The M Combo-Shot Procedure
(for V-STARS Version 4.5)
2007-10-09

Introduction

The M Combo-Shot procedure is used with the V-STARS Pro-Spot target projector in M-mode. This procedure is especially useful on shiny, highly-reflective objects and/or objects that have both very dark and very bright areas. Typically such objects cannot be completely measured in a single exposure because some areas are too overexposed while others are too dim.

M Combo-Shot mode greatly extends the dynamic range of Pro-Spot measurements. In single-shot mode, the maximum brightness ratio between the dimmest and brightest measurable targets is about 10 to 1. In Combo-Shot mode, this ratio can be greater than 4000 to 1!

M Combo-Shot mode works by taking a series of exposures in quick succession in which the Pro-Spot exposure is varied for each shot. The separate exposures are then combined together to measure the object. To use this method, the object, projector and cameras must not move for the entire series of exposures which typically only takes a few seconds. Therefore, it is important in Combo-Shot mode that all knobs and lock-downs on the tripods and equipment are tight. Also, the equipment and object should be on a stable platform.

This application note assumes you are familiar with normal operations of the Pro-Spot target projector and of the V-STARS software. If not, please refer to their manuals.

Throughout this guide **NOTE:** indicates particularly useful information. **WARNING!** is used when special attention should be paid to the information provided or else damage may result.

NOTE: To use M Combo-Shot mode, you must have INCA3 cameras and they must have firmware version 06.06.01A or greater installed. Also, you must use V-STARS Version 4.4SR2a or greater. However, there are many improvements in V-STARS Version 4.5 for the M Combo-Shot Procedure, and this manual is written for Version 4.5. If you are not able to use V-STARS Version 4.5, please refer to the earlier M Combo-Shot Procedure dated 2007-05-16   If you do not have the needed firmware or software versions, please contact GSI.

Triggering the projector

There are two ways to trigger the projector in Combo-Shot mode. The camera flashes can trigger the projector wirelessly using the projector's built-in flash sensor cell (this is the usual way in single-shot mode). However, this is not always desirable because sometimes, especially on shiny objects, the camera flashes can cause significant reflections on the object (called "hot-spots"). If this is the case, we recommend firing the camera flashes and projector separately. In this situation, you must fire the projector using the projector's sync cable.

NOTE: If your INCA3 firmware is version 06.06.01h or later and you are not operating wirelessly, you can plug the sync cable into either camera. Otherwise, the cable must be plugged into the SLAVE camera. (The MASTER camera has the **bold** lettering.   The SLAVE camera's lettering is not bolded.)   It does not harm the camera or projector if you plug the cable into the MASTER camera; the projector just will not fire, or will fire erratically depending on which version of firmware the cameras have.

Cell On   **Cell Off**   **Sync Cable**

When using the sync cable, you must turn off the projector's built-in flash sensor cell or the projector will still flash whenever the cameras flash. Turn the cell off by pushing the button in; the light will turn red.

When the camera flashes do not cause a problem with the exposure of the object, you can simply activate the projector's built-in flash sensor cell (push the button out and the light will turn green) and use the camera flashes to wirelessly fire the projector just like in single-shot mode. But be aware that this means the camera and projector will both flash ON EVERY PICTURE.   If the camera flashes do not cause a problem on the object, this way is recommended since wirelessly firing the projector is often more convenient than having to connect the projector sync cable to the slave camera.

In either case, the first picture flashed from each camera is used to orient all subsequent pictures from that camera. This is why everything must be stable throughout the entire sequence of pictures.

- **NOTE:** Even if all the projected dots on the object can be measured using a single exposure level, Comb-Shot Mode can still be very useful in two situations.
  1) **The camera flashes cause "hot-spots" on the object.** In this case, the first picture fires the camera flashes only (and so gets just the retro-targets needed to orient the cameras) while the second picture fires only the projector to get just the projected dots.
  2) **There are retro-reflective targets in the area where the dots are projected.** By firing just the camera flashes on the first shot, the projector dots do not interfere with the measurement of the retro-targets.

  For either of these two situations, use the "Dark and Flashes Not OK" standard settings as described in the next section.

Using Standard Settings

Setting the proper exposure settings for M Combo-Shot Mode can be challenging because the exposure depends on the material you are measuring. Fortunately, a template project and some standard settings are available to help you. These standard settings should work well for most situations. If they don't, read the remaining sections of this guide to see how to make your own exposure settings.

