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Fly Elise-ng
Immersive Calibration PRO v5.1
User Guide

1   Introduction

Immersive Calibration PRO is the most advanced computer assisted auto-calibration software solution for multi-projector setups.

Immersive Calibration PRO introduces a calibration workflow for calculating the geometrical correction and soft-edge blending needed for projecting from multiple projectors on different projection screen shapes. This workflow is a result of years of experience and development of multi-projection systems for commercial and non-commercial flight simulator visual systems, multimedia presentation and entertainment.
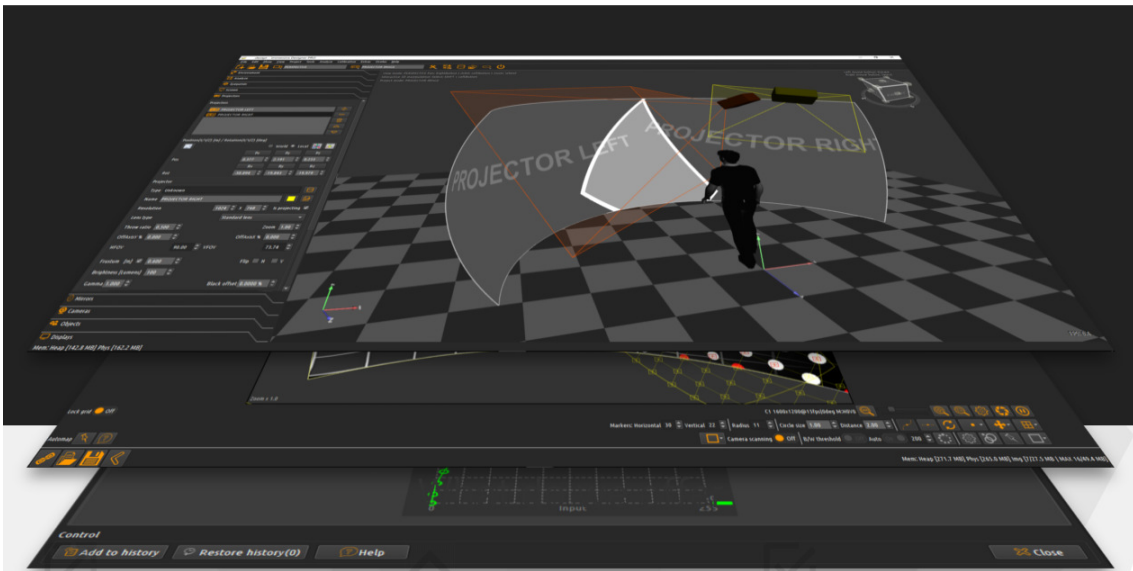
The user interface is full of advanced features needed to follow the auto-calibration workflow needed to map 2D projection scene (video playback, presentations, computer desktop, etc.) or 3D projection scene (games, simulators, CAD applications, etc.) to any projection screen shape.

The client/server architecture makes it possible to remotely calibrate distributed projection systems that consist of several networked projection channels.

After the calibration is finished the software exports the geometrical correction and soft-edge blending data that can be loaded in our warping software Immersive Display PRO. Next to that, the software will export the virtual camera position, orientation and zoom per projection channel needed for projecting 3D scenes for games, simulators, etc. Ex: The software will export the cameras for FSX/Prepar3D that need to be copied into the camera section of the flight of mission files of FSX or Prepar3D. Also a general virtual

camera description will be exported that can be integrated in any 3D based API, framework, scene or game engine, etc. (like DirectX, OpenGL, Open Scene Graph, etc.).

The built-in plugin system allows extension of the software by using plug-ins. Plugins are provided for different cameras, exporters, post-exporters, etc.

Immersive Calibration PRO supports up to 30 projectors that can be configured in different horizontal and vertical stacking.

Immersive Calibration PRO is designed for home and professional environments. Applications include:

- Home Entertainment System
- Flight, Ship and Car simulators
- Business Data Visualization
- Interactive & Touch Displays
- Conference rooms
- Video Playback
- Live Digital Motion Graphics
- Etc.

2   System requirements

The following is the required minimal configuration:

- PC with 2.0 GHz or higher processor (32bit or 64 bit)
- 2 Gb or more RAM
- A moderate graphics card (NVIDIA, AMD/ATI, Intel)

Other requirements (optional):

- Digital camera or Web camera + a tripod (optional)
- Laser pointing device (optional)

3 Definitions

Before describing the workflow for a perfect calibration, a number of definitions will be created that will be used through the document.

Computer Display: This is a graphical display provided by the computer graphical card. Single graphical cards can provide one or more displays. The displays from all video cards and enumerated by Windows and presented to the user in the "Graphical Properties" screen.
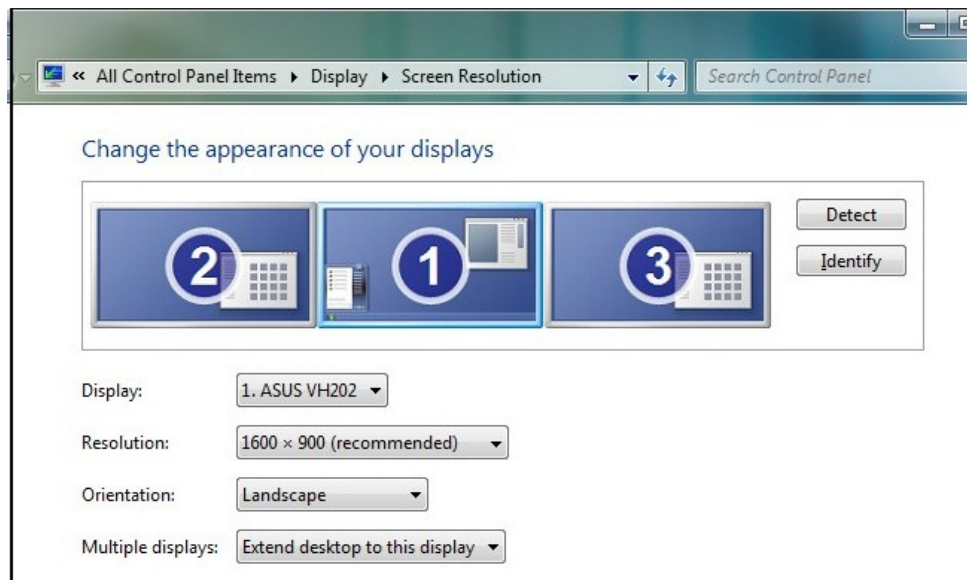
One display can provide output for one or more projectors. Single displays can also be grouped in larger displays the provide output for more projectors.
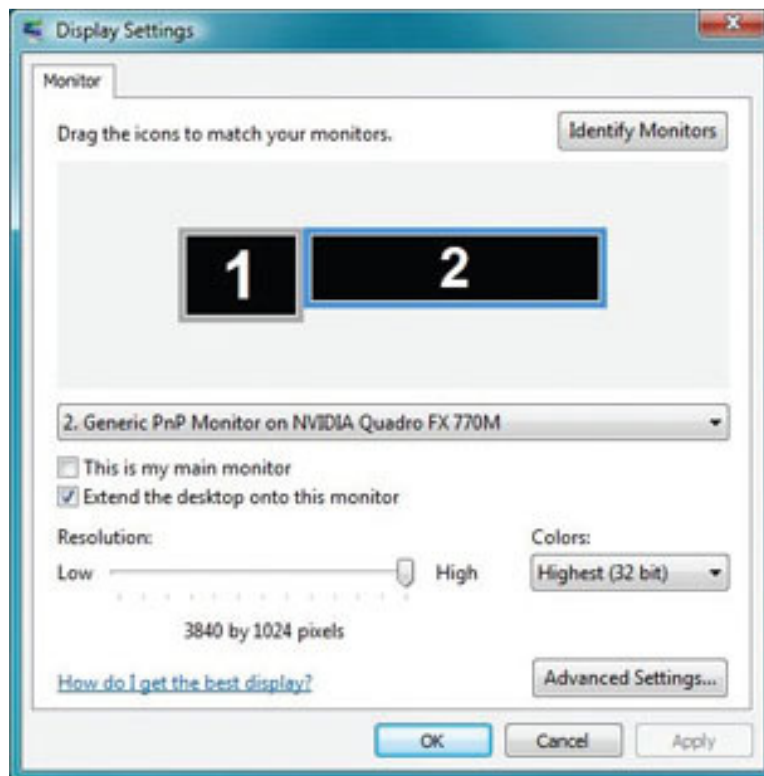
Example: When a Matrox TrippleHead2Go is connected to an output, one display will be presented with a resolution 3x (single display resolutions). Matrox TrippleHead2Go can be used to connect 3 projectors to this display.

Example: When using *ATI Eyefinity* graphical card, the individual displays can be combined in a single grouped display in different configurations (2x1, 3x1, 2x2, 3x2, etc.).

Example: When *NVidia* graphical cards are used, the NVidia 2D surround can be used to combine the displays in one single wide display. *NVidia Quadro* cards also support grouping using the NVidia mosaic technology.

Important: The resolution of the display has to be set accordingly to the native resolution of the projector connected to the display. If a single projector is connected to a single display, the resolution of the display has to be the same as the resolution of the projector. If multiple projectors are connected to a single display, the total resolution of the displays has to be set to the sum of the horizontal resolutions of all projectors in the rows and the columns.

Projector: This a single projecting device connected to one computer display. When a computer display has several outputs, several projectors can be connected to a single computer displays.

Projection screen: This is the projection surface used to project the images from one or multiple projectors. Projector images can fall completely on the projection screen or the projected images can overshoot the projection screen and part of the image will be outside of the projection screen.

Projections screen can be of any shape and size. When using projection screens with cylindrical or partial dome shape our workflow provides extra calibration possibilities for projecting 3D scenes for games, simulators, etc. by calculating the perspective frustums of the 3D scene virtual cameras.

For the purpose of mapping of the projection screen, the screen has to be marked in equidistant *columns* and *rows*. Physical markers or laser pointer can be used to mark the projection screen.

Camera View: This is the view of a single static digital photo camera or a webcam. The images of a single camera view contain part of the whole projection screen. Single camera view can contain the complete projection image of single or multiple projectors. So, the camera has to be positioned to capture the whole image of one or more projector on part of the projection screen. This view is used when mapping of the screen and projector grids is done in the camera image (*Map on camera mode*).
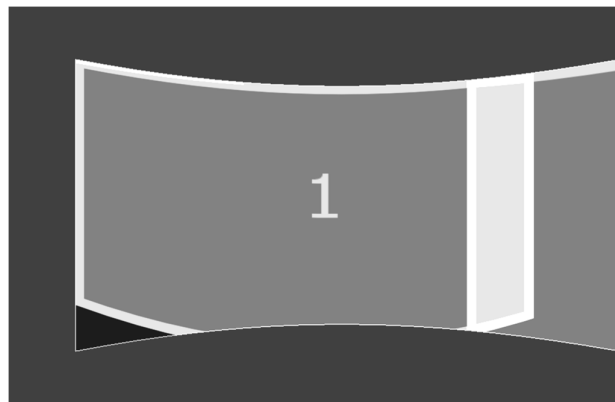
Projector View: This is the view of a single projector. It is similar to camera view with the difference that the view is shows as if the projector is replaced with a camera with the same field of view as the projector frustum. This view is used when mapping of the screen grid is done on the projector (*Map on projector mode*).

Mapping Grid: This a linear of curved 2D grid used to point to the screen columns and rows or projected markers in the Camera View or Projector View. Mapping grid has horizontal and vertical control points that can be moved with the mouse or keyboard keys in the Camera View. The number of the control points is the same as the featured to me mapped.
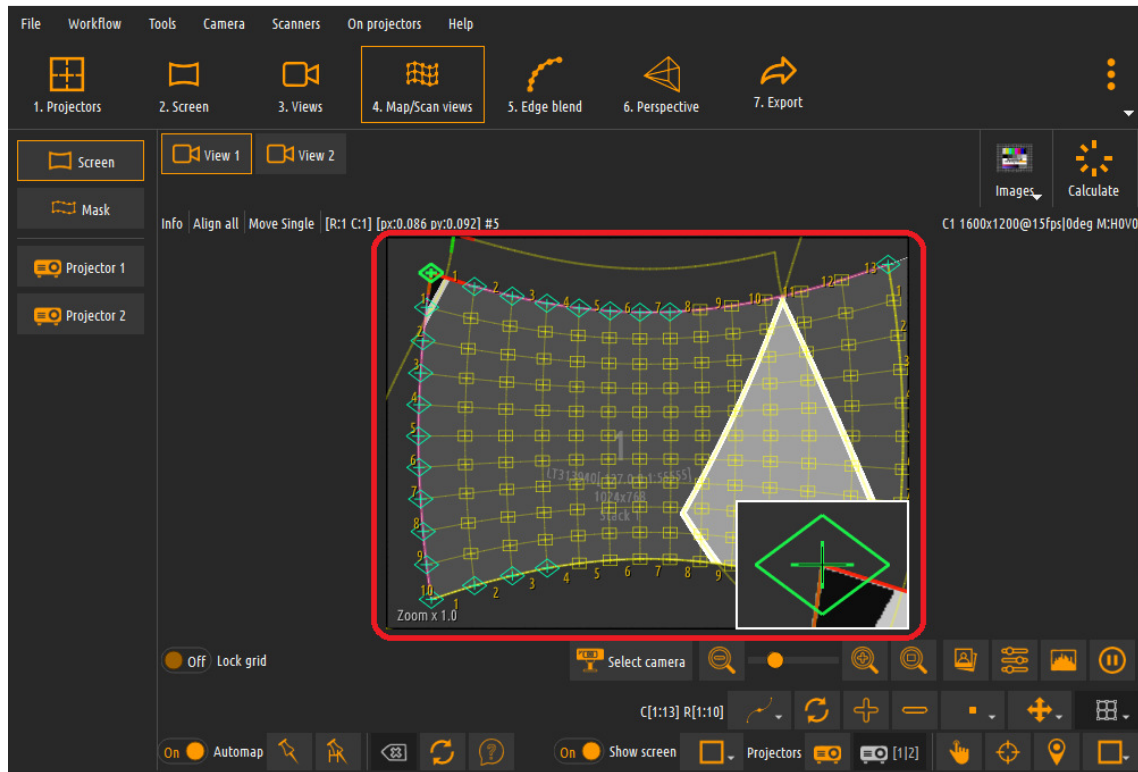
Rendering Client: This a PC connected to the projectors. It has one or more computer displays whose outputs are connected to one or more projectors. A single instance of Immersive Calibration PRO started on the Rendering Client PC can manage only one display. Multiple instances of Immersive Calibration PRO can be started on one rendering client PC.

The Rendering Client receives commands and information form the Controller Server PC about what to be presented on the display and the projectors. After the calibration is completed the Rendering Client also receives the geometrical correction and soft edge blending information for calibration preview.

Controller server: This is a single computer running Immersive Calibration PRO. Only one instance if Immersive Calibration PRO can run in Controller

Server mode. The Controller Server computer can be the same as the Rendering Client computer as long as Immersive Calibration PRO is shown on a separate display.

Immersive Calibration PRO on the Controller Server PC will create one combined virtual display and will connect the projectors from the Rendering Client to this virtual display.

Immersive Calibration PRO in Controller server mode will calculate the geometrical correction and soft-edge blending for all projectors.

Note: When using single camera view, the Rendering Client and the Controller Server are combined and run on the same PC. This simplifies the hardware requirements for calibrating multiple projectors with one camera view.

Camera calibration: Camera Calibration is an essential step in the preparation for automatic screen mapping when using cameras with radial distorted images. For the calibration procedure the user has to capture a well-known calibration grid (e.g. chessboard) several times from different positions and camera distances. The estimated points from the grid and the knowledge about the original points are used to estimate the radial/tangential/affine distortion parameters of the camera and its intrinsic parameters.
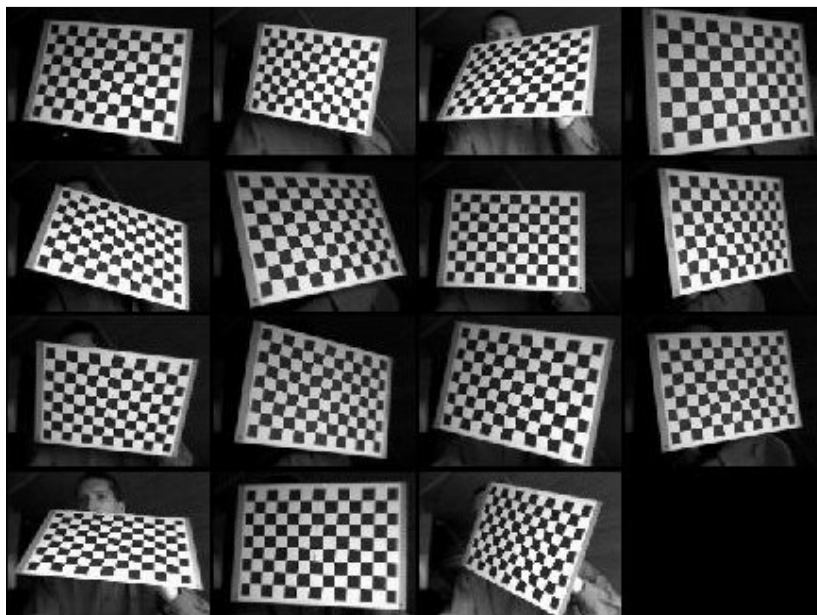
The camera distortion parameters and the camera intrinsic parameters are used during the automatic screen grid mapping to accurately map the

complete screen grid in a single view based on a minimal number of know screen points.

