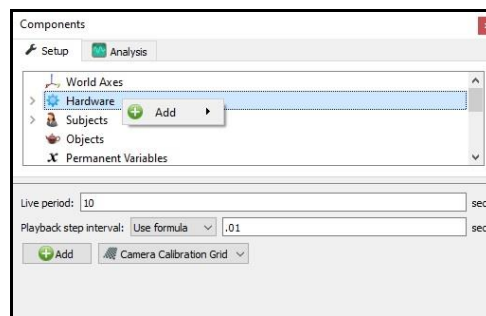


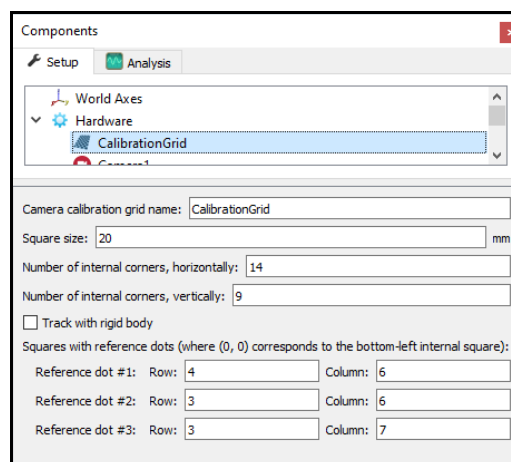
The MotionMonitor xGen Software Guide: Calibrating Integrated Video

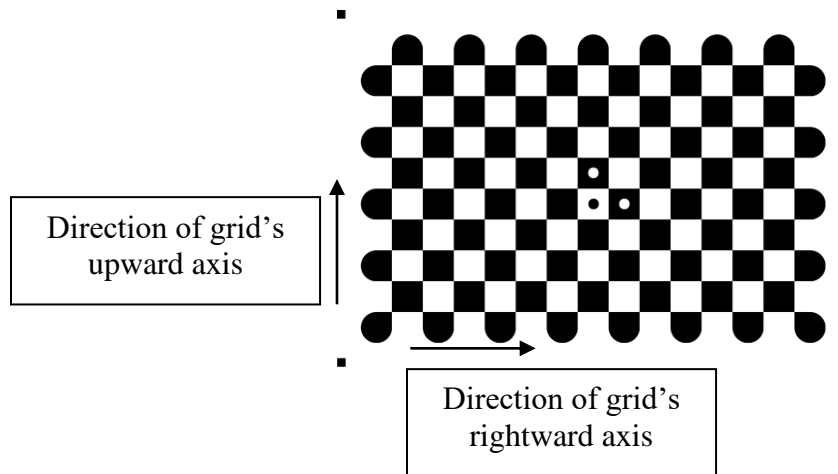
This document reviews the procedure for calibrating reference video devices in The MotionMonitor xGen to allow for the camera to be aligned with other hardware devices for video overlay purposes or when capturing video for markerless processing engines. The process of calibration includes the determination of the camera's intrinsic and extrinsic properties. The process for calibrating any camera is the same and for the purpose of this document we will review the process using a Basler camera. If needed, the configuration parameters for setting up a camera can be reviewed in the Configuring Basler cameras and Configuring Microsoft LifeCam (and other digital video cameras) knowledge base articles. Only parameters pertinent to calibrating the cameras will be described within this knowledge base article.

- 1) The camera calibration process will require a Camera Calibration Grid. Add a Camera Calibration Grid device from the Add button in the parameters panel at the bottom of the Components window or by right clicking on the Hardware node and adding the device through the cascading drop list.



- 2) Click on the CalibrationGrid device to bring up the CalibrationGrid parameters panel. Specify the camera calibration grid name, which will be used internally for referencing the grid. For the Square size, measure the dimension of an inner square on the grid and enter that value here, in mm. Specify the number of internal horizontal and vertical corners. If the 'Track with rigid body' checkbox is left unchecked, the system will assume that you are using a calibration grid provided by your Client Support Engineer, which should contain reference dots in 3 of the middle squares (a sample image of this grid is displayed below). Enter the rows and columns where the dots appear in the corresponding edit fields, the order does not matter. Please note that the bottom-left internal square is referenced as (0,0). The settings specified in the dialog below match those that would be entered for the sample grid also displayed below.