The procedure using the standard settings is as follows:

1) Make sure both cameras are set to f-16, and the Pro-Spot iris is fully opened. Aim and position the Pro-Spot and adjust the Pro-Spot focus. Adjust the Pro-Spot awnings as desired to cover the area of interest on the object. If necessary, close the Pro-Spot iris as much as needed so the projected dots are in reasonable focus on the object. (Closing the iris will reduce the brightness of the dots and may make it harder to get the dimmest ones.)
2) Use the template project called "M Combo-Shot". This project sets the scanning and exposure parameters that typically work best for M Combo-Shot projects.
3) Import the Driver file for the project.
4) Import the two camera files used for the project. Make sure they are connected.
5) Enter M-mode by pressing the Unstable ("U") button on the toolbar. Aim the cameras so they cover the area of interest and see enough retro-targets to get a good camera orientation.
6) Check the exposure of the retro-targets, and, if necessary, adjust the camera flash power. Exit M mode by pressing the "M" button and repeat Steps 5 and 6 until the retro-target exposure is OK.
7) Once the retro-exposure is set, check whether the camera flashes are causing "hot-spots" on the object that are bright enough to be a problem. (A hot-spot is probably a problem if its brightest grey value gets above 20-30). If you are not sure if the hot-spots are caused by the camera flashes, take an exposure with the camera flashes turned off to see if the hot-spots remain. If they do, the camera flashes are not causing the hot spots.

8) If you determine the camera flashes are causing a problem with hot spots on the object, then you should connect the wired sync cable to the projector. See the previous section for instructions on using the wired sync cable..

9) If the camera flashes are not creating hot-spots, then do not use the wired sync cable and turn on the projector's built-in flash sensor.
   NOTE: If the Pro-Spot does not flash, move the Pro-Spot power unit so its sensor cell receives enough of the camera flashes to trigger the Pro-Spot.

10) Import the projector data for the project by selecting Import from the Project menu and clicking on Projector(s). Select the Pro-Spot by Serial number and the type of slide you are using.

11) Select Combo-Shot Setup from the M-Mode menu. An empty dialog box will appear.

12) Press the Arrow button next to the drop-down list at the top of the dialog. A list for some standard situations will appear. If you determined the camera flashes did not cause problems, you will be using one of the items in the list that says "Flashes OK". Otherwise, you will be using one saying "Flashes Not OK".
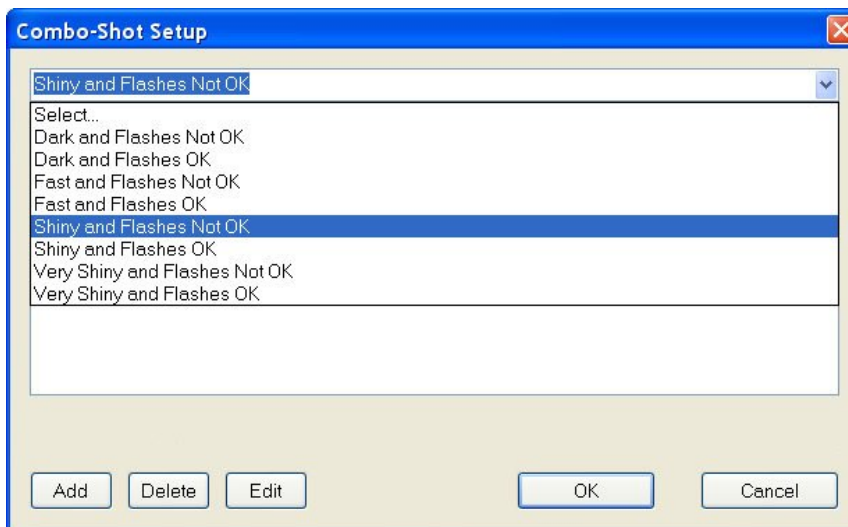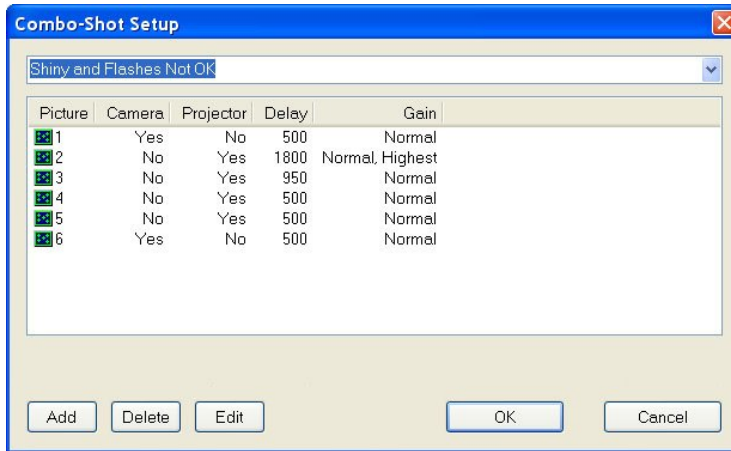

13) Next estimate whether the object is "Dark", "Shiny" or "Very Shiny" and choose the corresponding item from the list. The "Dark" settings take the fewest shots and the least amount of time so if you are unsure, choose "Dark". If this does not get everything, then choose "Shiny" and if this does not get everything, choose "Very Shiny".
   NOTE: For the "Dark" and "Shiny" settings, the projector recharge rate should be set to "High" (push the rabbit button). For "Very Shiny" it should be set to "Medium" (push the diamond button).