This procedure eliminates the use of laser pointing device with image stacking or other physical markers on the screen.

Immersive Calibration PRO supports calibration of photo cameras and all digital cameras.

4   Workflow

Immersive Calibration PRO introduces a calibration workflow for calculating the geometrical correction and soft-edge blending needed for projecting from multiple projectors on different projection screen shapes. The workflow includes server steps:

- Prepare the projection setup and decide on the number of camera views. If a single camera can capture the complete projection use the Single View method.
  If a single camera cannot capture the projection screen use several camera views or projector views per projector. Each projector has to be partially or completely visible in at least one view.
- Map the *screen* in the *camera view* or the *projector view*. The screen has to be divided in equidistant *columns* and *rows*. The screen map grid has to be aligned with the columns and rows. When a calibrated photo camera or digital camera is used, mapping of the screen can be done automatically.
- In *Map to camera* mode, automatically scan and map the projector using a camera.
- When using known screen shape (Ex: Cylindrical, Dome, Partial Dome of Cave screen), setup the virtual camera *perspective frustums* for projecting 3D content from 3D game or simulation engines.
- Calculate the geometrical correction and soft-edge blending so that projected content on the projection screen will look undistorted and uniform.
- Load the calibration result in Immersive Display PRO and apply the correction to the windows desktop and any other program or game.

5 First time Bonjour installation

In order to automatically recognize and connect the client and the server PC on the network, a zero-configuration service is used. For this purpose, the Bonjour service needs to be installed on both the client and the server PC.
From the Immersive Calibration PRO locate and double click on the INSTALL_FIRST_BONJOUR.bat script. This will start the installation of Bonjour. This installation step is needed only once and should be performed the first time Immersive Calibration PRO is used on the PC.
Follow the installation steps of Bonjour install script and finish the installation.
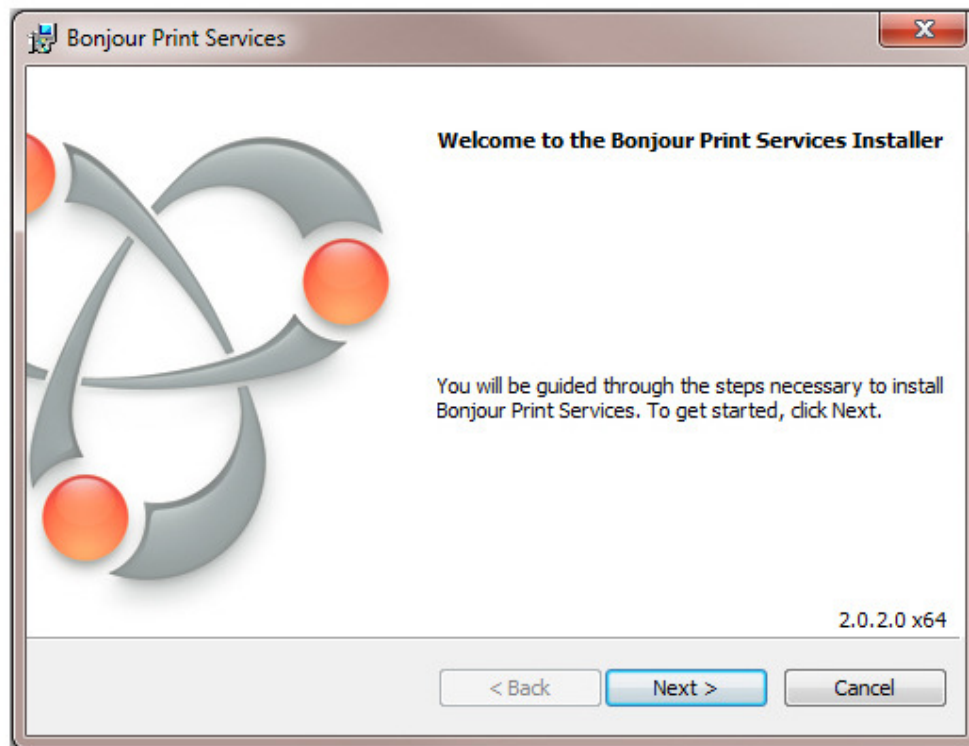
Note: If using firewall, make sure that the firewall is disabled on both the client and the server PC in order to allow the client and the server PC to connect to each other without being blocked by the firewall.

6 User interface

6.1 Single View

Use the Single.exe program to start single view calibration.

The single view calibration can be used when a single camera can capture the complete projection from all projectors on the projection screen. The shape of the screen and the exact dimensions of the projection screen are not relevant.

In the single view calibration mode, the rendering client and controller server are combined in one and both run on the same PC.

Only one computer display can be calibrated at a time. All projectors have to be connected on the same computer display.

Single view calibration produces a single head calibration results that can be used to "wallpaper" the combined image from all projectors on the screen.

Single view calibration is a step-by-step guided calibration.

**Note**: A HD web camera or a digital camera is required to perform the Single View automatic calibration.
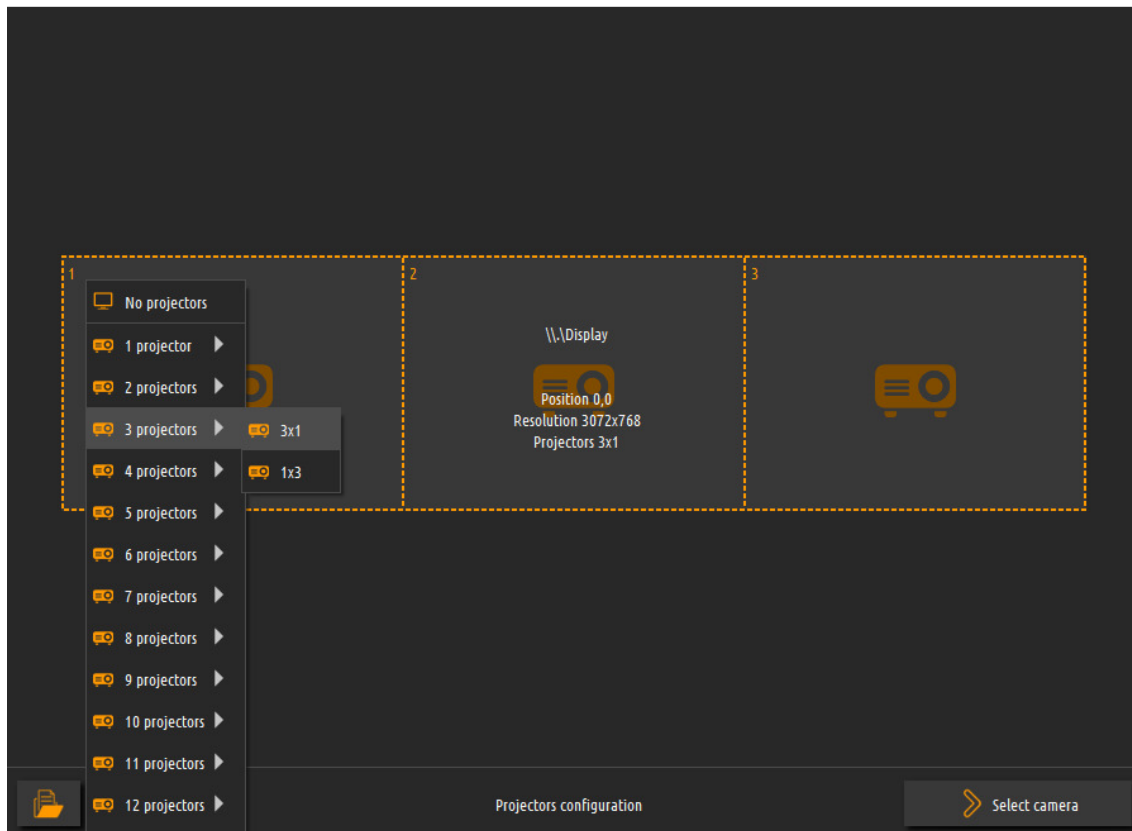
In the projector configuration window select the display to be calibrated and select the projector configuration to match the number of projector and projector setup.
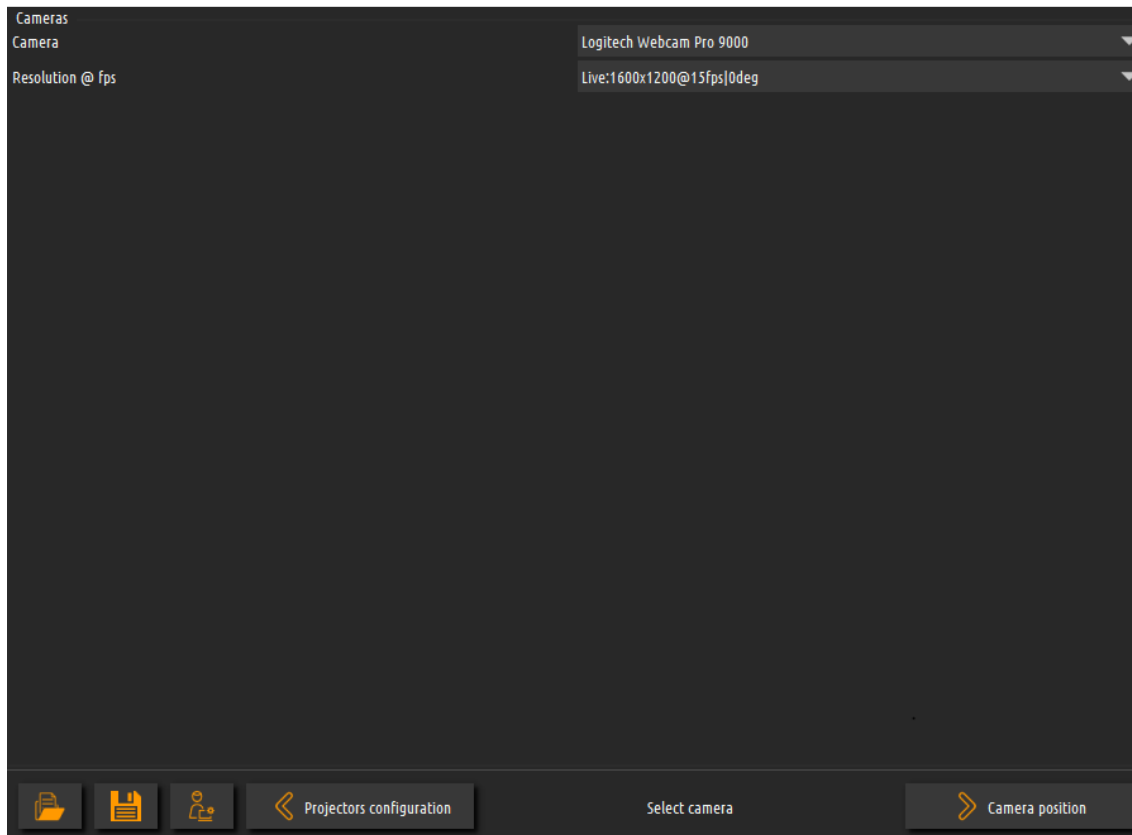
In the camera selection window select the Select the camera to be used during the calibration.

Any web camera recognized by Windows or a digital camera supported by the software can be used for calibration, but a high-definition camera is preferred for better calibration. Select the highest camera resolution for best calibration result.
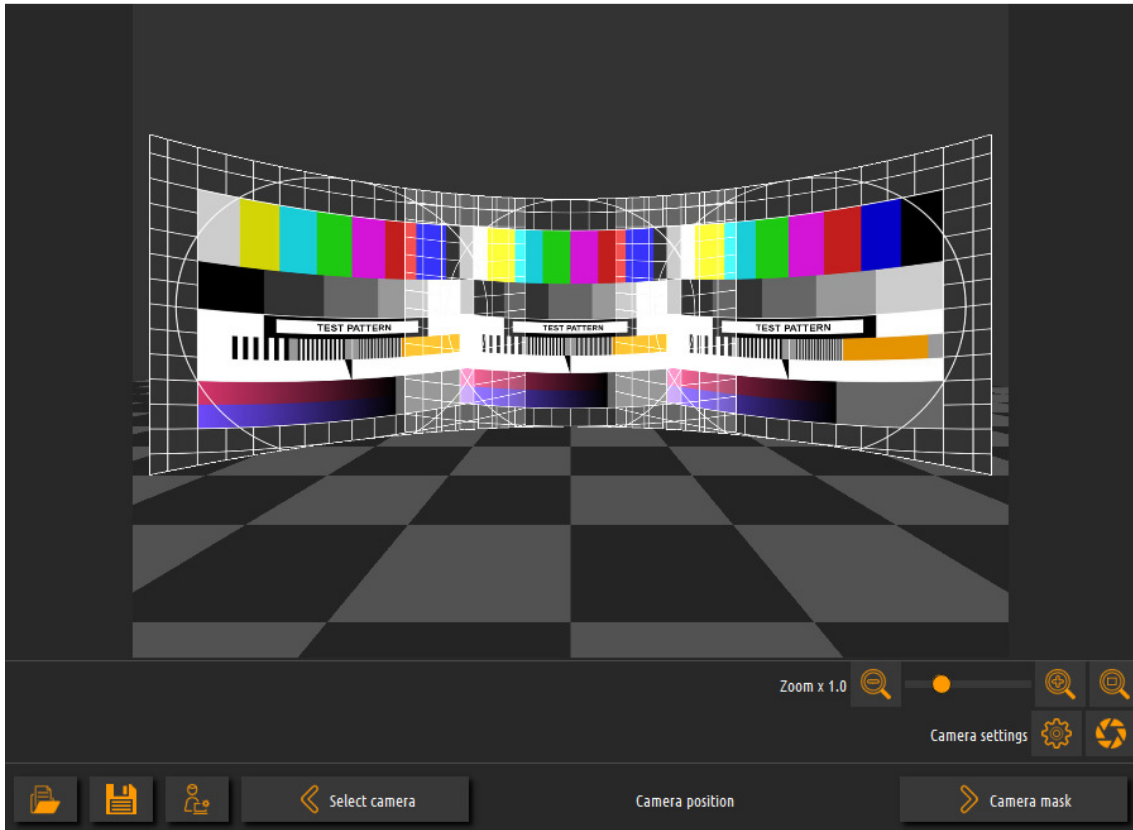
Position the camera so that the camera can capture the complete projection. For the best results the projection should cover the camera view as much as possible.

Adjust the camera properties using the *Camera settings* button. Adjust the properties so that the camera image will look as close as the projected.

Note: The camera has to be fixes and should not be moved during the rest of the calibration.
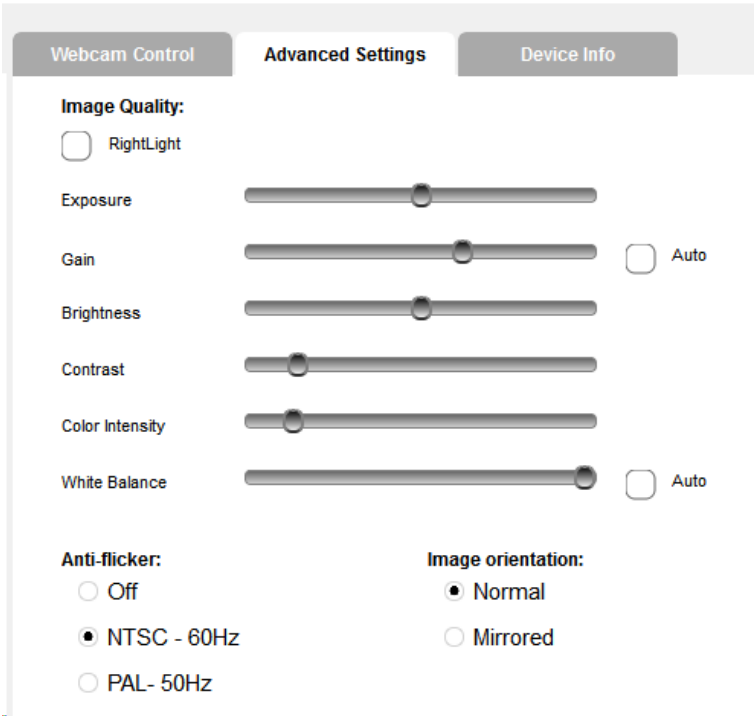
For successful calibration it is important that all automatic camera features (auto-focus, auto-zoom, white balance, etc.) have to be turned off.