Note: Only the internal squares on the grid are used in the calibration process. The image above shows “squares” with rounded edges on the external sides, but all internal squares need to be the same dimensions. The orientation of the grid is also important. The grid is expected to have 3 dots in the middle, as seen above. The upward and rightward directions of the grid are the upward and rightward directions as the grid is displayed above. The upward direction would be going from the row containing two dots towards the row with a single dot. The rightward direction would be going from the column with two dots towards the column with a single dot. In the next step, the direction of these axes with respect to the physical world axis layout during the extrinsic calibration readings will need to be specified. The grid's center will need to be known and can be determined by locating the midpoint of the width and height of the grid when measuring all of the internal squares.

The 'Track with rigid body' checkbox is typically left unchecked, but when enabled provides an alternative alignment method using data from a kinematic tracking system. The dimensions of the calibration grid are identified using a stylus and the calibration grid is tracked using a rigid body from a kinematic tracking system. After specifying the rigid body and stylus to use, click the “Calibrate” button to calibrate the calibration grid for this method.

- 3) From the Camera device parameters panel, click on the Setup and Advanced arrows to expand the parameters for the Camera. Based on the software release key, you may see all or only some of the following features. Typically, the Setup and Advanced sections will only need to be modified during the initial configuration. Only parameters pertinent to calibrating integrated reference videos will be described here. To review settings not covered here, refer to the knowledge base article for your camera.

The screenshot shows the 'Components' window with 'Camera1' selected. The 'Setup' section is expanded, showing the following settings:

- Camera name: Camera1
- Camera type: Basler
- Serial number: 40271315
- Transformation type: None
- Selected audio source: <none>

The 'Advanced' section is also expanded, showing the following settings:

- Strategy: Classic
- JPEG quality: 95
- Encoder: NVENC H.264 (GPU 0: NVIDIA RTX A4000)
- Bitrate: 60000 it/sec
- Frame rate: 100
- GOPSize: 1
- Container: MP4
- Calibration grid to use: CalibrationGrid
- Calibration advancement method: Use timer
- Time interval: 1 sec
- Re-use previously captured dynamic images
- Number of dynamic images to capture: 90
- Required number of valid dynamic images: 10
- Static placement of grid (when applicable):
 - Location of grid's center: Use formula $\text{vec}(-0.054, 0.30525, 0.003)$
 - Direction of grid's rightward axis: Positive X-axis
 - Direction of grid's upward axis: Positive Y-axis
- Apply image enhancement

At the bottom of the panel, there are buttons for 'Apply to All', 'Calibrate...', 'Calibrate All...', 'Show Results...', and 'Test All...'. There are also checkboxes for 'Viewfinder' (checked) and 'Deactivate'.

The Strategy and Encoder refer to the method and GPU used for encoding the video. The Classic strategy will use CPU and RAM and the Fast method will use GPU for encoding and is capable of processing images into video at a much higher rate, but requires a CUDA capable NVIDIA graphics card. The JPEG quality, Bitrate, GOP Size and Container type are all parameters that determine how the video file will be generated as well as the quality and size of the resulting video file. The Frame rate will update automatically after activation based on what measurement rate the camera is set to run at. It is important that all cameras operate at the same Frame rate. When collecting video for a markerless processing engine, keep in mind that there may be specific settings required for the camera parameters.

The "Calibration grid to use" should be selected from the drop list of available calibration grids that have been added to the workspace, as described in the previous steps.

A series of images will need to be captured to provide calibration data across the camera field of view, details for this process will be described later. The calibration process can consist of calibrating a single camera, clicking the “Calibrate” button, or calibrating all the cameras simultaneously, clicking on the “Calibrate All” button. The “Calibrate All” button will only be available for calibrating Basler cameras and will use the “Number of dynamic images to capture” and “Required number of valid dynamic images” settings specified for the camera from which the button was pressed. However, the remaining Advanced parameters for each camera still need to be specified. Webcams must be calibrated individually.