14) After you have chosen the settings, they will be listed in the dialog box. It shows the flash, delay, and camera gain settings for each shot in the sequence. Close the Combo-Shot Setup Dialog by pressing the OK button.

Combo-Shot Setup

Shiny and Flashes Not OK

Picture	Camera	Projector	Delay	Gain
1	Yes	No	500	Normal
2	No	Yes	1800	Normal, Highest
3	No	Yes	950	Normal
4	No	Yes	500	Normal
5	No	Yes	500	Normal
6	Yes	No	500	Normal

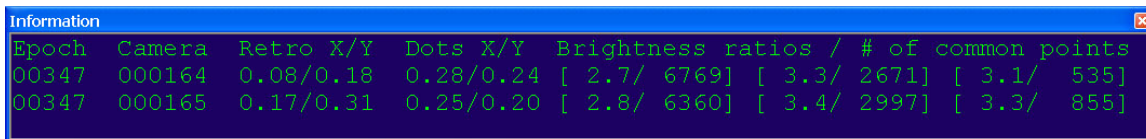Add   Delete   Edit   OK   Cancel

15) To take a sequence of Combo-Shot pictures, you must be in Combo-Shot measurement mode. If the Combo-Shot Mode button on the Measurement Type toolbar is not highlighted, press it to highlight it. Then, press the trigger ("**T**") button on the M–Mode toolbar or press the remote trigger to start the Combo-Shot sequence.

16) The picture taking will proceed using the values in the Combo-Shot dialog box. Once the picture taking is complete, pictures are transferred from the cameras to V-STARS in the order they were taken. The display and scanning of the pictures will be shown in the picture windows. When all the scanning is done, a composite picture will be displayed in each picture window. It shows the background from the first picture, and the target areas ("patches") around each selected target. The brightest acceptable target is the one that is selected. The composite picture can look a little strange since it actually contains patches from all the pictures. This picture is provided for visualization only; the actual pictures were scanned to measure the targets.

17) After all the pictures are processed, the projector matching process correlates and measures the projected targets. The results are presented in the usual way in a Triangulation 3D file. If you did not get all the projected targets you desire, try the other standard settings. If you still do not get all the desired targets, you will have to set the exposure settings yourself as described in the following sections.

18) After each measurement (epoch), the information window will provide statistics indicating how stable the setup is and how much the combo-shot exposures overlap. A typical listing is shown below.

Information

Epoch	Camera	Retro X/Y	Dots X/Y	Brightness ratios / # of common points		
00347	000164	0.08/0.18	0.28/0.24	[2.7/ 6769]	[3.3/ 2671]	[3.1/ 535]
00347	000165	0.17/0.31	0.25/0.20	[2.8/ 6360]	[3.4/ 2997]	[3.3/ 855]

A line is displayed for each camera. The X/Y values list the stability statistics in the horizontal (X) and vertical (Y) directions for the retro-reflective targets and projected dots. The values for the retro-reflective targets indicate whether the camera and/or object are moving significantly. A number of ~.25 is typical. A number above .5 indicates the cameras and/or object may be moving enough to significantly affect the

accuracy and reliability of the measurement and steps should be taken to find the cause and reduce it.

The values for the projected dots indicate whether the Pro-Spot is moving, and a number of ~.5 is typical. A number above 1.0 indicates the projector may be moving enough to significantly affect the accuracy and reliability of the measurement, and steps should be taken to find the cause and reduce it.

The Ratio/# fields indicate the brightness ratio and the number of common points (those that could be measured in both pictures) between successive projector exposures. In this situation, there were four projector shots so there are three sets of these values. For example, the first projector shot was 2.7 and 2.8 times brighter than the second projector shot for cameras 164 and 165 respectively. The typical ratio should be 2 to 5. The number of common points can vary considerably but must be more than 10 to get a ratio.

NOTE: If you selected the "Dark and Flashes OK" settings, no statistics are displayed since only one shot was taken, and so stability is not a concern. If you selected the "Dark and Flashes Not OK" settings, statistics are only displayed for the retro-reflective targets since the projector was fired only once.

19) If the setup is not stable, try using the appropriate "Fast …" settings file. These settings will take fewer pictures by varying the projector exposure more between shots (accuracy may be reduced somewhat because of this). The stability statistics should be smaller, while the ratio values should be larger (typically 5 or more). If the stability statistics are still large and you cannot make the situation more stable, the results you get may be less accurate than normal.