Press the camera properties button to open the camera properties widow. This window is provided by the camera drivers and can look differently for different cameras.
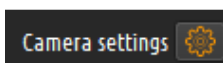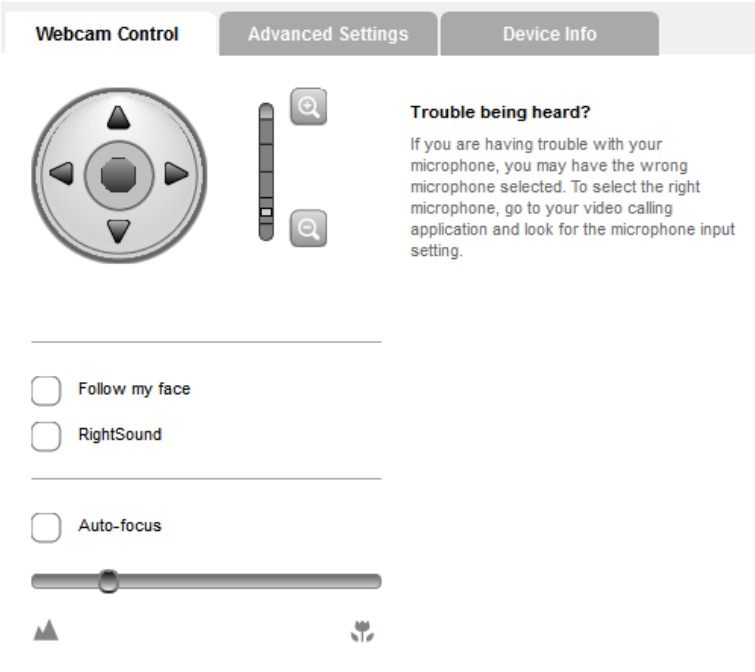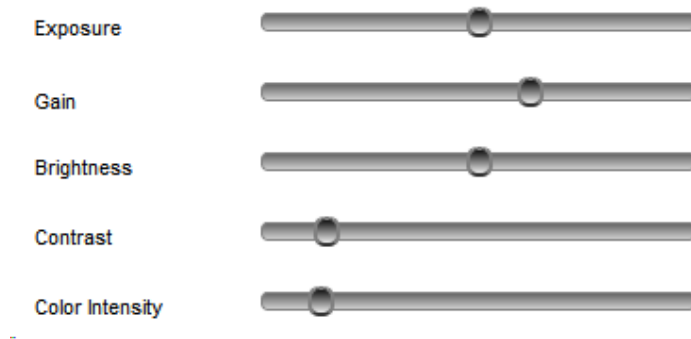
No Auto focus

No Auto Gain and Auto White Balance

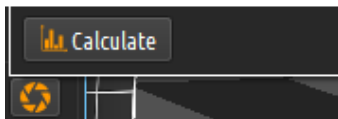Use the camera controls to adjust the camera image for the best projector scanning and calibration results.

The primary control of the camera image is the "Exposure" control. Use the Exposure to get the most natural looking camera image.
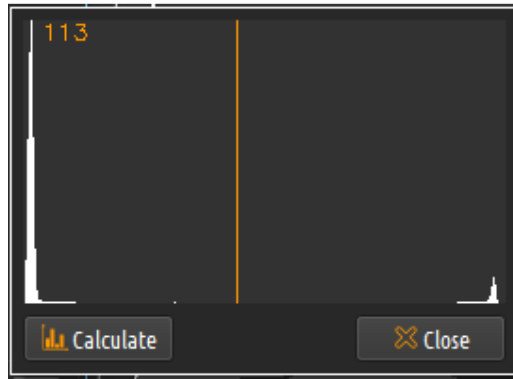The camera image should look natural and should not be too dark, too bright or saturated. The black and darker colors and the white and brighter colors should utilize the complete camera colors range.

In order to help and facilitate the adjustments of the camera properties, the software comes with a tool called Histogram to evaluate and calculate the used camera dynamic range.

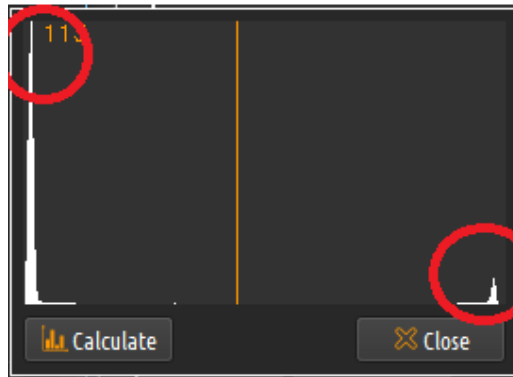Select the Histogram button and press on the calculate button.

The software will project a number of patterns on the projection screen and will calculate the range between the dark colors and the bright colors as well as the middle distance.
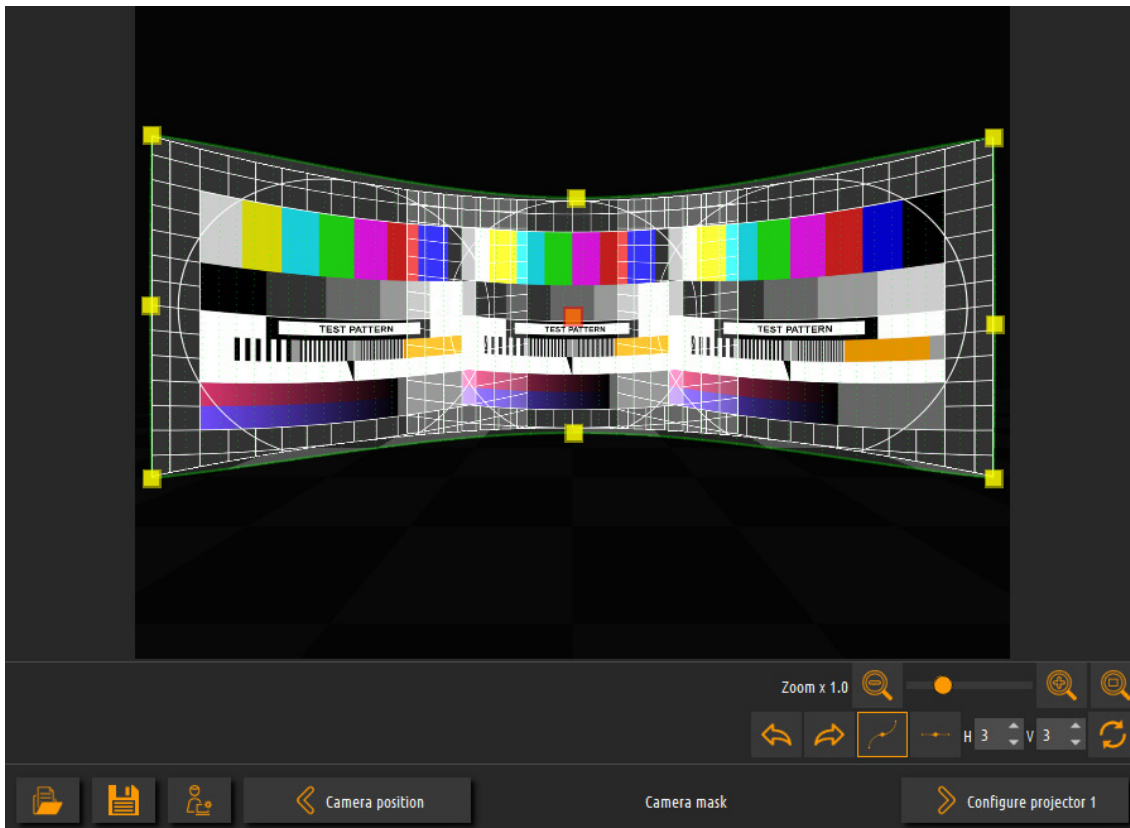
Camera histogram

The camera histogram shows two peeks. The left peek is for the dark colors and the right peek is for the bright colors.

Camera histogram peeks

Use the camera properties (primarily the Exposure) to change the camera properties in such a way that the two peeks are as far as possible and that the orange line lies in the middle between those peeks.

Note: Make sure that you recalculate the Histogram each time the camera parameters have been changed.

Use the camera mask control points to "mask" the projection. This will "help" the automatic calibration to focus inside the masked region and discard the images outside of the masked region (Ex: reflections, ambient light, etc.).
Pick one of the control points with left-mouse button click. Drag the control point while the left mouse button is clicked. Use the right-mouse button for fine adjustment.

Use the toolbar to adjust the mask The *Import* button loads a previously exported mask file. The *Export* button saves the current mask to a file for later use. The mask can be loaded later.

The button can be used to select the mask edges curve mode. In this mode the mask lines between the control points are curved and can follow the contours of a curved projection screen.

The [icon] button can be used to select the mask edges linear mode. In this mode the grid lines between the control points are strait lines and can follow the contours of a non-curved projection screen.

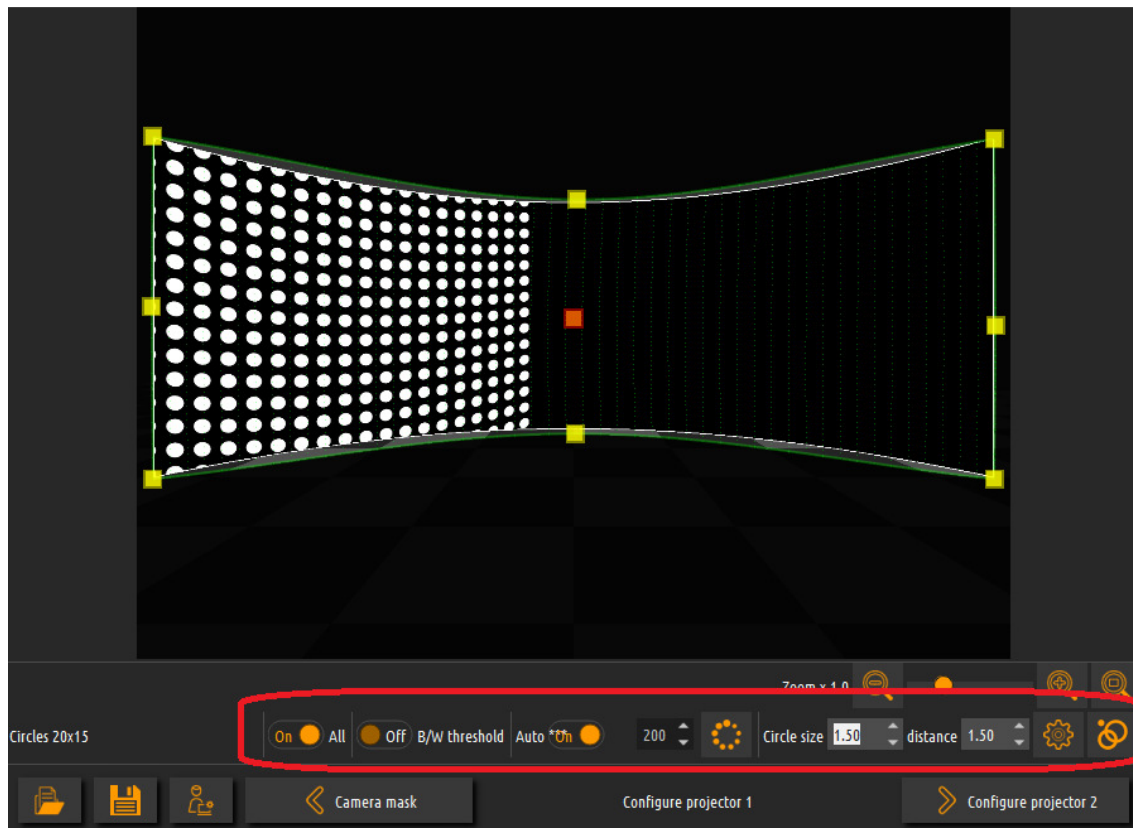The [icon] button can be used to completely reset position of the control points in the mask lines.

User can also increase and decrease the control point along the horizontal and vertical edges of the grid

Each projector will project a series of images with circles. In order to "recognize" the circles in the images, all projected circles have to be clearly visible in the camera view.

The *Black/White threshold* can be used to distinguish the projected circles from the other ambient light. Adjust the *B/W threshold* until only the projected circles are visible as white circles.

When *Black/White threshold* is checked the software will automatically determine the threshold based on the ambient light and the background

image. Press the *Refresh Threshold* button to refresh and automatically calulate a new value of the threshold. This is needed when the ambiental light conditions have changed or when the camera position has changed.

Use the *Circle size* to adjust the size of a single circle. The smaller the circle, the better the calibration result. However, the bigger the circles, the better the circles are viewed in the camera view and better recognized.

If some circles are partially visible, they can be disabled from the recognition step. Press the *Configure visible circles* button to open the wi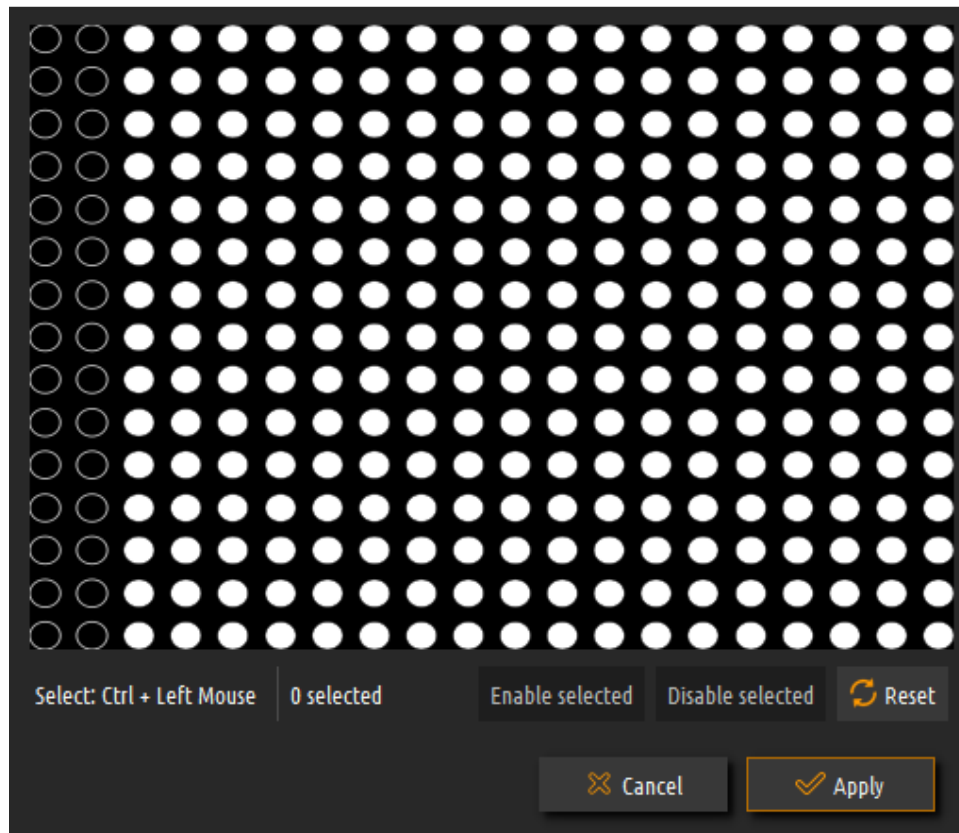dow with the configuration of the visible circles. In this window press on the circle using the left mouse button to toggle the circle visibility.

Press the *Recognize circles* button to initiate the procedure for circles recondition. After the procedure has finished, the recognized circles are shown with green color.

Although there are circles that are not recognized in this step, the software will take care that those circles are still automatically mapped in the next step.
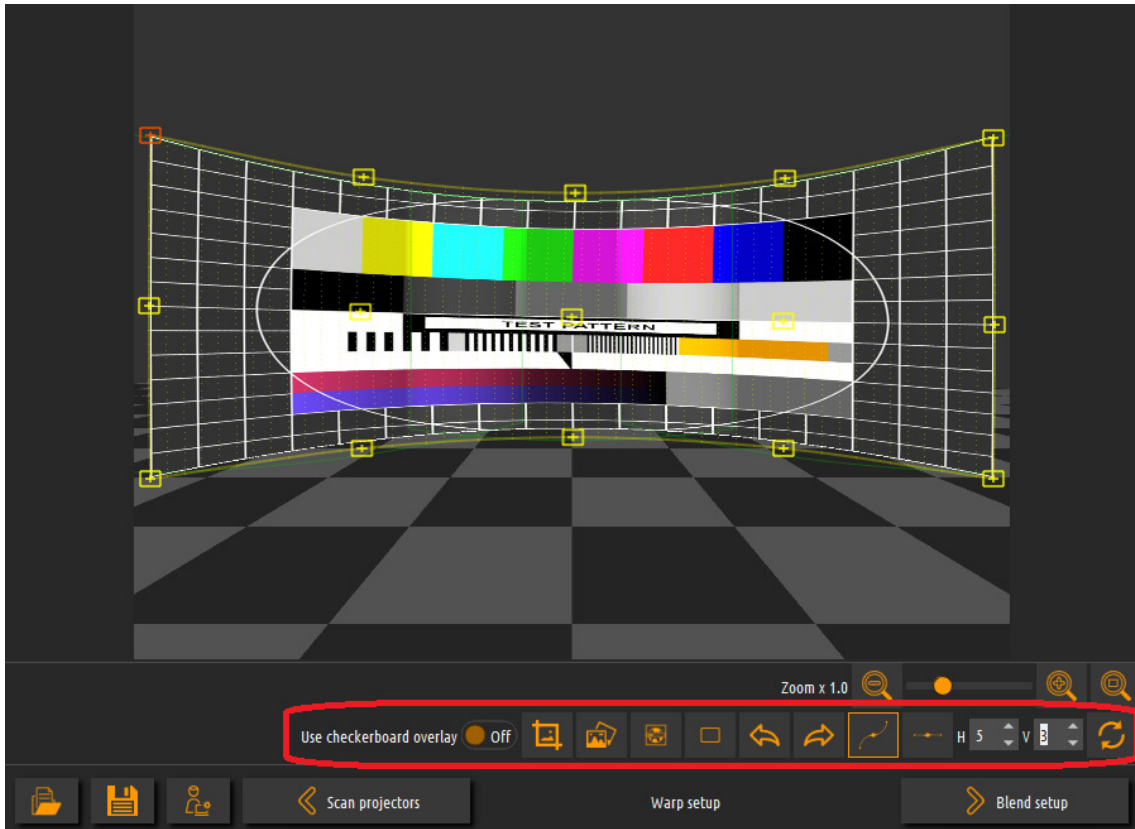
In the screen warp setup window Use the screen grid control points to map the unified projection on the projection screen.