Whether a single camera or multiple cameras are being calibrated will dictate what should be specified in the “Number of dynamic images to capture” field. This field indicates the total number of readings that will be taken. Readings get taken at the specified “Time interval”. If calibrating all cameras, all cameras will capture readings simultaneously and any images that don’t contain valid calibration data images will be ignored for the calibration calculations. For instance, if the “Number of dynamic images to capture” is set to 60 and the “Time interval” is set to 1 second, this would result in the software simultaneously capturing an image from each camera approximately every second for 60 seconds. This would provide 60 seconds to cover the field of view for all cameras. The “Required number of valid dynamic images” provides a threshold for ensuring that an adequate number of images are included in the intrinsic calibration. If a camera does not satisfy the minimum number of dynamic images, you will be notified through the calibration results dialog, and the camera will not complete the calibration process.

For the default calibration process, when “Track with rigid body” is not selected in the CalibrationGrid parameters panel, the software will guide the user through 2 steps. First, an intrinsic calibration followed by an extrinsic calibration. The Intrinsic calibration consists of taking dynamic readings of the calibration grid and will calculate several parameters, including the optical center, focal length, and distortion of the camera lens. The extrinsic calibration consists of taking static readings of the calibration grid and will determine the position and orientation of the camera relative to a global coordinate system. For the extrinsic calibration, the “Location of the grid’s center”, “Direction of grid’s rightward axis” and “Direction of grid’s upward axis” should be specified to match how the grid is positioned relative to the global coordinate system during the extrinsic calibration readings. These settings will be ignored when the “Track with rigid body” selection is enabled in the CalibrationGrid parameters panel.

Since it can be difficult to physically place the center of the grid at a known point in the world coordinate system, the measured distance from the center of the calibration grid to one of the physical corners of the calibration grid can be measured. The corner of the calibration grid can then be more easily aligned to the world origin or known location in the world and the edges of the calibration grid can be aligned to a physical object in the world, such as the corner of a force plate, to ensure the proper orientation and physical alignment of the calibration grid. The physical location of the center of the grid relative to the global coordinate system’s origin should be entered in the Camera Device parameters panel “Location of grid’s center” edit field as a vector. Refer to the previous step for more information regarding the calibration grid axis layout and centroid position.

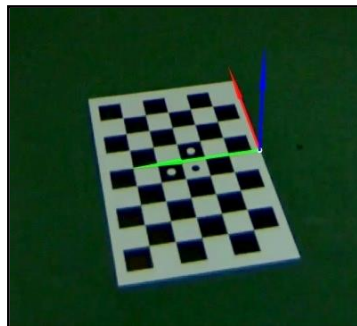
The ideal extrinsic alignment would be where all the cameras can see the calibration grid when it is positioned for the extrinsic calibration images. However, in the real world the camera coverage may require that some cameras not completely see the grid when in this position or the distance and orientation of the camera might make it impossible for the extrinsic calibration process to identify and determine the origin of the grid. In these instances, where a camera cannot process the extrinsic calibration images, the software will automatically proceed to an “anchor” method for determining the extrinsic camera calibration where dynamic images that were successfully captured in tandem with a calibrated camera are used to determine the location of the camera. This is an iterative process that continues to run until all cameras can be calibrated are calibrated. After the calibration process is

completed, a separate calibration results dialog will be presented for each iteration of the anchor calibration method that is performed. It should be noted that errors would be compounded with each iteration of the anchor calibration method, so this should be avoided. Following the description for performing the intrinsic calibration that follows is usually sufficient for ensuring that multiple iterations of the anchor calibration process aren't necessary.

The "Re-use previously captured dynamic images" check box will allow you to perform an extrinsic only calibration. The previously captured intrinsic calibration files will be used in place of capturing new intrinsic calibration files. It is important that the "Number of dynamic images to capture" has not changed from the previous calibration as the software will assume that there are this many existing intrinsic calibration images in the camera calibration folder. Calibration images are saved in the C:\ProgramData\Innsport\TMM_xGen\Calibration Grid Images directory.