What to do if the Standard Settings Don't Work

If the Standard Settings procedure above does not work satisfactorily because it misses the dimmest projected dots, the easiest thing to try next is to change the f-number of both cameras and repeat the appropriate steps above (Starting with step 4). Try setting the cameras to f-11 first and if that is not satisfactory, try setting them to f-8. Each change of the f-number will increase the projected dot (and retro-target) brightness by a factor of two.

At step 4, if you have camera files for the f-number of the cameras import them. In step 6 you should adjust the camera flash power setting to compensate for the change in f-number. Reduce the flash power setting by 3 for f-11 and by 6 for f8.

If the dimmest dots are still missed, move the projector closer to the object so the light is more concentrated. Moving the projector halfway closer to the object will increase the projector dot exposure by about a factor of 4. If you cannot move the projector closer, then try more setups at the current distance back. If all this fails, you will not be able to measure these dimmest dots.

The following sections describe how to set exposure settings yourself.

Setting the target scanning parameters and shutter exposure

The normal target scanning parameters are generally used for Combo-Shot mode. It is very important to have the Overexposure filter on because the Combo-Shot procedure uses the brightest ACCEPTABLE exposure of a target.   If you have the filter off, then overexposed targets will be used instead of targets in later pictures that are not overexposed.

Also, you should normally have the shape and brightness filters on. However, if you are willing to accept even very dim and misshapen targets rather than not measure them at all, then you should turn these filters off. However, be aware that very dim and misshapen targets will likely have poor accuracy.

Although the camera shutters will be in synchronization down to 8 milliseconds in M-Mode, don't use a shutter exposure of less than 15 milliseconds or else you won't be fully synchronized with the Pro-Spot projector.   You can use longer exposures than 15 milliseconds but this will increase the background exposure (which sometimes is desirable when you want to see a "ghost image" of the object in the picture).

NOTE: If you are using the "M Combo-Shot" template, the Overexposure, Shape and Brightness filters will all be set appropriately for most Combo-Shot applications, and the shutter exposure will be set to 15 milliseconds so we recommend you always start with the template project.

Changing Pro-Spot exposures

You can take up to eight pictures in Combo-Shot mode (although 3 to 6 is more typical). For each picture, you can fire the camera flashes or the projector or both. You can also set the camera gain separately for each picture. Since there is no direct control of the Pro-Spot projector power, you vary the Pro-Spot exposure by setting the delay time between pictures. The recharge rate selected on the Pro-Spot power unit and the delay time together determines the level of Pro-Spot exposure. The table below shows the relationship between the recharge rate selection and the recharge time needed for various power levels.   These values are a rough guide. They will vary somewhat from this depending on the unit and especially on the length and gauge of the AC power cable to the unit (these values are typical when using the AC power cord provided with the unit and no extension cords are used).

Table 1. Pro-Spot Exposure Parameters

Power Level	Recharge Time (seconds)		
	High (rabbit)	**Medium (diamond)**	**Low (turtle)**
*Full – 100%	5	9	25
Half – 50%	3	5	12
Quarter – 25%	2	2.5	7
Eighth – 12%	1	1.8	4
Sixteenth – 6%	.5	1.2	2.5
1/32 – 3%	Can't do	.9	1.5
1/64 – 1.5%	Can't do	.5	1.0
1/128 – 1%	Can't do	Can't do	.5

- *If the Pro-Spot is not set at full power, then the first Pro-Spot picture is at that lower power setting. However, since the power level setting has no effect on the recharge rate, the power level of the remaining shots is still determined by the delay time as shown in the table above.

Determining Exposures and Number of Shots

When deciding how to set the parameters for taking a series of pictures it is often helpful to set the proper exposure for the first and last projector pictures, and then decide whether any intermediate pictures are needed. The first projector picture (since it flashes at full power) is the one that will get the dimmest targets on the object while the last projector picture (since it typically flashes at the lowest power) gets the brightest targets.

Setting exposure for the full-power shot

It is easiest to decide on the exposure for the full-power shot by taking single-shots as you normally would and checking the exposure (either by looking at the targets or by scanning the picture to see what targets are successfully scanned). To take a normal single-shot exposure, just select the regular Single-Shot Pro-Spot icon on the Measurement Type toolbar, and then press the Trigger button.

If the full power picture is not getting the dimmest targets, you need to increase the exposure. You can do this in several ways each of which has its advantages and disadvantages. These are summarized in the table below.

