the distance with a piece of tape on the string.

You typically need one person to hold the string end at the correct location by the subject, while another person positions the light at the correct distance and angle for each shot. For small objects, where the string length is only a few feet, one person can hold both the string and the light.

Make sure to move the string out of the shot before capturing the image.

Taking test shots for focus and exposure

You can use autofocus with a focusing light to get an approximate focus, then switch the lens to manual focus (MF) mode for your test shots, so that the camera does not automatically change the focus.

For larger objects that are farther away, the result of autofocus may be good enough. For smaller objects and macro work, you will probably need to refine the focus manually. In any case, the lens must be set to manual focus before you actually begin image capture.

When you have finished taking your test shots, always make sure that the lens is in manual focus mode, so that it does not automatically refocus. You have to set manual focus mode with the physical switch on the lens; be very careful that the focus ring on the lens, and the camera itself, do *not move* when you do this.

In addition to refining the focus, use the test shots to check the exposure. See "Setting exposure: shutter and aperture settings" on page 26.

- If you are not using a computer, use the image and histogram on the back of the camera to check the focus and exposure.
- When using a computer, there is a little more setup before you take your test shots:
  - Make sure the camera is connected to the computer with the USB cable, and turn both the camera and the computer on.
  - Start the camera control application.
  - Create a folder in which to store the captured images, named according to your own naming convention. (You will take a set of test images first, but you don't need to keep them.)

Be sure to specify this folder as the storage location for the session in your camera-control utility. Set the filename template here as well. Typically, you will have a folder for the project, with a subfolder for the capture session, named "original-captures".

- ▷ Enable Live View and switch the lens to autofocus (AF) mode. Use autofocus to get an approximate focus, then switch the lens to manual focus (MF) mode for your test shots and fine-tune your focus while viewing an area of interest in your subject at full resolution in the Live View window.
- ▷ Use the settings screen of your camera-control utility to set the proper exposure; see "Setting exposure: shutter and aperture settings" below and"White balance" on page 28 .

Take test shots in RAW format. You can then use Adobe Camera Raw (ACR) or a similar tool to check or set the final focus and exposure settings and to correct white balance.

When you have adjusted focus and exposure, you are ready to start your actual capture session; see "Capture sequence" on page 30.

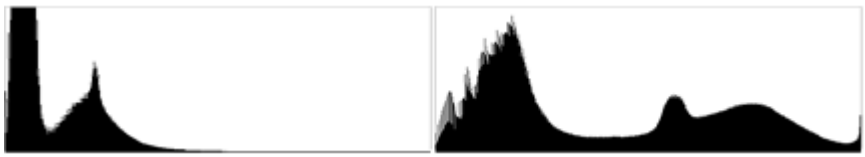
Setting exposure: shutter and aperture settings

In addition to accurate focus, RTI photography requires the optimum combination of light intensity, shutter speed, and aperture. Your goal is to have every element of the subject and the front third of the black spheres in focus and visible, and to collect as much light as possible while avoiding under-exposure and over-exposure at the extremes.

- ▶ For optimum performance from your lens, avoid using apertures smaller than f/11 (depending on your lens). Smaller apertures (higher f/numbers) can result in degradation of the image; the overall depth of field is increased, but you lose sharpness. You can research "lens diffraction" for more details of why this is so. A good target aperture range is between f/5.6 and f/11, if possible.
- ▶ Determining exposure always requires two test shots, one with the light at 65 degrees, and the other with the light at 15 degrees. You must take both shots using the same shutter speed (or flash power) and the same aperture. Make sure the camera is in manual exposure mode.
- ▶ After you have determined the proper exposure, take an additional test exposure without the flash, to be sure there is no ambient illumination affecting the image. This test shot should appear totally black.

Checking exposure with the histogram

If you are running untethered to the computer, you can use the camera's histogram to check the exposures of the lightest and the darkest images, and to make sure that no whites are blown out, and no shadows are too dark. The lightest image is the one taken with the light nearest the zenith (at 65 degrees inclination), and the darkest is the one taken with the light nearest the horizon (at 15 degrees inclination).