The "Apply image enhancement" check box, which defaults to being enabled, changes the brightness and contrast of the calibration image data when it is processed. While this setting can improve calibration results in low to normal-lit environments, it can have a detrimental effect in well-lit environments and should be disabled. Although this setting can be enabled/disabled for each camera, when performing Calibrate All, the setting from the selected camera will be applied to all cameras. This setting only applies to the calibration images.

The images below show an example of a grid's position and orientation relative to the world axes and the screen capture of the "Static placement of the grid" settings that were used to define the grid's placement.



Static placement of grid (when applicable):	
Location of grid's center:	Use formula <input type="text" value="vec(-0.054,0.30525,0.003)"/>
Direction of grid's rightward axis:	Positive X-axis <input type="text"/>
Direction of grid's upward axis:	Positive Y-axis <input type="text"/>

The upwards direction of the grid is facing the world's positive y axis, and the rightward direction of the grid is facing the world's positive x axis. The origin or center of the grid is specified relative to the global coordinate system's origin. In this example, the center of the grid is located -0.054m in the x-direction, 0.30525m in the y-direction, and 0.003m in the z-direction from the global coordinate system's origin.

The "Viewfinder" checkbox allows for the display of video in the Live window to be toggled on and off. It is recommended to enable the viewfinder when performing the calibration process to see the area covered for each camera and to disable the viewfinder when multiple video devices are being used during data collection. This will reduce computer resources in use while performing critical data collection and data processing procedures. The Viewfinder can be disabled/enabled with a script command, so toggling the Viewfinder before and after each recording would not need to be performed manually. Note that more RAM may be used when performing recordings with the Viewfinder enabled.

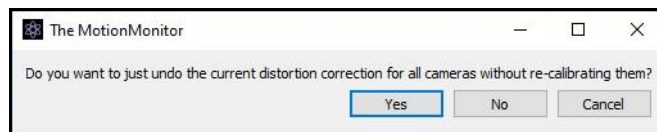
The “Apply to All” button will apply the Advanced parameters panel settings for the currently selected camera to all cameras under the Hardware node.

When the “Show Results” button is selected for a Basler camera, the results dialog will display the calibration results for all Basler cameras in the workspace. When the “Show Results” button is selected for a Webcam, only the results for that webcam will be displayed in the dialog. A timestamp will be provided with the results for each camera, indicating when the camera was calibrated. Any cameras that were calibrated using the anchor method will indicate that 0 static images were successfully captured.

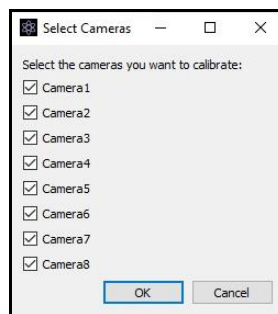
The “Test All” button is a diagnostics button that allows for the calibration of all cameras to be reprocessed using the current camera settings and existing images in the Calibration Grid Images directory.

Click the “Activate” button when the desired settings have been selected and to view the real time display of the camera or to perform a calibration or recordings.

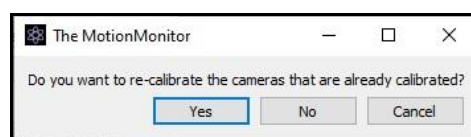
- 4) When ready to proceed with the calibration process, click one of the calibrate buttons in the Camera Device parameters panel. The first message will ask whether to just undo the existing or current calibration/s. Selecting “Yes” will undo any existing camera calibration/s and clear out the images in the Calibration Grid Images directory. Selecting “No” will proceed with the camera calibration and selecting “Cancel” will cancel out of the camera calibration process, neither proceeding with a new calibration nor resetting an existing calibration.



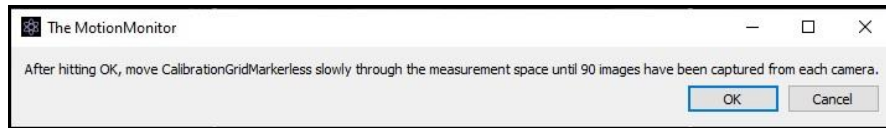
- 5) If the “Calibrate All” button was clicked, a dialog will be presented to confirm which of the cameras should be calibrated.