Action to increase Pro-Spot exposure	Limit	Main feature	Background effect	Retro-target effect
Open Pro-Spot iris	Wide open	Reduces depth of sharp focus (and sharpness in general)	None	None

Increase camera gain (High = 2x Normal Highest = 2x High)	Highest (4 x brighter than at Normal Gain)	Can change gain from shot-to-shot but accuracy is ~10% worse at high and ~20% worse at highest compared to normal gain.	Proportional	Proportional
Open camera iris (change lens f-number)	f-8 (4 x brighter than at f-16)	Cannot change from shot-to-shot. Accuracy is reduced 10-20% if the camera was calibrated at a different f-number.	Proportional	Proportional

Open the Pro-Spot iris. Opening the Pro-Spot iris wider will increase the exposure but will reduce the depth of sharp focus on the object (and reduce the sharpness in general). However, because only the brightness of the projected dots has changed, there is no effect on the background and retro-target exposures. If the targets on the object are still acceptably sharp, this is usually the best way to increase the exposure.

Increase the camera gain. The camera gain is usually set at the normal setting. This provides the best signal-to-noise ratio and therefore the best accuracy. The camera gain can be set to the high setting which increases exposure brightness by a factor of 2 over the normal setting or to the highest setting which increases exposure brightness by a further factor of 2 (4 x normal). Changing the camera gain increases the brightness of everything (projected targets, retro-targets, background). If you are also exposing the retro-targets on the full-power shot, you can and should reduce the camera flash power setting (if it is on) to compensate for the increased retro-target exposure. The background exposure may not be a problem (unless the room lighting is bright) and you can reduce it in several ways. We discuss ways to do this later since the same techniques apply when you increase the exposure by opening the camera iris. Although increasing the camera gain reduces accuracy by about 10% for each step increase in gain (10% for high, 20% for highest), the camera gain can be changed from shot-to-shot. This provides more exposure flexibility than changing the camera iris (f-number).

NOTE: If you decided to increase the camera gain for the full-power shot, you should select both that gain setting and the normal gain setting for the full-power shot.

Open the camera iris. Opening the iris on the cameras (both should be set to the same f-number) will increase the exposure of the projected targets but will also increase the background exposure and the retro-target exposure by the same amount. You should reduce the camera flash power setting to compensate for the increased retro-target exposure. The background exposure may not be a problem (unless the room lighting is bright) and you can reduce it in several ways. We discuss ways to do this later since the same techniques apply when you increase the exposure by changing the camera gain. Unlike the camera gain, the f-number cannot be changed from shot-to-shot so it is less flexible.

Geodetic Systems

The normal opening for the camera iris is at f-16. You can increase the opening up to f-8 (which increases exposure by a factor of 4). However, changing the f-number reduces accuracy by about 5-20% for each f-stop change from f-16 (5-20% reduction at f-11, 10-40% reduction at f8).

- **NOTE:** There is no reduction in accuracy if you use a high-accuracy camera calibration file that was done at the f-number setting. However, you must remember to use this camera calibration file for the project, and GSI must do this one-time, high-accuracy calibration.

Reducing the background exposure

There are several ways to reduce the background exposure. First, however, you should determine whether the background exposure needs to be reduced. To get good accuracy, the peak brightness of a target should typically be at least 20 grey levels above its background. Since dimmer targets have fewer grey levels this is where you should look to see if the background is too bright.

If you need to reduce the background exposure, you must first determine what is causing it. The background exposure is caused by two independent, additive effects. First, is the illumination from the camera flashes. Normally, this effect is slight but it gets more significant as you get closer to the object, especially since both camera flashes are illuminating the object. To determine the effect the strobes have on the background, you can take two shots, one with the camera flashes on, and one with them off (you should not fire the Pro-Spot when taking these shots). If the effect of the camera flashes on the background is significant, then you should setup your Combo-Shot sequence to fire just the camera flashes on the first (and last) shot and just the Pro-Spot on the other shots.

The second effect on background exposure is caused by the ambient lighting. You can reduce this by decreasing the camera shutter exposure time but do not set it to less than 15 milliseconds or you will not have complete synchronization with the Pro-Spot. The only other way to reduce the background exposure is to reduce the ambient lighting by turning out lights or shading the object.

NOTE: Increasing the f-number of the camera lenses, or decreasing the camera gain will also reduce the background exposure but these techniques also reduce the target exposure proportionally so they are of little help here.

Setting the exposure for the lowest-power shot

The last projector shot is typically taken to get the brightest targets. Unlike the full-power shot, you must determine not only the other exposure parameters but also the Pro-Spot power level needed to measure the brightest targets.   Typically, this is done by taking a

series of single-shot test exposures while varying the projector power setting. Once the desired projector power setting is determined, you can then use Table 1 to determine the recharge rate and delay needed to get the desired power setting for this last shot.   Keep in mind you can vary the camera gain as well as the projector power from shot-to-shot to get the exposure you want. However, you cannot change the projector or camera iris openings from shot-to-shot.