Pick one of the control points with left-mouse button click. Drag the control point while the left mouse button is clicked. Use the right-mouse button for fine adjustment.

Use the toolbar to adjust the warp.

The *External image* button loads and shows external image. This image replaces the default Test image.

The *Show test image* button loads and shows the default Test image.

 The *Take mask* button uses the mask grid control points as a screen-warping grid.

The *Import* ⤺ button loads a previously exported warping grid file. The *Export* ⤻ button saves the current grid to a file for later use. The grid can be loaded later.

The button can be used to select the grid lines curve mode. In this mode the grid lines between the control points are curved and can follow the contours of a curved projection screen.

The button can be used to select the grid lines linear mode. In this mode the grid lines between the control points are strait lines and can follow the contours of a non-curved projection screen.

The button can be used to completely reset position of the control points of the warping grid.

User can also increase and decrease the control point along the horizontal and vertical edges of the grid.
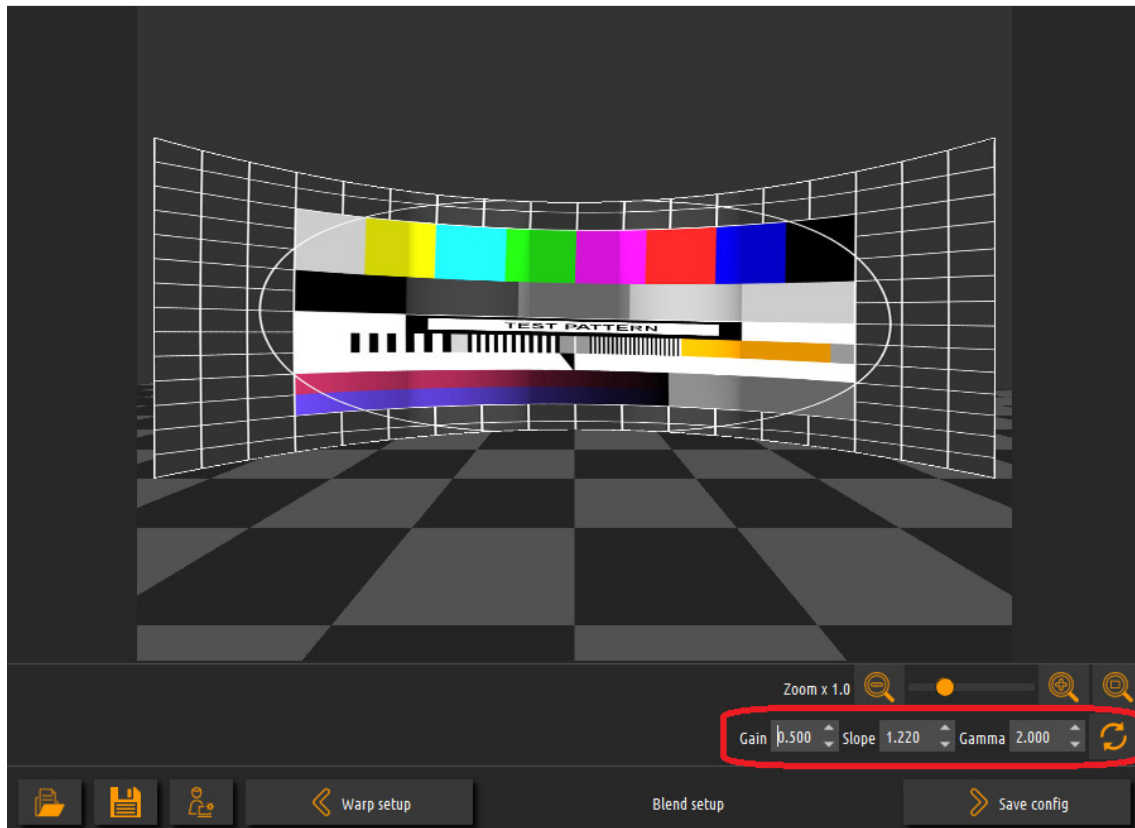
In the blend setup window adjust the blending ramp between the overlapping projector regions. Using the *Gain*, *Slope* and the *Gamma* controls the shape

and the value of the blending ramp can be fine-tuned so that the overlapping blending regions are seamless.

The *Gain, Slope and Gamma*, parameters influence the fade-in and fade-out profile of the overlapping regions of the projectors. *Slope* parameter determines the steepness of the blend profile and *Gamma* determines the curvature of the profile.

Use the *Reset* button to reset the blending ramp to the default values. The default values for *Gain, Slope and Gamma* provide the best blending result for most of the projection environments. Depending on the color profile of the projected scene and the used projectors, slight adjustment in the Gamma and Slope settings will be sufficient for fine-tuning the blending regions.

After the calibration is completed the calibration can be saved in a *.procalib* file. This file contains the geometrical and blending information to project computer desktops, movies, animations, games and other content.
The saved *.procalib* file can be loaded in Immersive Display PRO to do the geometrical correction and soft-edge blending of the video output before the output is sent to the projector.

Select the External calibration from the projector configuration menu in Immersive Display PRO display. A file dialog will be opened to select a *.procalib* file. This file contains the projection setup for the display and all the needed geometric correction and soft-edge blending information. This will override the manual calibration in Immersive Display PRO. In Immersive Display PRO the users can still adjust the profile of the blending curves and the color profiles of the projectors. However, when using external calibration file the geometrical correction cannot be adjusted manually.

Note: Immersive Display PRO – Ultimate license is required to be able to use the *.procalib* result file. If no license is present the "Unregistered version" watermark will be overplayed on the output when using the *.procalib* result file.

6.2 Multi View

Multi view calibration is advanced calibration that can be performed with or without camera. When a single camera cannot capture the complete projection, multiple cameras can be used or a movable single camera can be used to position the camera to capture part of the screen.

When the screen geometry and dimensions are known, multiple view calibration will also produce multi-head calibration results. Multi-head calibration results contain perspective frustum information that can be used in 3D game and simulation engines to define individual game/engine camera vide that will be rendered on each projector. This allows projecting 100% geometrically correct 3D worlds on omni-directional displays like domes, cylinders, etc.

Immersive Calibration PRO supports many types of projection screen shapes, Cylinder displays and Dome displays.

The rendering client and controller server can run on single computer or on multiple computers. For the calibration purposes projectors have to be connected to the rendering client computer.

6.2.1 Rendering client

Use the Client.exe program, to start the rendering client.

The rendering client project contains information about the display and projector configuration that the rendering client is using. It also contains connection information to the controller server.

Note: Make sure that if a firewall is running on the controller server PC, the firewall will allow connection to the configured port.

Once started, the rendering client will try to connect to the controller server and "advertise" its displays and projectors. When a connection is established with the controller server, the window title bar will show the connection info.
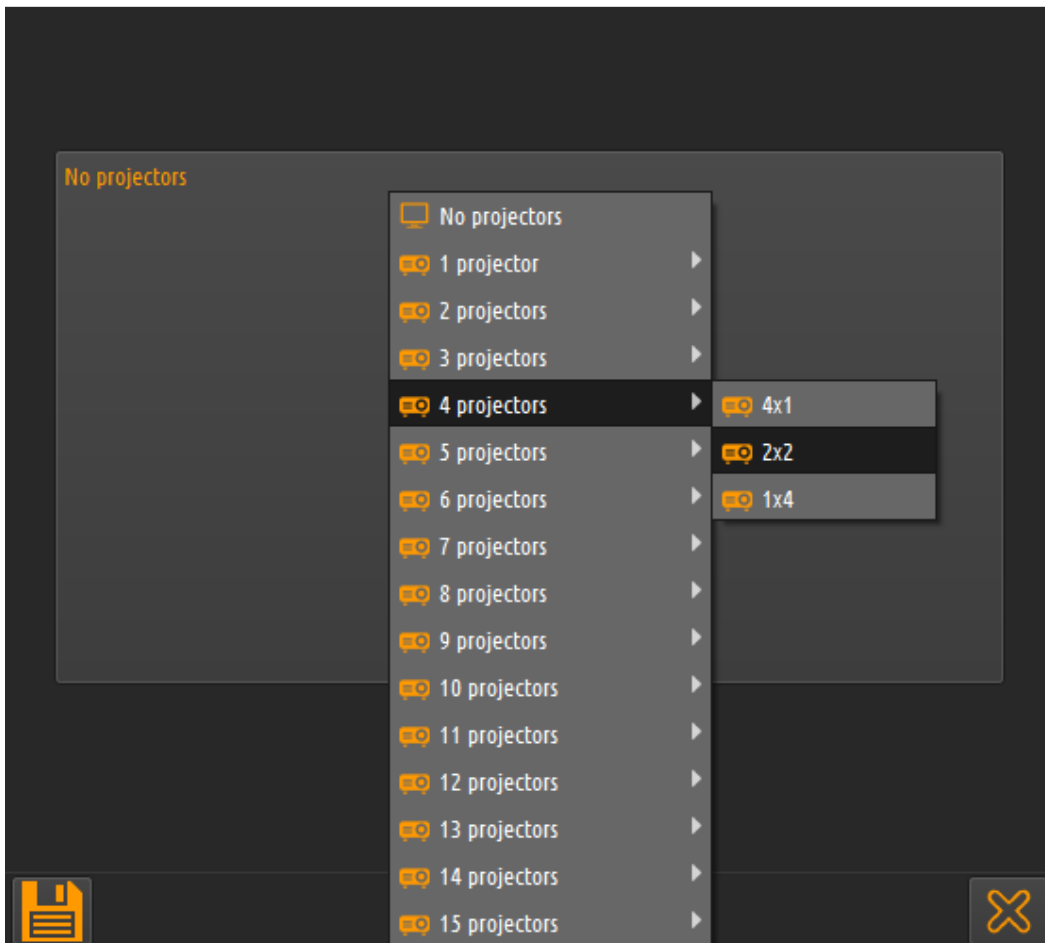
In the next screen, all available displays will be shown. Use the mouse right button to show the popup menu with the available projector configuration. The selected projector configuration should match the connected projectors to the display.
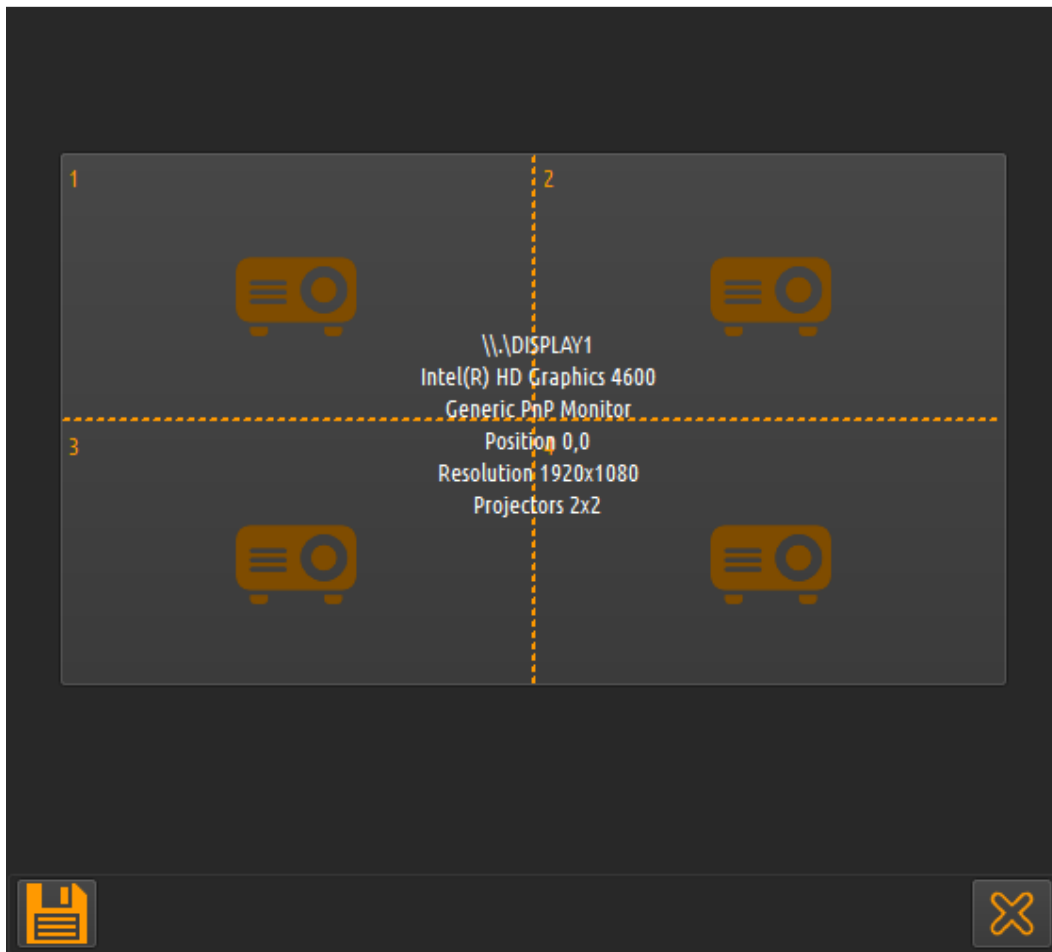
After the projector configuration is selected, a will screen window will be started on the selected display that will be used by the controller server for drawing the calibrated images.
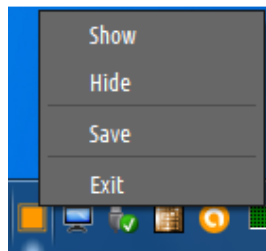
When configured the rendering client will be automatically minimized on the system tray and will wait and listen for connection from the server. Use the tray icon … to open, close or exit the rendering client.

6.2.2 Controller server

Use the Server.exe program to start the controller server.

One controller server is needed to calibrate one or more displays provided by the rendering clients.

When server.exe is started, a choice can be made to create a new project or load a previously saved project.
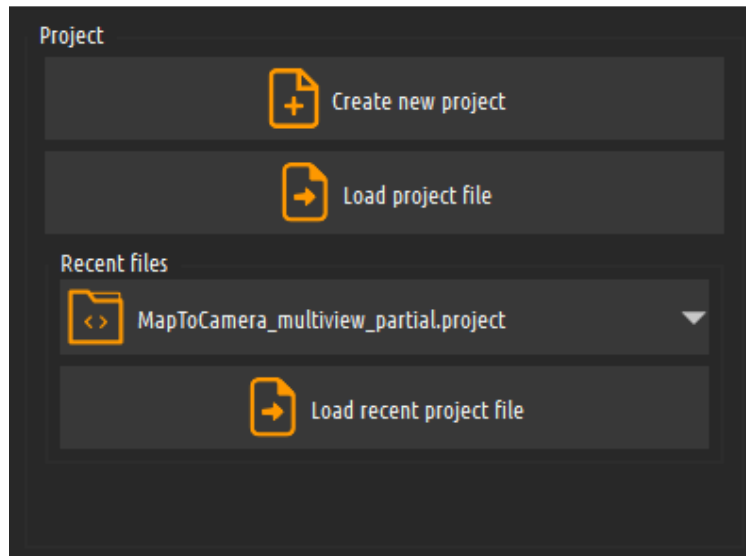
When creating a new project, the next window allows to select the projectors arrangement and the number of projectors layers (stacks) that are used. Up to 4 multi-stacking projector layers can be used to increase the brightness of the projected area on the projection screen.

For a "normal" alignment, a *tiled* (not stacked) arrangement is used.

When multi projection stacking is used, the projectors have to be assigned for each stack (layer).
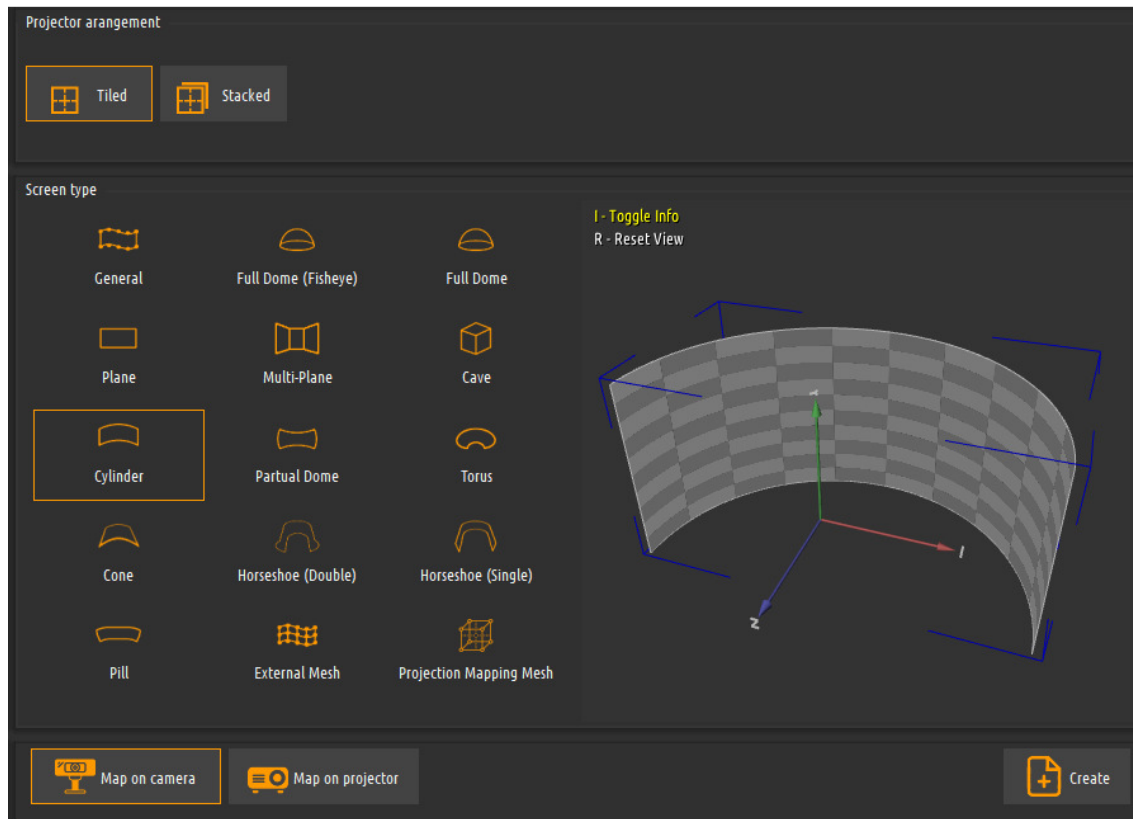
In the same window, the projection screen shape can be selected, as well as the mapping type: *Map on camera* or *Map on projector*.