These histograms, for example, show how the entire usable exposure range is bracketed by the extremes of inclination. The histogram on the left shows the darkest image, where the black end of the range predominates. The one on the right shows the lightest image, in which there is a good spread of light and dark usage all the way to the white side, but very few all-white pixels. A spike at the white end would

indicate blown-out portions of the image due to over-exposure. There could be a few pixels that are all white that represent the highlights on the sphere.

If the subject is very light or very dark, you might have to adjust the exposure range by continuing to check the histogram for a high and low angle shot, as the results from the usual balancing methods might not be accurate.

When you have set everything up, take a test shot without any flash or other lighting, and look at the histogram again to check for ambient light leakage into the image. If necessary, use a neutral density filter to block ambient light, and recheck your lighted exposures with the filter.

Checking exposure with a computer

This method relies on the use of standardized neutral gray targets (see "White balance" on page 28). Before adjusting exposure in software, you must make sure that all standard default image control settings in the RAW processor are zeroed out, and any curves set to linear. This is described in more detail in the *Guide to Highlight Image Processing*; see "Post-processing the image set" on page 32.

Use your RAW processor to adjust exposure so that the gray values (expressed in RGB values) match the nominal values of the photographic reference target you are using.

You only need to use one patch in a grayscale. For example, with the X-Rite ColorChecker (or its smaller version in the X-Rite ColorChecker Passport), you can use the N8 patch (light gray adjacent to the white patch) and set to an RGB value of 200. The AIC PhD target (which uses X-Rite patches) is used similarly, but it is particularly convenient because its linear proportions allow it to remain within the field of view where it can also display other identifying information.

To determine exposure by this method:

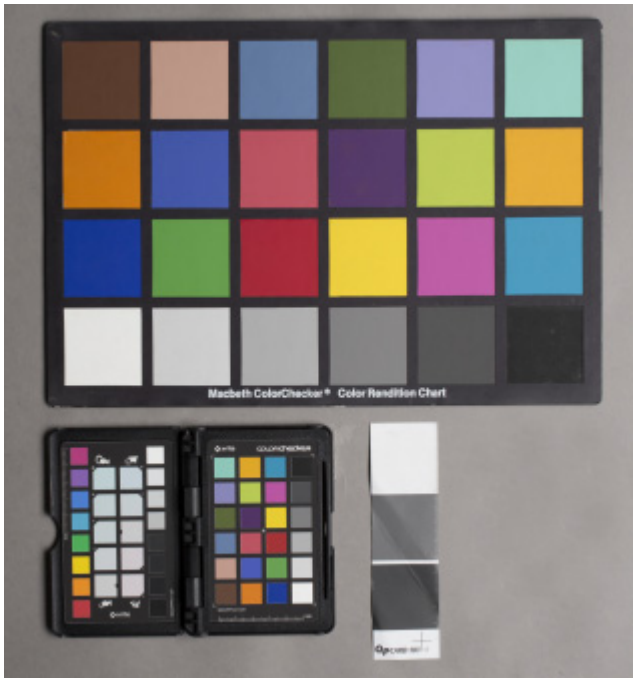
- Place the gray card or the grayscale portion of a color card in the field of view along with the subject, in such a way that you can crop out the card if desired. Sometimes, particularly with small subjects, it is hard to fit the entire grayscale into the image's field of view. In this case, hold the card slightly above the subject in order to take a test shot that includes at least the reference gray patch on the card.
- Take the two test shots, one with the light at 65 degrees, and the other with the light at 15 degrees. You must take both shots using the same shutter speed (or flash power) and the same aperture. In order to do this, you must make sure the camera is in manual exposure mode.
    - If using flash, set the flash to the power setting recommended by the flash unit's aperture/distance reference scale if available; otherwise, set the flash at full power.
    - If using a continuous light source, set the camera manually to the exposure indicated with the light held at 65 degrees.
- Open both images in your RAW processor and zero any default settings.
    - Adjust exposure using the Exposure slider until the appropriate RGB values for the reference gray are reached in the 65 degree image.
    - Synchronize the 15 degree image to that exposure and check that the image is satisfactory for that lighting position as well. It is much darker, but not so dark that important information is lost.
    - Do not expect the gray values in the two images to match; they must not. The RTI software expects a light-to-dark exposure variation within the set of captured images. If the gray values DO match, then your flash is likely set to automatic exposure, resulting in unusable capture images.