If you cannot get the brightest targets even at the projector's lowest power setting ($1/16^{th}$ power), keep in mind (see Table 1) that power levels less than $1/16^{th}$ are possible, but there is a problem. You cannot set the power slider lower than $1/16^{th}$ to check the exposure. However, you can temporarily close down the projector or camera iris to reduce the exposure for the brightest targets further so you can determine the exposure level needed. We recommend you completely close down the iris because this reduces the exposure by a factor of about 10 compared to the when the iris is fully open.   Then use Table 1 to determine the equivalent power level.

NOTE: Return the camera or projector iris to the original position for the actual exposure.

 If you still cannot get the brightest targets at the lowest possible power level shown in Table 1 (very unlikely) you can further reduce the exposure by actually (not just temporarily) closing the camera or projector iris. However, then you will have to go back and check the target exposure for the full-power setting to see if you still get the dimmest targets. If you don't, then you will have to make a compromise to decide which targets you want to get.

Setting the exposure for any intermediate shots

After you have determined the exposure for the first and last projector shots, you can decide if any intermediate shots are needed. If you did not get all the targets in the first and last shots, you definitely need one or more intermediate shots. However, you may also want intermediate shots even if you get all the targets in the first and last shots. This is because intermediate shots may give a better exposure for some of the targets than in either the first or last shot. Of course, more shots take more time so one must decide whether the extra shots are worth the extra time. These decisions will take some experience and judgment but we can provide some guidelines here.

The best way to see if any intermediate shots are needed is to enter the values you have decided on for the first picture (which gets the dimmest targets), and for the last picture (second picture which gets the brightest targets) into the Combo-Shot setup dialog and use the statistics V-STARS provides to determine the ratio between the two shots. To see how to do this, skip forward to the sections titled "Setting up Combo-Shot Mode", and "Triggering the Combo-Shot Sequence", and then come back here.

 If the ratio shown in the information dialog is a factor of two or less, you do not need an intermediate shot. If the difference is greater than 4, you should probably add at least one

intermediate shot (unless time or stability is an issue). Usually the exposure ratio for successive pictures should be between 2 and 4.

An example helps show the use of intermediate shots. Suppose the ratio shown in the information window is about 16. Then, our first and last projector shots are as shown below.

Picture #	Projector Power	Gain	Comment
First	Full	Normal	Gets dimmest targets
Last	1/16th	Normal	Gets brightest targets

Since the ratio is greater than 4 we should add some intermediate shots. Varying the exposure by a factor of two between successive shots will require a total of five projector shots. Remember we vary the exposure by varying the time between exposures. Using the data in Table 1 (for the high recharge rate), the table below shows the sequence for these pictures.

Picture #	Projector Power	Gain	Elapsed Time	Comment (using high recharge rate)
First	Full	Normal	0 sec.	Gets dimmest targets
Second	1/2	Normal	3 sec	½ power recharge rate ~3 seconds
Third	1/4	Normal	5 sec	¼ power recharge rate ~ 2 seconds
Fourth	1/8	Normal	6 sec	$1/8^{th}$ power recharge rate ~ 1 second
Last	1/16	Normal	6.5 sec	Gets brightest targets.

If the first picture is actually a camera-flash only picture (taken to expose just the retro-reflective targets), and a final camera-flash only picture is added at the end to check the camera and object stability, the entire sequence takes seven pictures, (and this adds about 1 second to the elapsed time). Remember, the setup must be stable for this entire time. Furthermore, this many pictures can take some time to process.

You can go faster by taking fewer pictures. If the ratio between successive shots was a factor of four the picture sequence would be as shown below.

Picture #	Projector Power	Gain	Elapsed Time	Comment (using high recharge rate)
First	Full	Normal	0 sec	Gets dimmest targets
Second	1/4	Normal	2 sec	¼ power recharge rate ~2 seconds.
Last	1/16	Normal	2.5 sec	Gets dimmest targets..

The elapsed time is just 2.5 seconds for the projector pictures and 3.5 seconds if separate camera-flash only pictures are taken at the beginning and end. Also, since there are fewer pictures to process, the results are available sooner.

We used the high recharge rate because it allows us to do the Combo-Shot sequence in the shortest amount of time thereby minimizing concerns about stability. However, if the projector power for the last shot is less than 1/16th of full power, we cannot use the high recharge rate. For example, if the exposure ratio between the first and last shots was 64, we would have to use the medium recharge rate. If we wanted to vary the exposure by a factor of two, the sequence would be as shown below (using the medium recharge rate times in Table 1).