Note: When a camera is used (digital camera or web cam), the "Map to Camera" method will require a camera images to be used to map the screen and projector grids to the screen edges and projector circles on the camera image. When a camera cannot be used die to different reasons (Ex. Large objects, cockpits, etc… in front of the screen), then the "Map to projector" mapping method should be used. In that case, a camera is not needed for calibration and mapping. Only the screen grid has to be mapped for each projector. The projector view is used to map the screen grid per projector.

When a general (unknown) screen shape is selected, user does not need to provide the dimensions of the projection screen. Any continuous surface can be used as a projection screen. User can map the combined projection image from all projectors on the screen surface using the display grids mapping per camera view.

Note: When an unknown projection surface is used, the virtual camera perspective frustums per projector cannot be calculated and are not available in the mapping GUI.

The next window shows the common workflow in defining and completing a multi-projection alignment.

The first step is to define the projectors setup.
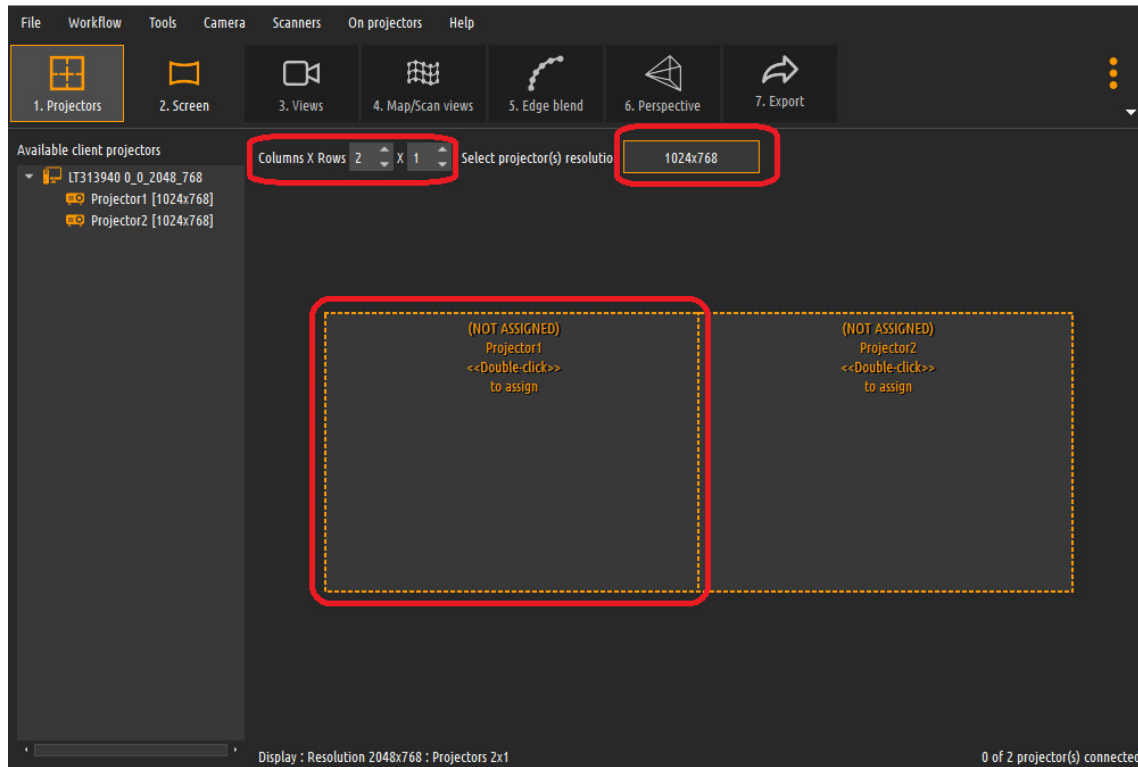
Use the columns and rows controls to create the projector configuration. The selected projector configuration should match the total number of projectors that are used.

Click on the projector resolution button, and select the resolution of a single projector. Use the projector native resolution.
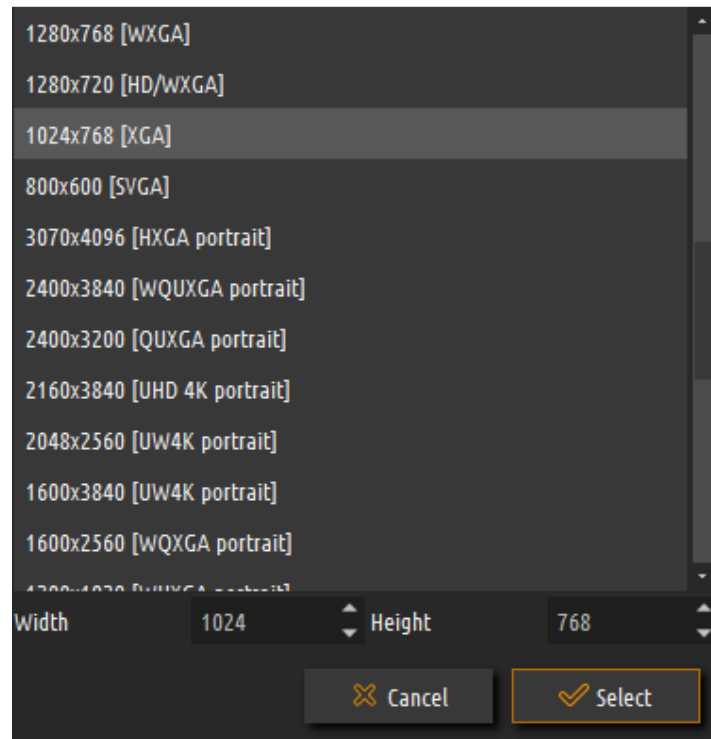
If the projector resolution is not in the provided list, user can enter a custom projector resolution.

Note: All projectors have to have the same resolution. For the best result the display resolution has to be chosen to match the native resolution of the projectors.

After the projectors configuration of the virtual display is selected, the individual virtual projectors are not connected to the actual projector. The virtual projectors have to be connected to the projectors connected to the rendering clients.

Double click on the projector icon to open a window with all connected rendering clients.
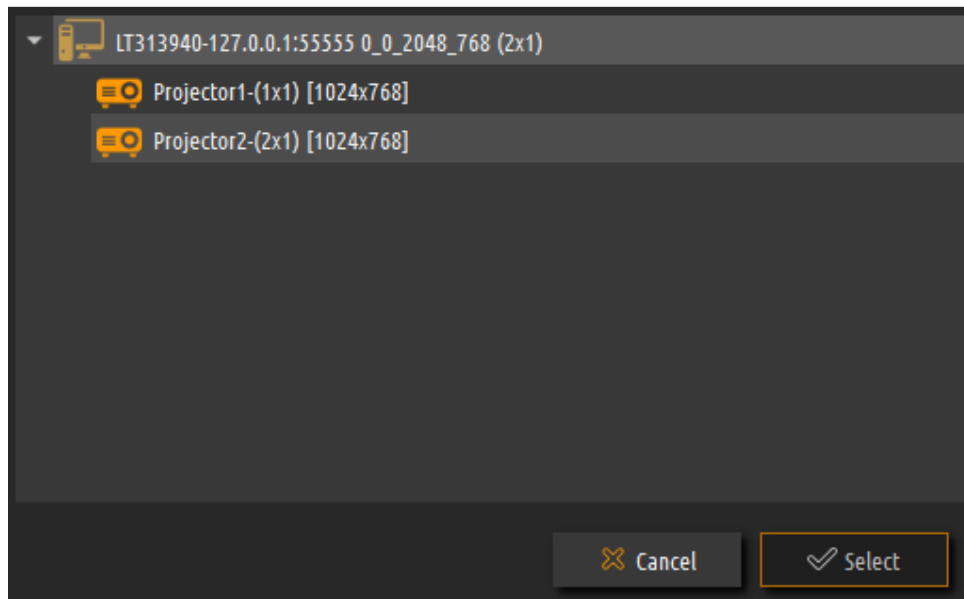
The remote projectors window contains list of all connected rendering clients and the projectors connected to the displays configured by the rendering clients. Select a projector from the remote projectors list for all virtual projectors.

If using multiple stacks, select the next stack and repeat the steps to connect the projectors for the selected stack.

6.2.2.1 Projectors overlap

Properly configured projector overlap is a prerequisite for successful multi-projector calibration and edge blending. At least 15% of projector images on the projection screen must overlap to be able to get edge-blending correctly. Immersive Calibration PRO provides easy means to verify and ensure the overlap between the projectors is enough.

From the On projector menu select Overlap check/All projectors. A special image with percentage of the projector image area will be projected from each projector.
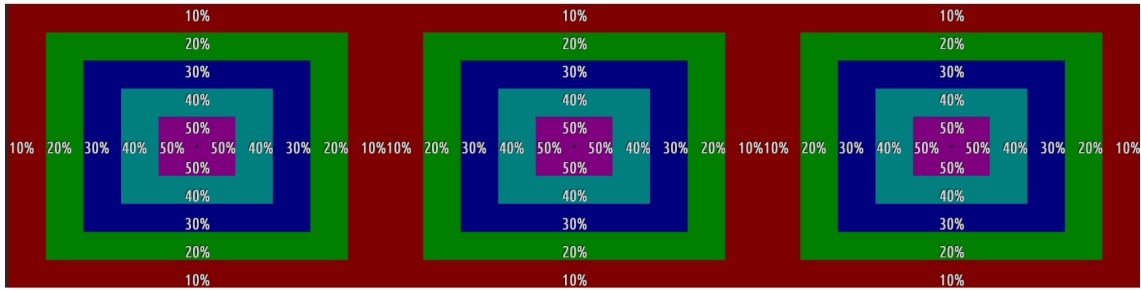
Look on the projection screen and verify that the projector images overlap by at least 15% by checking in which region the edges of the neighboring projectors end.
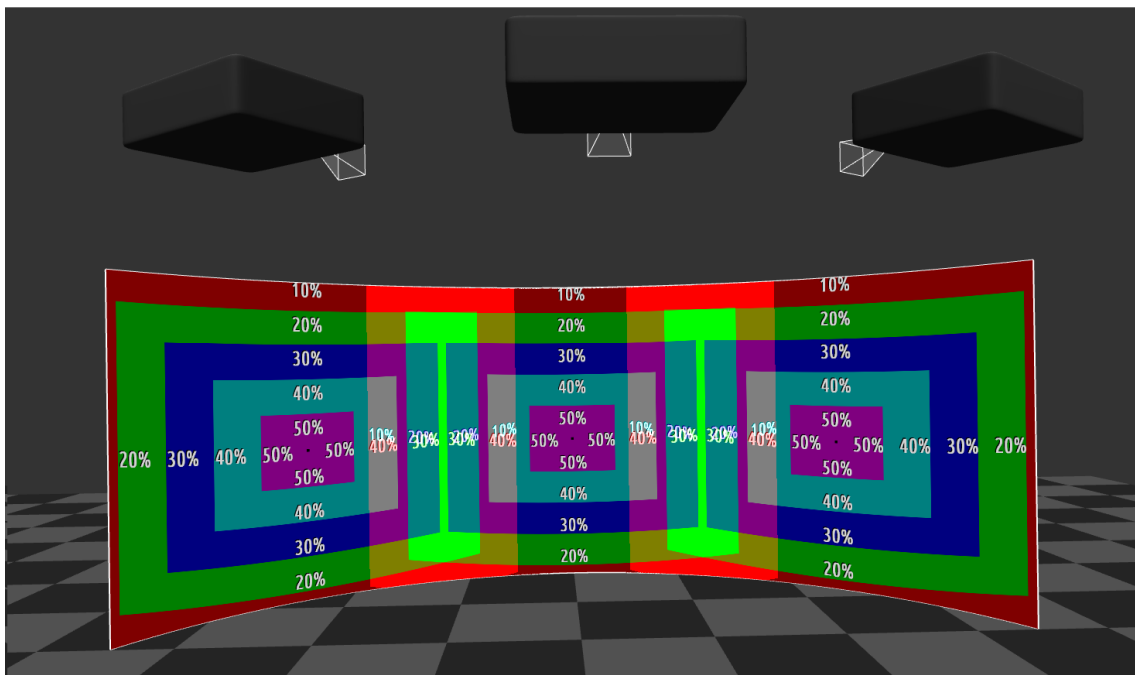
6.2.2.2   Projectors contrast & brightness

The projectors internal contrast and brightness is a key factor for getting perfectly edge blended images and color uniform image on the projection screen from the overlapping projectors.

Over saturation or under saturation of the color profile of the project image can lead to non-uniform edge-blending areas.

Before the calibration it is important to make sure that all projectors contrast and brightness settings are adjusted to prevent over or under saturation.

Immersive Calibration PRO provides features to facilitate the projectors contrast and brightness settings adjustments by looking on the projected image on the screen.

Adjust the projectors contract.

From the projectors settings menu, first select On projectors/Black/All projectors. Then from the on projectors/Contrast menu select the first projector. A special image will be projected to evaluate the projector contrast.

Set the projector contrast in the project very high. The oversaturated projector will produce a wide bright area (see image)
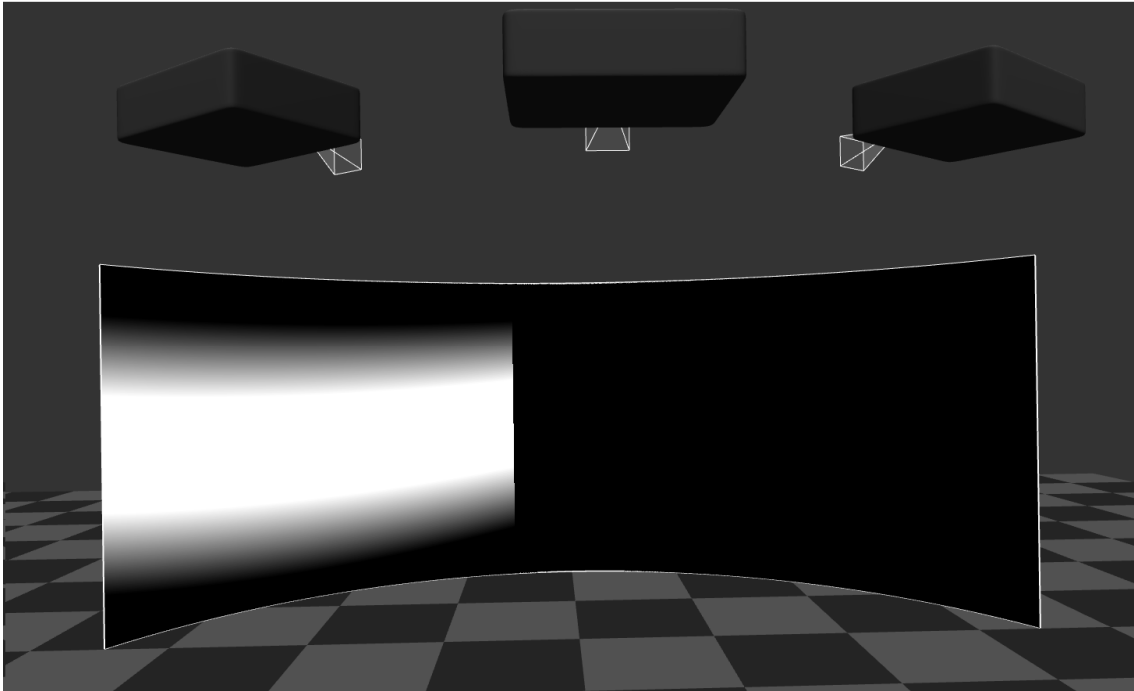
Then gradually decrease the contrast until bright white line shrinks into a line and does not shrink any more. This is the best projector contrast settings. **If you decrease the contrast further, the white line will only get darker.**
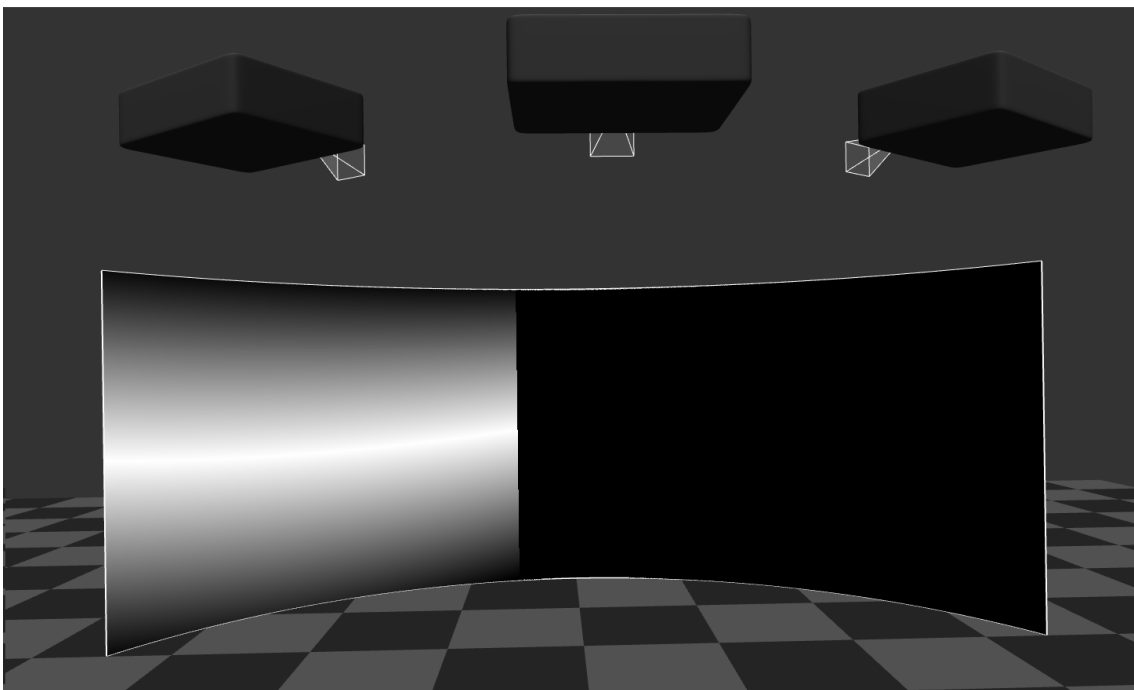
Repeat the same for all projectors.