White balance

Take one shot of your neutral grayscale or neutral gray reference card, using your RTI light source at the highest angle (65 degrees) to establish the correct color balance. You will use this in post-processing to correct the white balance of the entire image sequence. Make sure your gray card or color card is intended for digital photography -- a card meant for film will result in inaccurate colors.

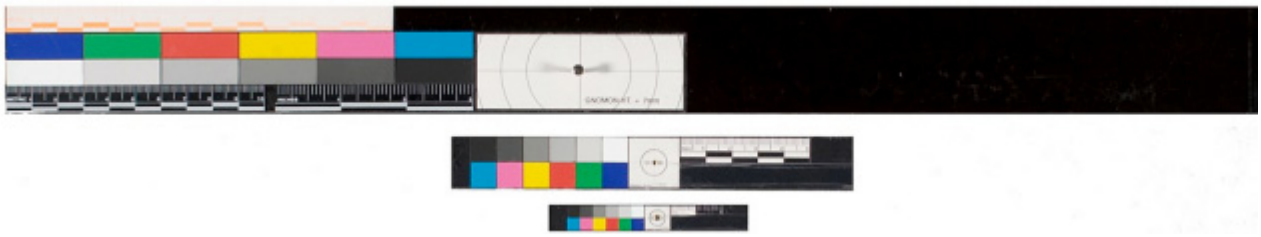
If you don't want the grayscale to appear in your final images, you can do this as a test shot; if the grayscale remains in the image set, use only the one taken at the highest angle for white balancing. Make sure that this image is correctly exposed before proceeding.

- Open the image in your RAW processing software.
- If using a grayscale card, use only the lighter gray patches for white balancing; do not choose the white patch or the dark gray or black patches.
- Check the RGB values of the neutral gray. The three numbers should match closely, at least within 5 units. If they do not, use the white balance tool in your RAW processor to bring it to neutrality.
- Synchronize all exposures in your RTI image set to the corrected white balance.



Various kinds of color-balance and gray cards:

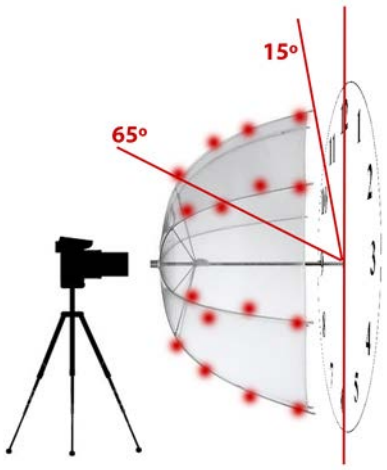
- *X-Rite ColorChecker Exposure Aid*, 8 1/2 x 11"
- (left) *QPcard QP101 Calibration Card*
- (right) *X-Rite ColorChecker Passport*
- Three sizes of the *AIC PhD Targets* (available from http://www.rmimaging.com/aic_phd.html)



Capturing images

To create an image sequence, you must take at least one shot with the light source at each position in an imaginary light dome around the object.

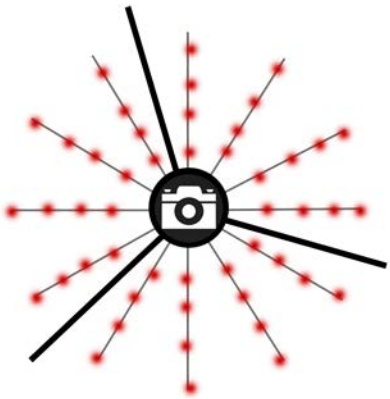
Imagine that the dome is like an umbrella, in which each rib extends from the center of the camera lens (the top of the umbrella) out to points surrounding the subject like the numbers on a clockface.