Picture #	Projector Power	Gain	Elapsed Time	Comment (using medium recharge rate)
First	Full	Normal	0 sec	Gets dimmest targets
Second	1/2	Normal	~5 sec	Half power recharge time ~5 seconds
Third	1/4	Normal	~7.5 sec	¼ power recharge time ~2.5 seconds
Fourth	1/8	Normal	~9.3 sec	1/8th power recharge time ~1.8 seconds
Fifth	1/16	Normal	~10.5 sec	$1/16^{th}$ power recharge time ~1.2 second
Sixth	1/32	Normal	~11.4 sec	$1/32^{nd}$ power recharge time ~.9 seconds
Last	1/64	Normal	~11.9 sec	$1/64^{th}$ power recharge time ~.5 seconds

The above sequence takes seven pictures and ~12 seconds. If a camera-flash only picture is taken at the beginning, then we are at eight pictures, which is the limit. So we could not take a final camera-flash only picture to check the camera and object stability. We could also flash the camera strobes on the final projector shot so we could check the camera and object stability but this may cause reflections on the object.

Remember the projector, cameras and object must be stable for this entire time (~12 seconds). It can also take some time to process eight pictures. For example, it takes 3 to 5 seconds per picture to transfer and scan each picture, and 3 to 6 seconds to do the final processing of all the pictures (but there is no stability requirement during this period, in fact, after the last flash you can move the equipment if needed to prepare for the next Combo-Shot sequence). So the entire time from first picture to final results will take somewhere between 36 and 58 seconds (~12 seconds to take the pictures, 21 to 40 seconds to process the pictures, and 3 to 6 seconds to do final processing).

You can take fewer pictures to reduce the picture taking and overall processing time. Varying the exposure ratio by a factor of four between successive pictures means only four pictures are needed for this example. The table for this situation is shown below.

| Picture #	Projector Power	Gain	Elapsed Time	Comment (using medium recharge rate)
First	Full	Normal	0 sec	Gets dimmest targets
Second	1/4	Normal	~2.5 sec	¼ power recharge time ~2.5 seconds
Third	1/16	Normal	~3.7 sec	$1/16^{th}$ power recharge time ~1.2 second
Last	1/64	Normal	~4.2sec	$1/64^{th}$ power recharge time ~.5 seconds

Elapsed time is only ~4 seconds so less stability is required. Also, we now can take a beginning and ending camera-flash only picture, if needed, which increases the number of pictures to six and elapsed time to ~5 seconds.

NOTE: If time permits, it is better to vary exposures by a factor of two between shots, but if time is at a premium or the environment is unstable, you can vary exposures by a factor of four or more between shots to reduce the picture taking time (and overall processing time).

Setting up Combo-Shot mode

Once the exposures and number of shots for Combo-Shot mode are determined, you set their values in the Combo-Shot Setup dialog.   To do this, select Combo-Shot Setup from the M-Mode menu. If this is the first time you have done this, a blank dialog box like the one shown below will appear. Otherwise, the dialog box will have values from the most recent Combo-Shot sequence.

NOTE: If you like you can use one of the standard settings as a starting point for your settings by selecting the desired one from the drop-down list at the top of the dialog.

Empty Combo-Shot Dialog   Sample Filled-in Combo-Shot Dialog
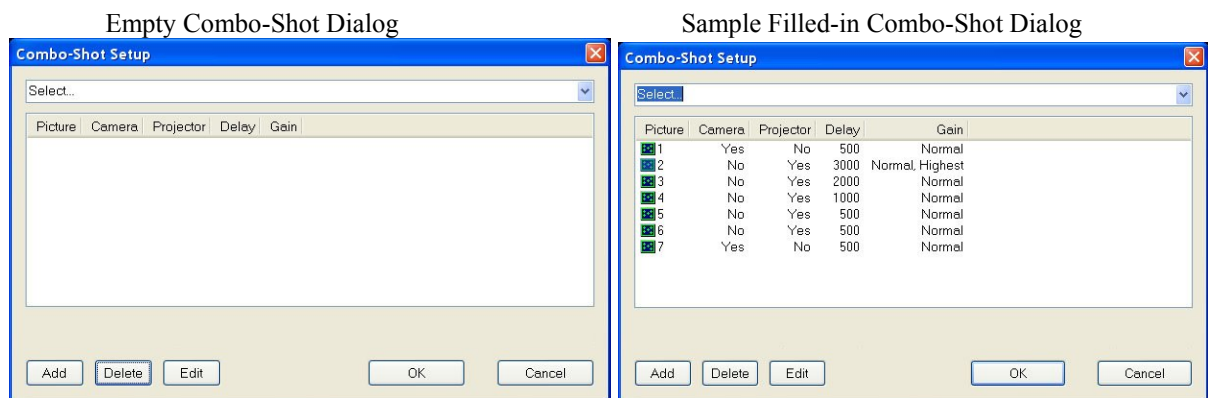
To delete an entry, select it and press the Delete button. Pressing the Add or Edit button will bring up a dialog that allows you to set the various parameters for a shot. A sample is shown below with the values for the first projector shot (Picture 2) from the example above.
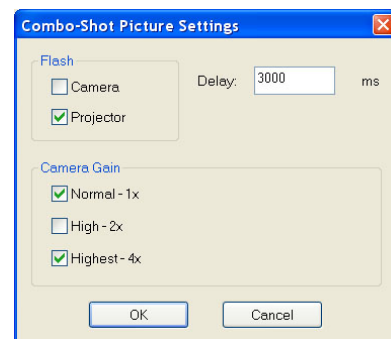