- 6) If some of the selected cameras have a current calibration, a message prompt will be provided to confirm that you want to re-calibrate the cameras that are already calibrated. Selecting “Yes” will calibrate all the cameras, selecting “No” will only calibrate the cameras without a current calibration, and selecting “Cancel” will cancel out of the camera calibration process.

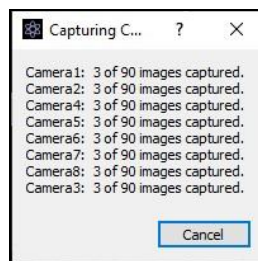


- 7) If “Yes” was selected any existing calibrations will be reset and the next dialog will prompt the user to perform the intrinsic (dynamic) calibration for the number of images specified in the Camera Device parameters panel, as previously described.

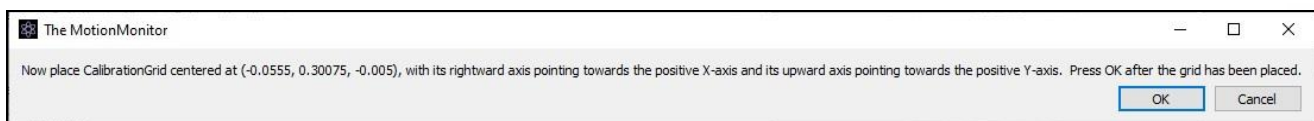


This process should consist of slowly moving the calibration grid though the entire field of view for the camera/s. The grid orientation should be angled with respect to the camera so that the side of the grid is tilted/angled towards and away from the camera (rotating about a vertical axis). This side-to-side tilting movement will help to ensure that the camera includes robust images for the intrinsic calibration as well as to provide images captured in tandem from multiple cameras for the “anchor” calibration method, if necessary. This process should be repeated ensuring that images are taken at different depths or distances from the camera. Tilting the grid upwards and downwards (rotating about a horizontal axis) can be performed too, but depending on lighting this might be more likely to result in a glare on the grid which could yield unusable images for calibration. Issues with glare are more likely to occur when additional lighting is added to a capture environment. Only images that contain all the inner squares of the grid will be usable for the calibration.

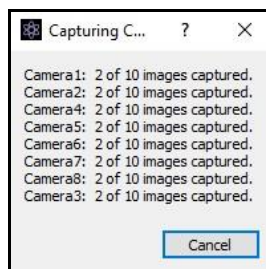
During the image capturing process, a dialog will display the progress.



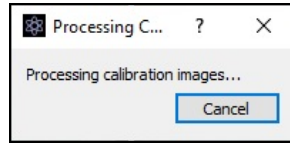
- 8) After the intrinsic calibration frames are captured, the extrinsic (static) calibration will be performed. A dialog will prompt the user to place the calibration grid centered and oriented according to what was specified in the Camera Device parameters panel. The capture environment should be evenly lit, to avoid any issues with glare on the calibration grid.



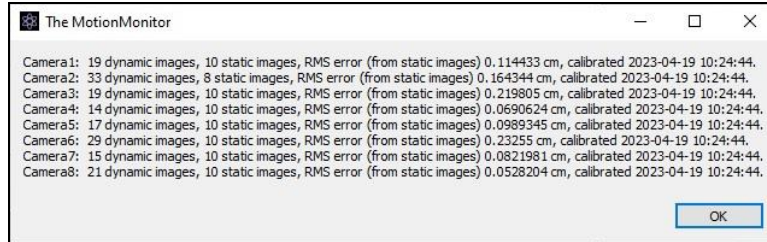
During the image capturing process, a dialog will display the progress.