Adjust the projectors brightness.

From the projectors settings menu, first select On projectors/Black/All projectors. Then from the on projectors/Brightness menu select the first projector. A special image will be projected to evaluate the projector brightness.

Set the projector brightness in the project very low. The under saturated projector will produce a wide dark area (see image)
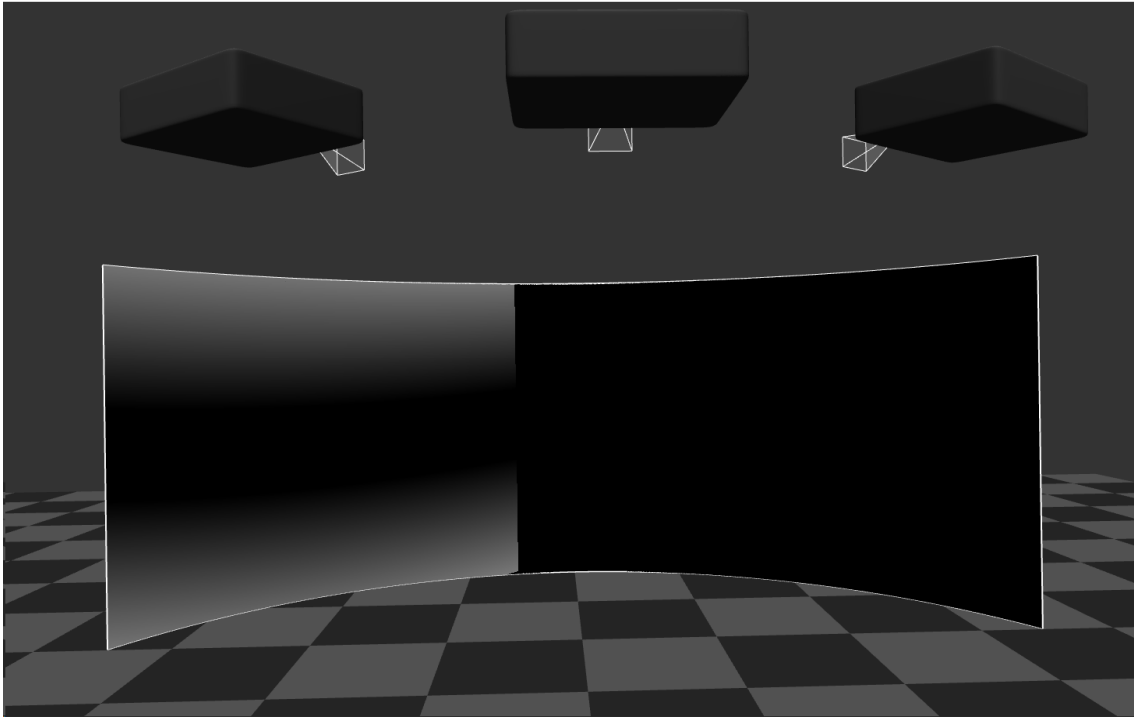
Then gradually increase the brightness until dark black line shrinks into a line and does not shrink any more. This is the best projector brightness settings. **If you increase the brightness further, the dark line line will only get brighter.**
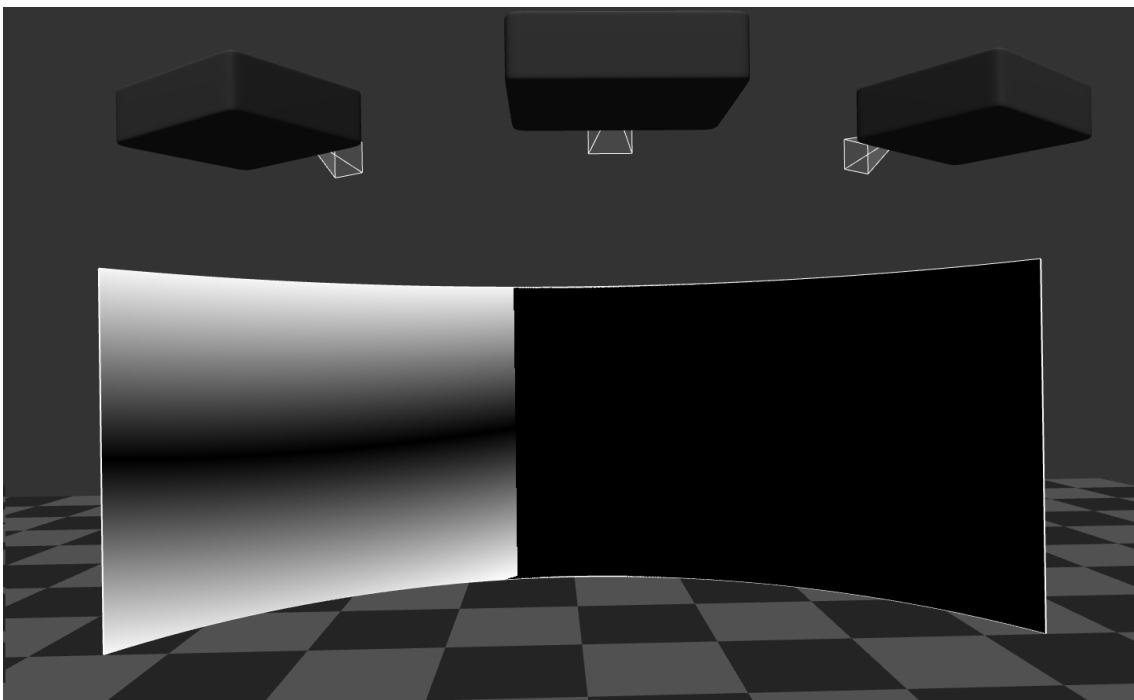
Repeat the same for all projectors.

6.2.3 Screens configuration

Different screen configurations are available depending on the selected screen type.

For mapping the screen into the camera view or projector view, each screen has to be divided in equidistant columns and rows. The column numbers start from the most left edge of the projection screen. Column number 1 is the first column from the left of the projection screen.

The rows start from the top most edge of the screen. Row number 1 is the first row from the top of the projection screen.

6.2.3.1 General screen
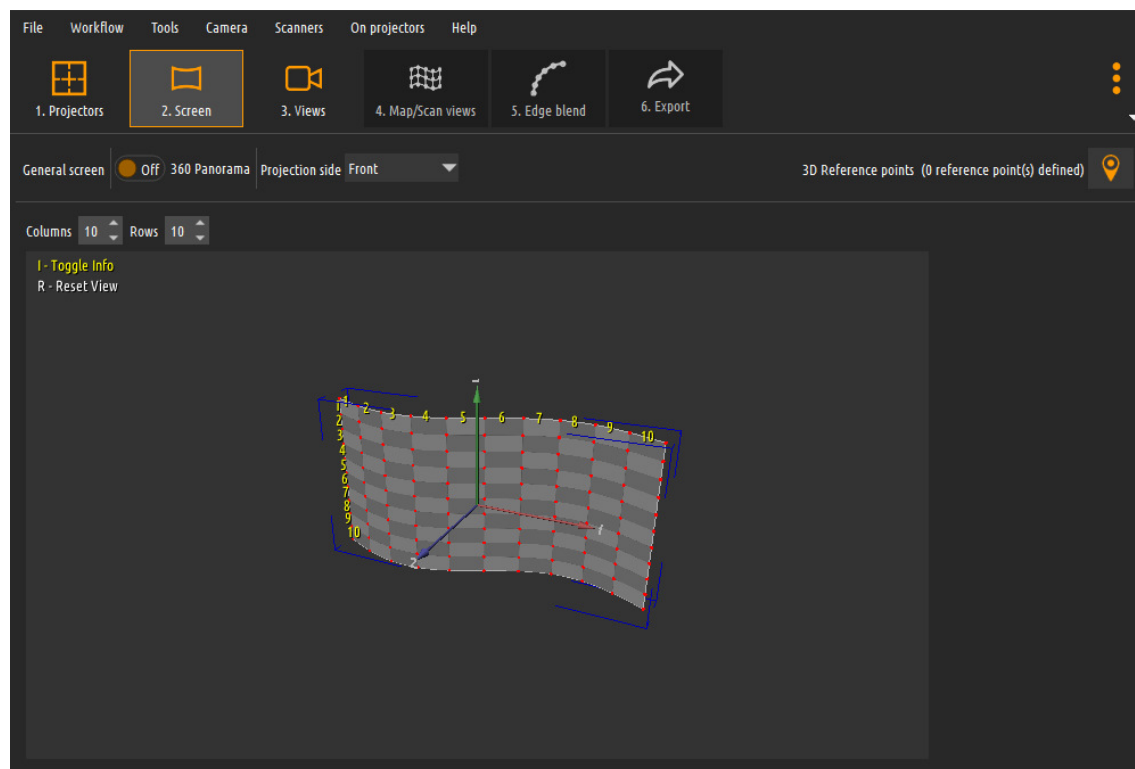
For general (unknown) projection screen geometry, the screen configuration can be used to enter the number of columns and rows the projection screen is divided into.

Because the geometry of the projection screen is not known, the combined projected image from all projectors will be mapped equidistantly to the complete projection screen.

6.2.3.2 Plane screen
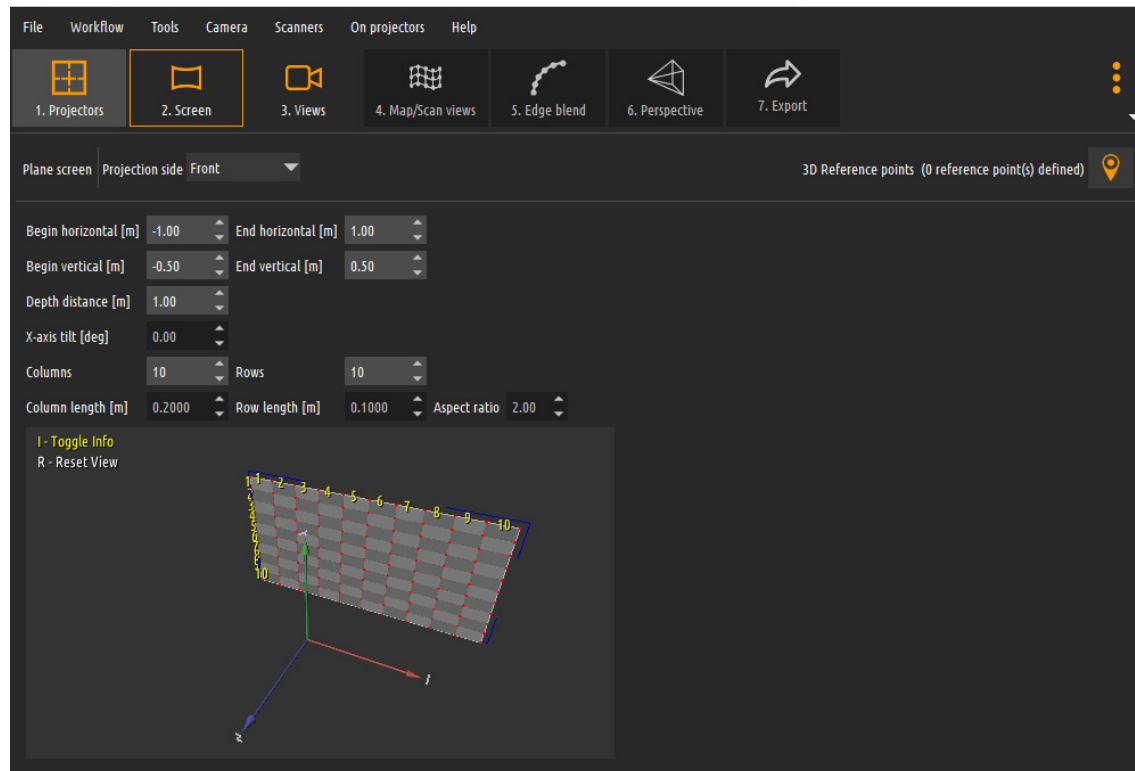
For a **planar (plane) projection screen** the users can enter the width and the height of the screen as well as the depth (distance of the screen from the eye-point).

6.2.3.3 Multi-plane screen

Multi-plane screen is a screen which has one or more planar surfaces. Each surfaces can be defined separately using 3 surface points. Each projector can be assigned to only one surface. Each surface will be calibrated separately.
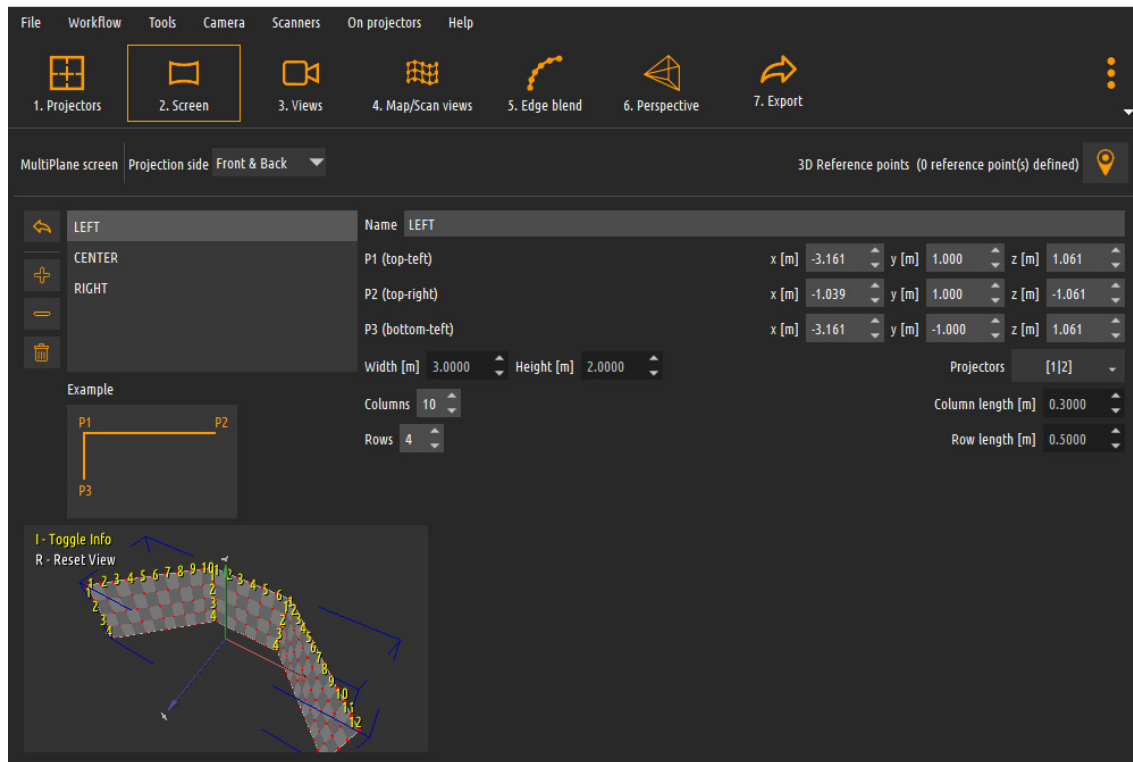
Up to 2 independent surfaces can be defined for one multi-plane screen. Each surface is defined buy a name and the 3 points in 3D space.

P1 is the reference top left point or the surface. P2 is the top right point. The distance between P1 and P2 defines the surface width.