Add/Edit Picture Settings Dialog

Remember the delay you set is in milliseconds and is the delay AFTER the shot. A delay of 0 means the next picture will be taken as soon as possible (typically .5 seconds, or 500 milliseconds later). The delay for the last shot is meaningless and is not used.

The sample dialog above is for the first example (high recharge rate) in the "Setting the Intermediate Exposures" section except initial camera-flash only shot has been added to expose just the retro-reflective targets. Also a final camera-flash only shot has been added to check for stability. The entire sequence takes a total of 7 pictures. To help illustrate, a timeline of the sequence is presented below.

#	Time	Event
1	0	The first shot fires the camera flashes only. This picture illuminates only the retro-targets and is used orient the cameras for all the following pictures. The camera flashes are turned off for the five following projector-only shots which means the projector sync cable is used. The delay is 500 which means the next picture with the full-power projector flash fires as soon as possible, typically .5 seconds after this one.
2	0.5	The first projector shot fires at full power to get the dimmest targets. The camera gain is set to highest and normal. This is almost always the case for the first projector shot. Setting both gains allows us to get as many targets as possible. The delay is 3000 which means the next picture will fire 3 seconds after this one giving the strobe time to charge up to about one-half power for the next shot.
3	3.5	The second projector shot fires at about one-half power. The gain is only set to normal, because the highest gain setting is not usually needed when the ratio between successive shots is less than 4. The delay is 2 seconds which means the next shot will be at about ¼ power.
4	5.5	The third projector shot is at ¼ power. Since the camera gain is unchanged, the overall exposure is ½ that of the previous shot. The delay is 1 second which means the next shot will be at about $1/8^{th}$ power.
5	6.5	The fourth projector shot is at $1/8^{th}$ power. The delay is .5 seconds which means the next shot will be at about $1/16^{th}$ power.
6	7.0	The last (fifth) projector shot gets the brightest dots. The brightness ratio of each successive pair of projector shots is shown in the Information window.
7	7.5	The final shot (seventh shot overall) fires only the cameras and is used to check the stability of the cameras and object by checking the movement of the retro-targets. The stability results are displayed in the Information window.

Triggering the Combo-Shot Sequence
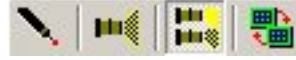
After setting the values for the Combo-Shot sequence in the Combo-Shot Setup dialog, you can trigger a sequence.   To take a Combo-Shot sequence, you must be in Combo-Shot measurement mode. If the Combo-Shot Mode button on the Measurement Type toolbar is not highlighted, press it to highlight it. Then, pressing the trigger button ("**T")** on the M –Mode toolbar or pressing the remote trigger will start the Combo-Shot sequence.

The picture taking for the example will proceed as shown in the table above. Once the picture taking is complete, pictures are transferred from the cameras to V-STARS in the order they were taken. The display and scanning of the pictures will be shown in the picture windows. When all the scanning is done, a composite picture will be displayed in the picture windows. It shows the background from the first picture (in this case the ones with the camera flashes only), and the target areas ("patches") around each selected target. The brightest acceptable target is the one that is selected. The composite picture can look a little strange since it actually contains patches from all the pictures. This picture is provided for visualization only; the actual pictures were scanned to measure the targets.

After all the pictures are processed, the projector matching process correlates and measures the projected targets.   The results are presented in the usual way in a Triangulation 3D file.

After each measurement, the information window will provide statistics indicating how stable the setup is and how much the combo-shot exposures overlap.   See the section above titled "Using Standard Settings" for an example and description.

You can trigger as many Combo-Shot sequences as you like. However, if you want to change the exposure parameters, you must change them in the Combo-Shot Setup dialog before triggering a sequence. To take a normal trigger, just select the regular Single-Shot Pro-Spot icon on the Measurement Type toolbar, and then press the Trigger button.

- **NOTE:** Be certain when you want to take a Combo-Shot sequence. Although there is no problem taking an inadvertent one, there is no way to stop it once it is started and the entire sequence can take some time.