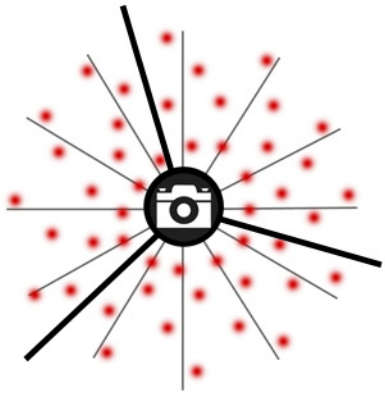
There should be 12 ribs; along each rib, there should 3-4 inclination points, depending on the desired quality (see "Quality trade-offs" on page 31). The ribs and inclination points should be at approximately equal distances from one another.

Considering the camera axis to be at 90 degrees from the subject, and the plane of the subject at 0 degrees, the lighting angles should be between 15 and 65 degrees.

For each shot, you move the light source to a point along a rib, from the lowest angle to the highest; then go over to the next rib and repeat, until you have gone all the way around. If you took each shot exactly along each rib, you would end up with a light spread like this:



Once you have developed the skill to place the light positions approximately along the ribs, then alternate the light positions from one side of the rib to the other, to get a spread more like this:



This is actually the effect you want, since it more closely approximates the perfect distribution of points that are all equidistant.

Capture sequence

1. Check your settings in the camera software to ensure that the values you chose during your test shots are still active.
2. If needed, brush dust, hair, and fiber out of the shot before capturing images.
3. Begin with the light at the 12 o'clock position (that is, along the first rib of the imaginary dome), and 15 degrees above the plane of the subject. Move the light to the correct distance as shown by the string. Position the light so that the center of the cone of light points directly at the subject and remains parallel to the string. When the position is established, move the string out of the shot.
4. To take the shot, trigger the camera from the computer, using the EOS Utility application, a trigger, or a timer device (see "Triggering trade-offs" below).
5. Move the light to the next inclination point along the 12 o'clock rib of the imaginary dome.
6. Use the string to ensure that the light is the same distance from the subject, and adjust if necessary. Do not let any part of the string brush against your subject as you are capturing images. Any movement of the subject during image capture affects image quality. Every time, make sure the string is out of the shot and is not placed where it can cast a shadow onto the target.
7. Wait several seconds after moving before you take the next shot; this reduces any vibration or movement. Hold the light as steady as possible before and during the shot. Take care not to brush the camera tripod or sphere mounts. (This helps protect the subject, as well as ensuring accurate images.)
8. Continue moving the light and taking shots through all ribs and inclination points, to create a collection of 24 to 60 images. You can take fewer shots and still get good results; more shots provide greater quality in the resulting RTI. See "Quality trade-offs" on page 31.

You can get usable data even for situations where some light positions are partially blocked; for example, if the subject is placed close to the ceiling, floor, or walls. If you can't get far enough away with the light in some positions, you can skip those positions. If a whole region of images is blocked, the RTI viewing software cannot show the light change in the direction you have not shot, but other directions still work correctly, and a usable normal field, suitable for mathematical enhancement, is created.

If you accidentally shoot the string or a hand, you don't need to start over; you can discard that image later. Simply take another shot from the same lighting angle. Similarly, you can discard images if you overshoot, or get too close to the horizon, or too close to the camera. The only reasons to start over are if something has moved or the batteries in the camera have died (since changing the battery moves the camera).

If any element moves (a sphere, the camera, or the subject), you must start over, unless you already have enough images for a usable data set. If you are not sure there was movement, make a note or take a picture of your hand to mark the point at which you think movement occurred, and continue with the rest of the sequence. You must then check the image sequence to see if movement did occur at the suspected point, and if it did, discard the images shot after the point of movement.

Triggering trade-offs

You must trigger the camera remotely to avoid movement, but you can use either the camera-control software on the computer, or a remote trigger for the camera.

We highly recommend shooting from the computer so that you can look at your test shots, get the focus right, and so on. Files are named automatically, and when you are done, all the data is on the computer in a standard location.

If you use a remote trigger, a wireless connection is preferred. If you must use a wired connection, be sure to tie down the cords carefully so as to prevent any movement or vibration of the camera.