P3 is the bottom left point. The distance between P1 and P3 defines the surface height.
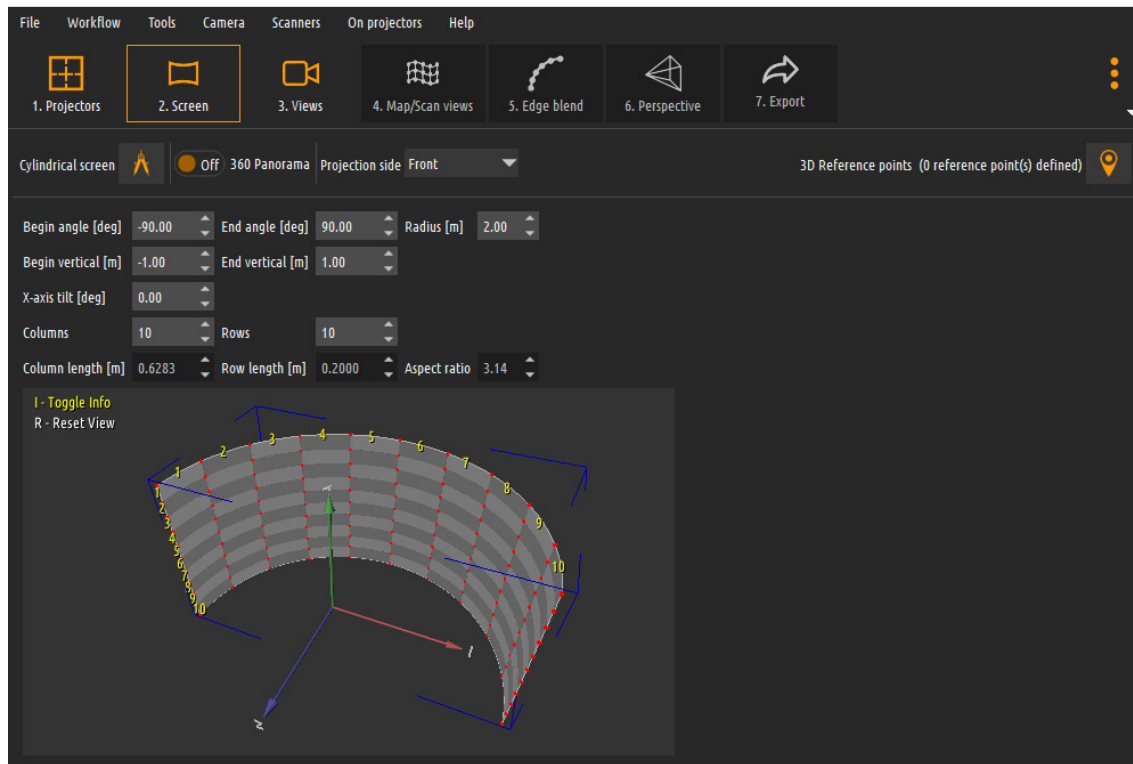
Each surface can be separately divided in rows and columns.

The defined projectors can be assigned to only one surface.

This kind of projection screen can be used to define asymmetric cave projection screen where the cave sides do not form cube, or they have different sizes.

Note: Instead of defining the surfaces with their 3 points P1, P2 and P3, Immersive Designer PRO can be used to define this kind of projection screen visually and export the screen definition in a file. This exported file can be imported using the import button.

6.2.3.4 Cylindrical screen

For a **cylindrical projection screen** which dimensions are known, next to the columns and rows, the user can also enter the height of the cylinder, the horizontal angle and the radius of the cylinder. This information will be used for calculate the frustums for the virtual cameras for the 3D games or simulation engine.

For cylindrical screen the total horizontal angle can be entered as *Begin angle* and *End angle* (in degrees) with respect to the center point of the screen.

The height of the screen can also be entered as *Begin vertical* and *End vertical* (in meters) with respect to the center point of the screen.

The *Radius* (in meters) is a distance from the center point of the screen to the projection screen surface.

The center point of the screen is the middle of the cylinder and will correspond to the eye-point from which the projected image will be observed with no distortion.

Angles on the left side from the central point start from 0 and decrease in the negative values. Angles on the right side start from 0 and increase to the positive values.

Similarly, the height decrease from 0 to the negative values to the lower part of the screen and increased from 0 to the positive values to the upper part of the screen.

Pressing the dimensions button ![button]opens an additional screen dimensions assistant window. Users can enter simple measurable dimensions of the real projection screen and the software will calculate the screen angles and the radius.
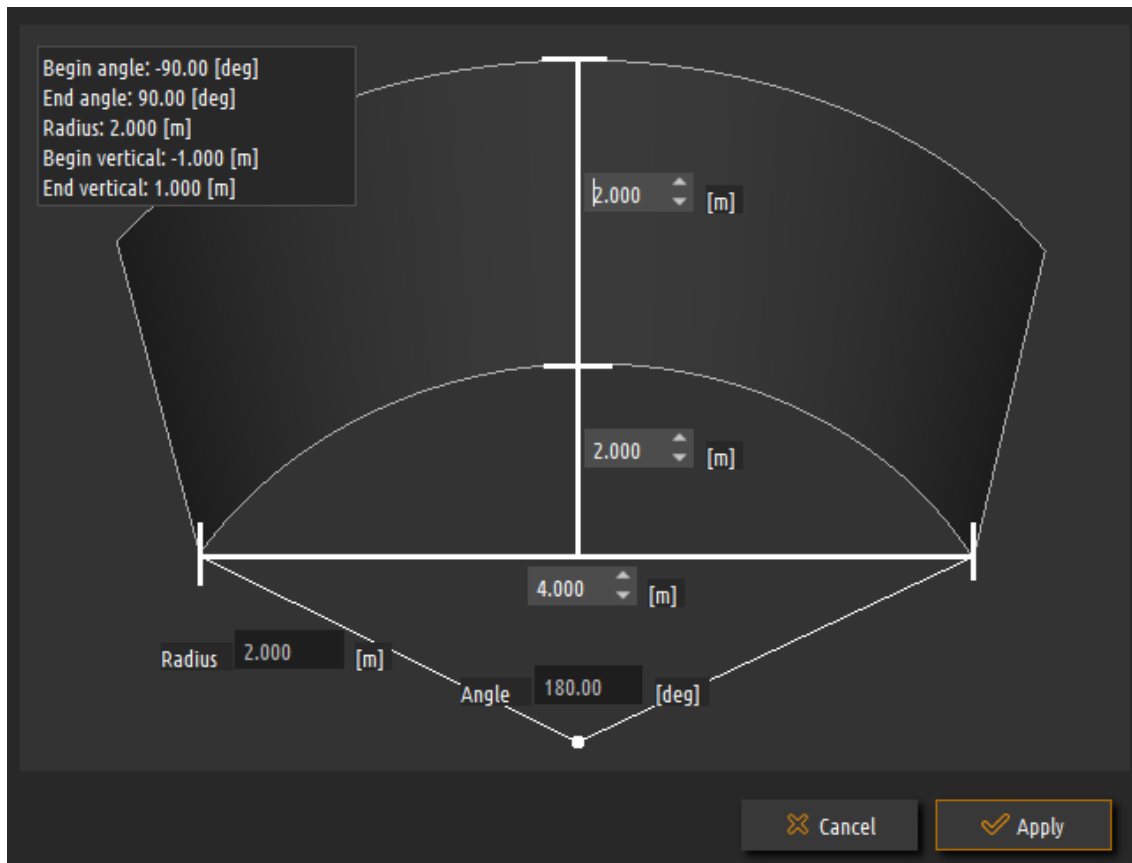
Ex: For a 220 deg cylindrical screen with a height 2 meter and radius 2 meter the values of the cylindrical screen settings should be:

Begin angle: −110 deg

End angle: 110 deg

Radius: 2 m

Begin vertical: −1 m

End vertical: 1 m

6.2.3.5 Partial dome screen
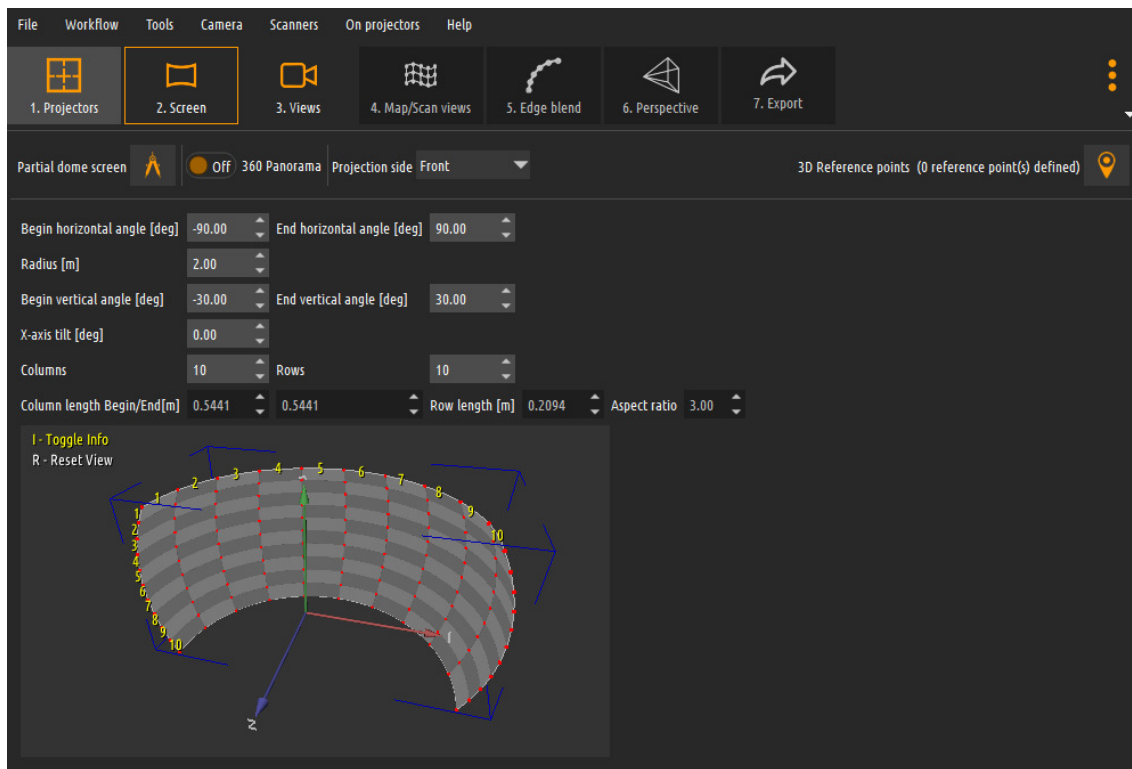
The screen settings window for a **partial dome screen** is similar to the settings for a cylindrical screen. The partial dome screen is a doubly curved screen along the horizontal and vertical axes.

For a partial dome screen the horizontal angle of the screen can be configured with *Begin Horizontal angle* and *End Horizontal angle* (in degrees). Similarly, the vertical angle of the screen can be configured with *Begin Vertical angle* and *End Vertical angle* (in degrees).

For a partial dome screen the R*adius* is the radius for the curvature.

Similar to the cylindrical screen the values are relative to the screen center point. The center point of the screen is the middle of the dome and will correspond to the eye-point from which the projected image will be observed with no distortion.

Angles on the left side from the central point start from 0 and decrease in the negative values. Angles on the right side start from 0 and increase to the positive values.

Similarly, angles on the bottom part from the central point start from 0 and decrease in the negative values. Angles on the upper side start from 0 and increase to the positive values.

Radius is distance from the center point of the screen to the projection screen surface.

Pressing the dimensions button [image] opens an additional screen dimensions assistant window. Users can enter simple measurable dimensions of the real projection screen and the software will calculate the screen angles and the screen radius.
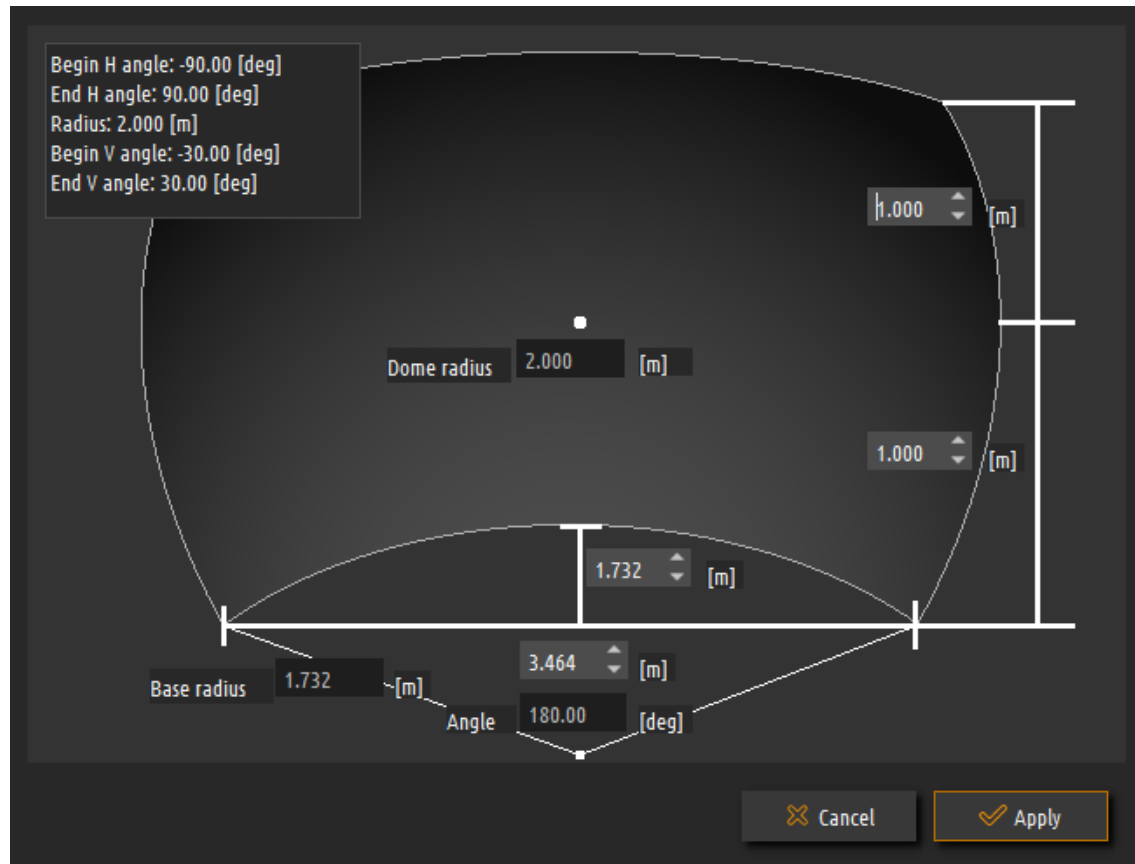
Ex: For a 180 deg dome screen with a vertical curvature of 90 deg and radius 2 meter the values of the partial dome screen settings should be:

Begin horizontal angle: –90 deg
End vertical angle: 90 deg
Horizontal radius: 2 m
Begin vertical angle: –45 deg
End vertical angle: 45 deg
Vertical radius: 2 m

6.2.3.6 Full dome screen
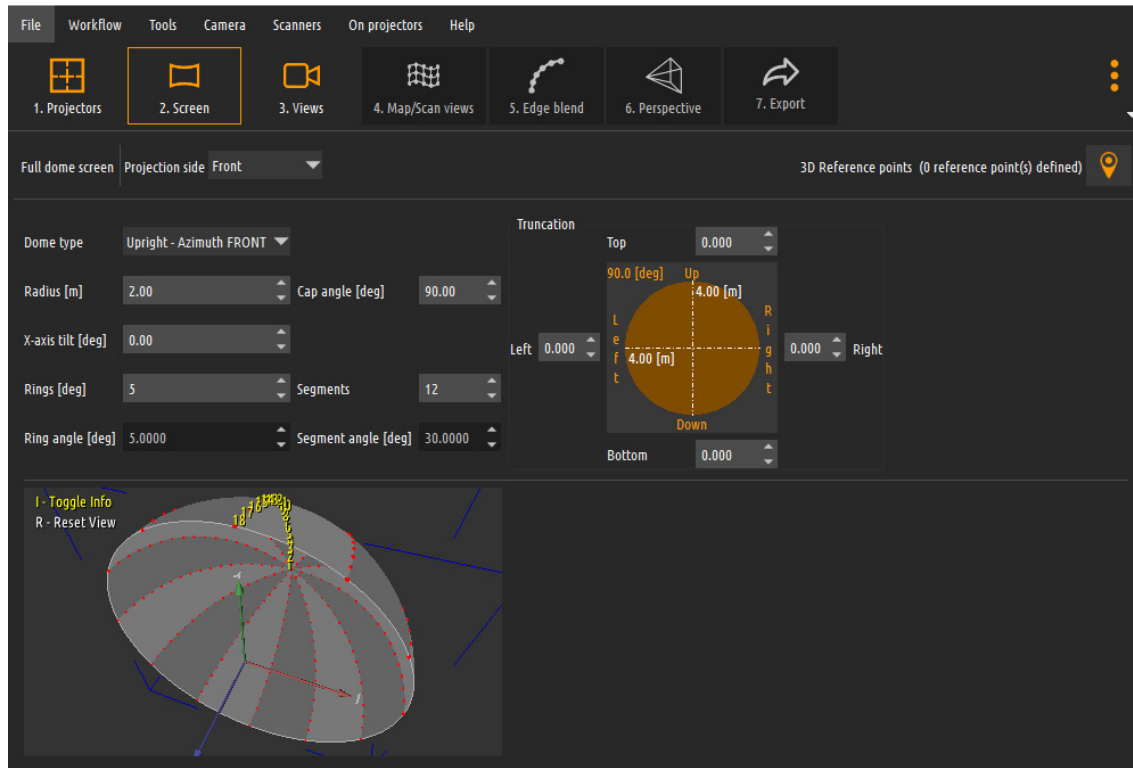
The screen settings window for a **full dome screen** is similar to the settings for a partial dome screen. The full dome screen is a doubly curved screen with angles of 180 degrees along the horizontal and vertical axes.