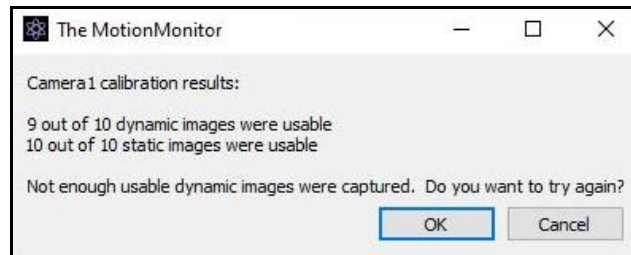
- 9) After the extrinsic calibration images have been captured, the system will process all the calibration images (intrinsic and extrinsic).



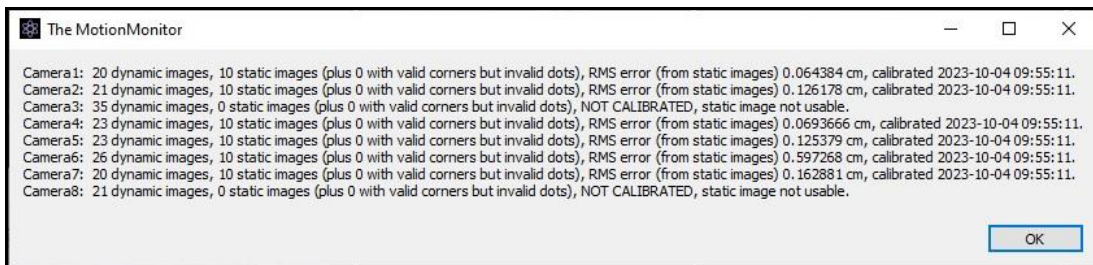
When the processing is completed, a dialog will display information including how many images were accepted for each camera and what the RMS error was for the static images.



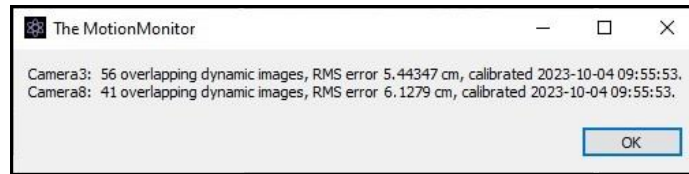
If a camera contains no usable dynamic images or fewer than the “Number of dynamic images to capture” specified in the Camera Device parameters panel, that camera will not be calibrated. The calibration process for that camera can be repeated or the camera can be left uncalibrated. If only a single camera was being calibrated, a dialog will ask if you want to try again. If multiple cameras were being calibrated, any cameras that failed would need to be calibrated through the Camera device parameters panel for that camera.



If a camera contains no usable static (extrinsic) images, the anchor method for determining the extrinsic camera calibration will be performed.



Any uncalibrated cameras that contained dynamic images that were successfully captured in tandem with a calibrated camera will display their calibration results in the subsequent dialog. If any cameras are still uncalibrated, the process will run again to see if any of the uncalibrated cameras contained dynamic images that were successfully captured in tandem with a calibrated camera that used the anchor method.

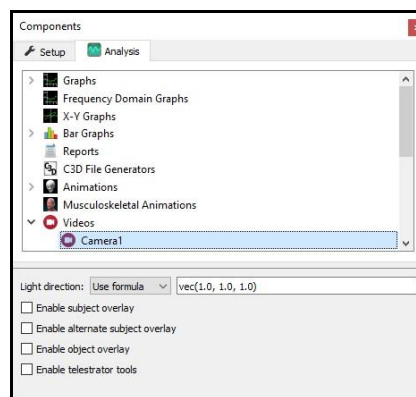


This process will continue until all cameras are calibrated. If a camera is unable to successfully calibrate, the static images can be recaptured, or the camera can be left uncalibrated.



A geometric median calculation is performed when processing all the calibration images to pair out any outliers in the calibration data.

- 10) If enabled, objects can now be viewed as an overlay in a video window, or data can be collected and used for processing with markerless processing engines for generating biomechanical data. Enabling the object overlay and viewing the World Axes can provide a visual reference for the camera calibration.



- 11) If a camera is moved, a lens setting is adjusted, the aspect ratio (Width x Height) is changed, or other configuration settings are modified the calibration process will need to be repeated.