If you choose to shoot an RTI sequence using a remote trigger, you should take test shots and look at the histogram on the camera. For larger, more distant subjects, you can often get a good enough focus using autofocus, then switch the lens to manual for the actual image sequence. For small objects, you generally need to take more test shots and make fine adjustments to get the correct focus and depth of field.

When you have finished taking test shots, shoot your hand or some other indicator, to provide an obvious visual cue for where the test images end and the session image sequence begins. This will make it much easier to sort out the images later. We have used a film clapper with a grease pencil to note this information, but anything will do.

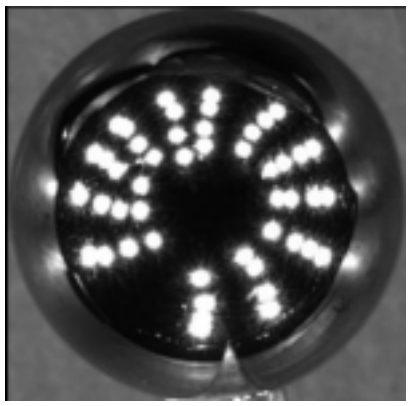
Quality trade-offs

Up to a point, the more images you capture, the higher the quality of the resulting RTI; that is, more input data allows the processing software to calculate more accurate normals and develop a better model for the surface topography of the object.

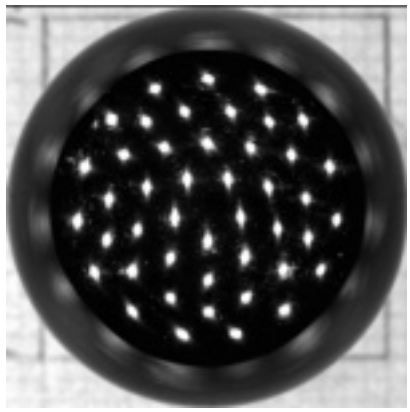
For interpretive purposes in RTI viewing software, this doesn't make too much difference, but if you want to use the data in subsequent algorithms, such as converting to 3D, or for measurement, you need more accurate normals.

Even with a small sample size, the normals are accurate relative to each other. The absolute accuracy, however (with respect to an input image with light from a particular angle), is less accurate with a smaller sample size. A large sample size means not just a greater number of images, but a greater sample of light directions around the hemisphere.

The accuracy of the light positions and their even distribution also affects the quality of the RTI. The following composite images of the light reflections in one of the reflective spheres show the distribution of source points for different capture methods.



This shows a regular distribution along each rib of an imaginary dome, with a space in the lower left quadrant where the camera stand prevented light placement. If a tripod is used to hold the camera, there are three such gaps.



This is the ideal distribution, created by a light dome that holds a set of individual lights, each in a specific location, and fires each light in sequence.

For best quality, we highly recommend shooting your images in the RAW format, although it is possible to shoot JPEG images and still produce an RTI.

One of many reasons to shoot RAW is that you have complete control of all processing applied to the image, and, very importantly, a record of the processing applied. If you shoot JPEG, the camera applies processing to the images according to its own algorithms. You cannot control it, and you do not have a record of what was done.

If you do decide to shoot JPEG images, choose the setting on your camera that reduces the amount of in-camera processing as much as possible. For more information about this trade-off, see this article in the CHI Forums:

http://forums.culturalheritageimaging.org/index.php?/topic/222-raw-v-jpeg/

Post-processing the image set

When you have finished acquiring the original images from the capture sequence, you must perform a set of post-processing operations to combine these images and ancillary data into the final RTI image file.

- You need to review the captured images for usability, add identifying metadata to each one, and create and save archival DNGs. You then convert the camera-raw or DNG files to JPEG format. The JPEG images are used to create the RTI.
- You use the RTIBuilder application to collect the data on the exact light direction for each image, which is computed from the highlights on the reflective spheres.
- When this is done, you can crop out the reflective spheres from the images.
- Finally, you use RTIBuilder to generate the final PTM or RTI file.

This subject is discussed in separate document, *Guide to Highlight Image Processing*. The software and documentation are available for download at:

http://culturalheritageimaging.org/What_We_Offer/Downloads/Process/index.html