For a partial dome screen the horizontal angle of the screen can be configured with *Begin Horizontal angle* and *End Horizontal angle* (in degrees). Similarly, the vertical angle of the screen can be configured with *Begin Vertical angle* and *End Vertical angle* (in degrees).

For a partial dome screen the *Radius* is the radius for the curvature.

The values are relative to the screen center point. The center point of the screen is the middle of the dome and will correspond to the eye-point from which the projected image will be observed with no distortion.

Angles on the left side from the central point start from 0 and decrease in the negative values. Angles on the right side start from 0 and increase to the positive values.

Similarly, angles on the bottom part from the central point start from 0 and decrease in the negative values. Angles on the upper side start from 0 and increase to the positive values.

6.2.3.7 Cave screen
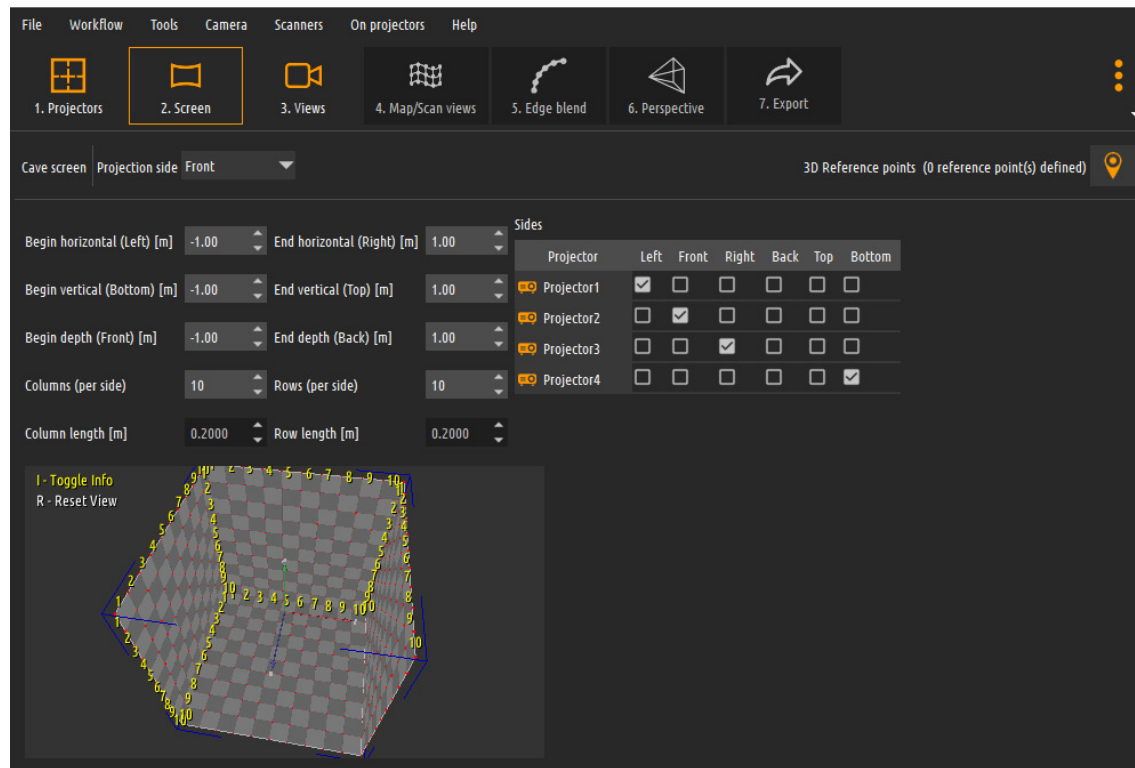
The screen settings window for a **cave screen** allows to specify the dimensions of the cube as well as specify which projectors are projecting on which side of the cube.

Each projector can be assigned to only one side of the cave. Multiple projectors can be assigned to the same cave screen. For all projectors on the same cave side, soft-edge blending will be calculated. For projectors on different cave sides, hard-edge (edge butting) will be calculated.

6.2.3.8 Horseshoe single curved screen
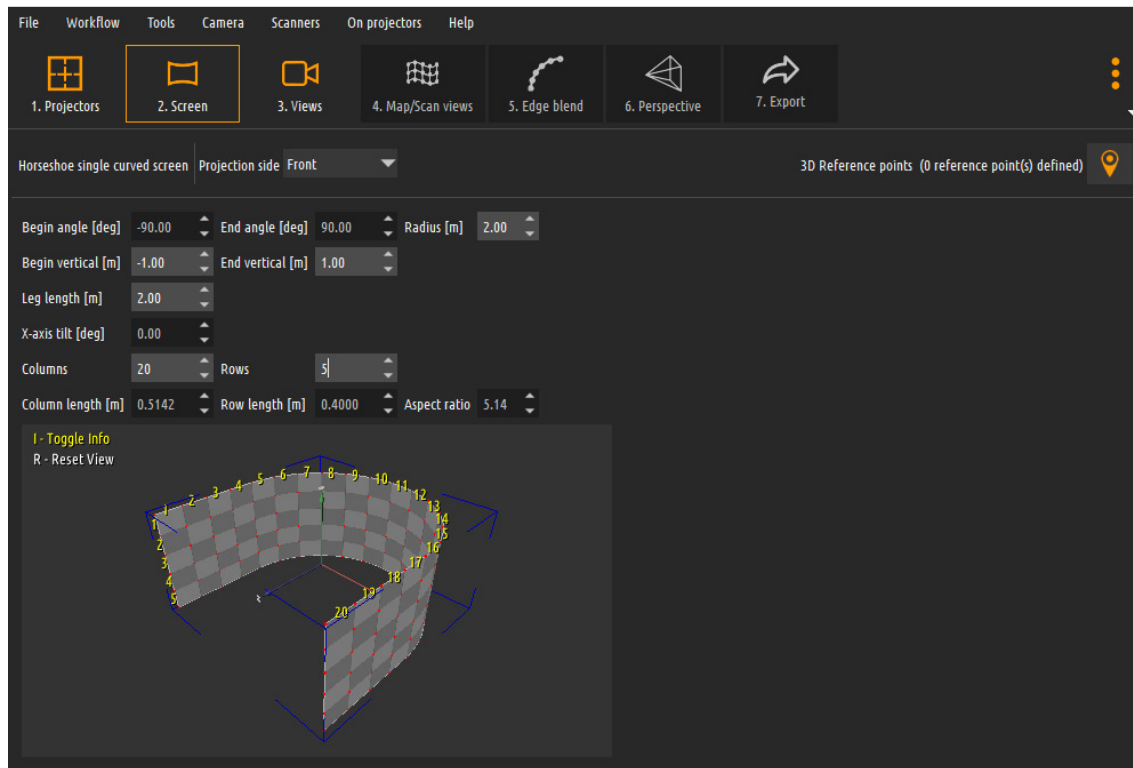
The settings for the **single curved horseshoe screen** are similar to the settings of the cylindrical screen. However, the horseshoe screen has always angle of 180 degrees and after the −90 and 90 degrees the screen shape continues with straight legs. The radius defines the radius of the curved area and the leg length defines the length of the extension legs after the −90 and 90 degrees curvature.

6.2.3.9 Horseshoe double curved screen
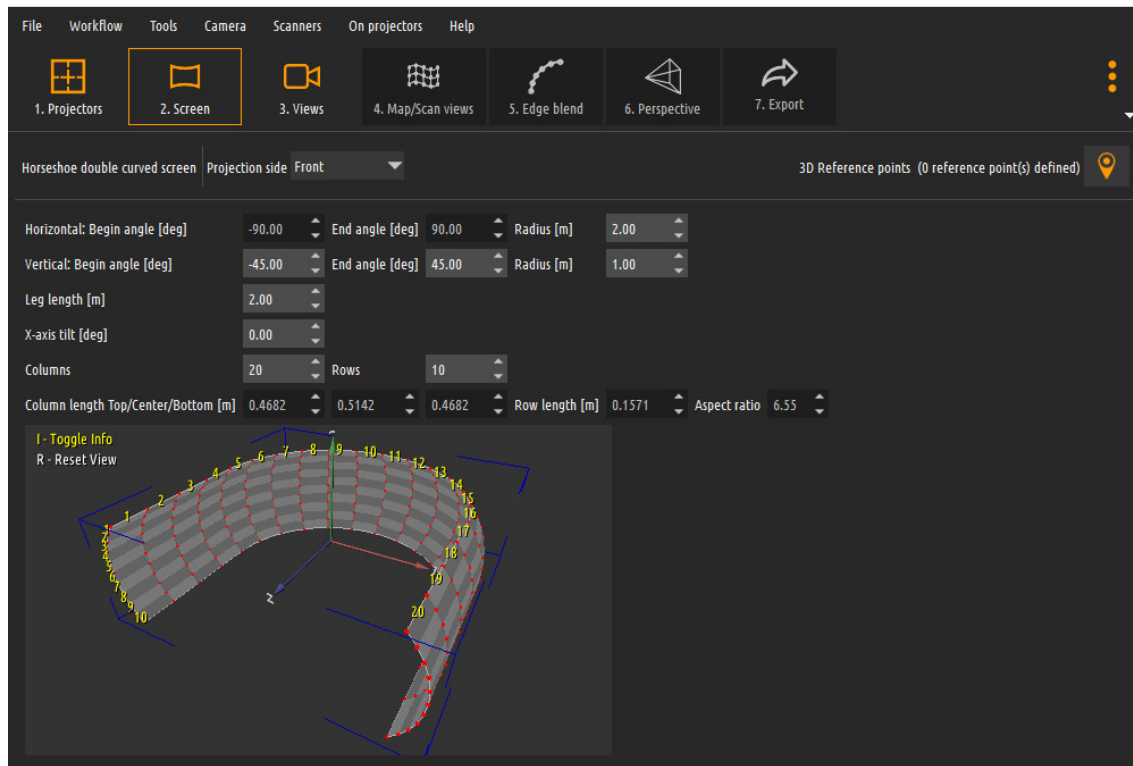
The settings for the **double curved horseshoe screen** are similar to the settings of the single curved horseshoe screen. The screen is curved along both horizontal dimension and the vertical dimension.

Additionally, to the horizontal dimension curvature settings, user can also define the vertical curvature by defining the curvature radius and the begin and end angle.

6.2.3.10   Cone screen

For a **cone projection screen** which dimensions are known, next to the columns and rows, the user can also enter the height of the cone, the horizontal angle and the radius at the bottom and the top of the cone. This information will be used for calculate the frustums for the virtual cameras for the 3D games or simulation engine.

Angles on the left side from the central point start from 0 and decrease in the negative values. Angles on the right side start from 0 and increase to the positive values.

Similarly, the height decrease from 0 to the negative values to the lower part of the screen and increased from 0 to the positive values to the upper part of the screen.

6.2.3.11 Toroidal screen
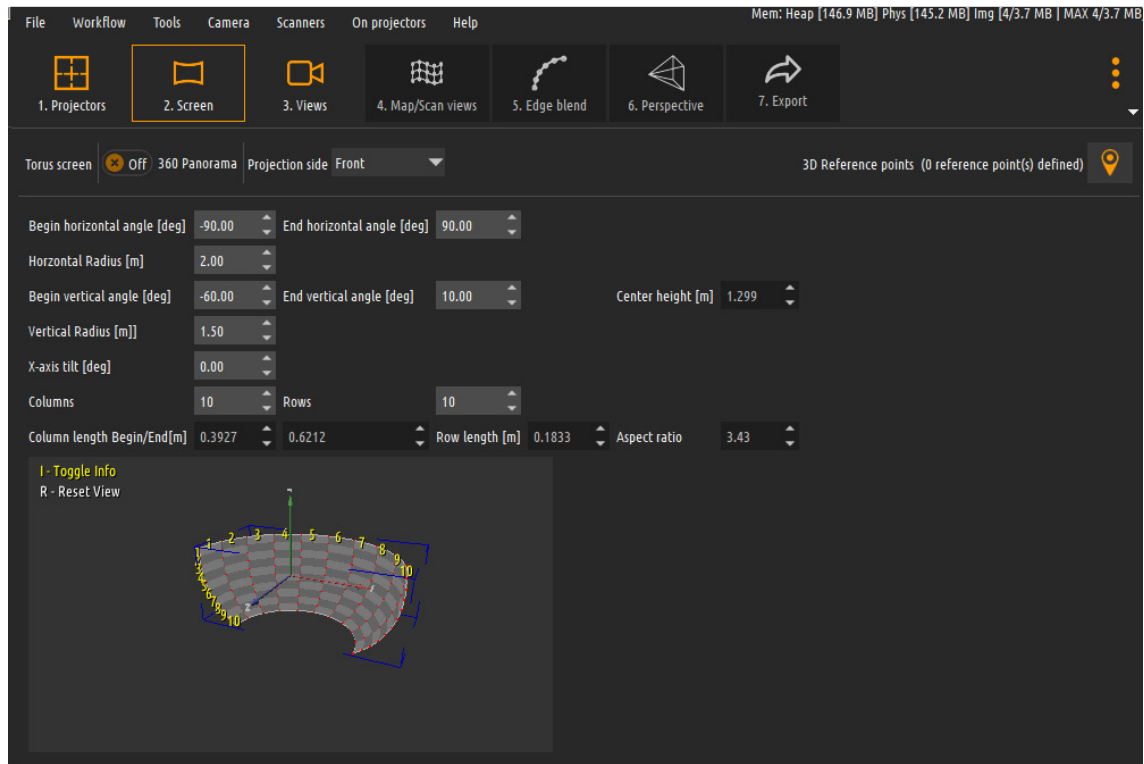
For a **toroidal projection screen** which dimensions are known, next to the columns and rows, the user can also enter the horizontal and vertical radius separately as well as the horizontal and vertical begin/end angles for the torus screen shape. This information will be used for calculate the frustums for the virtual cameras for the 3D games or simulation engine.

Angles on the left side from the central point start from 0 and decrease in the negative values. Angles on the right side start from 0 and increase to the positive values.

Similarly, the vertical angles decrease from 0 to the negative values to the lower part of the screen and increased from 0 to the positive values to the upper part of the screen.

6.2.3.12 Pill screen
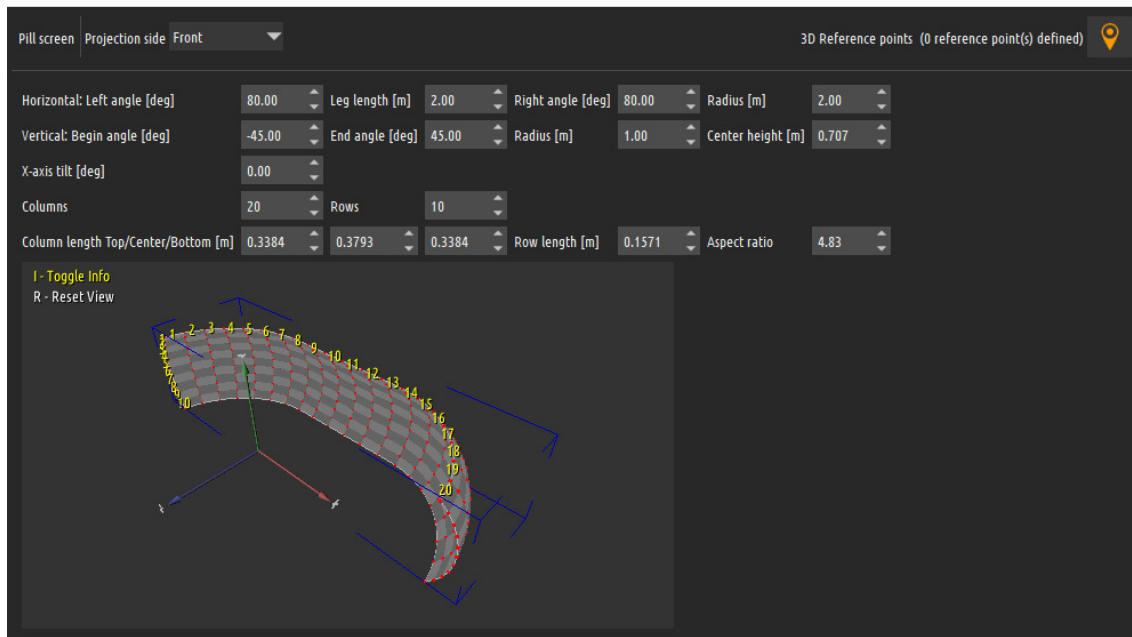
A pill shape screen is a special shape screen with the form of a half-pill. Users can configure the screen by entering the horizontal and vertical curvature angles as well as the radius of the pill. The leg length determines the length of the flat part of the pill.

The screen can be divided in equidistant rows and columns, that can be used to map the screen in the camera views during the calibration.

6.2.3.13   External mesh screen
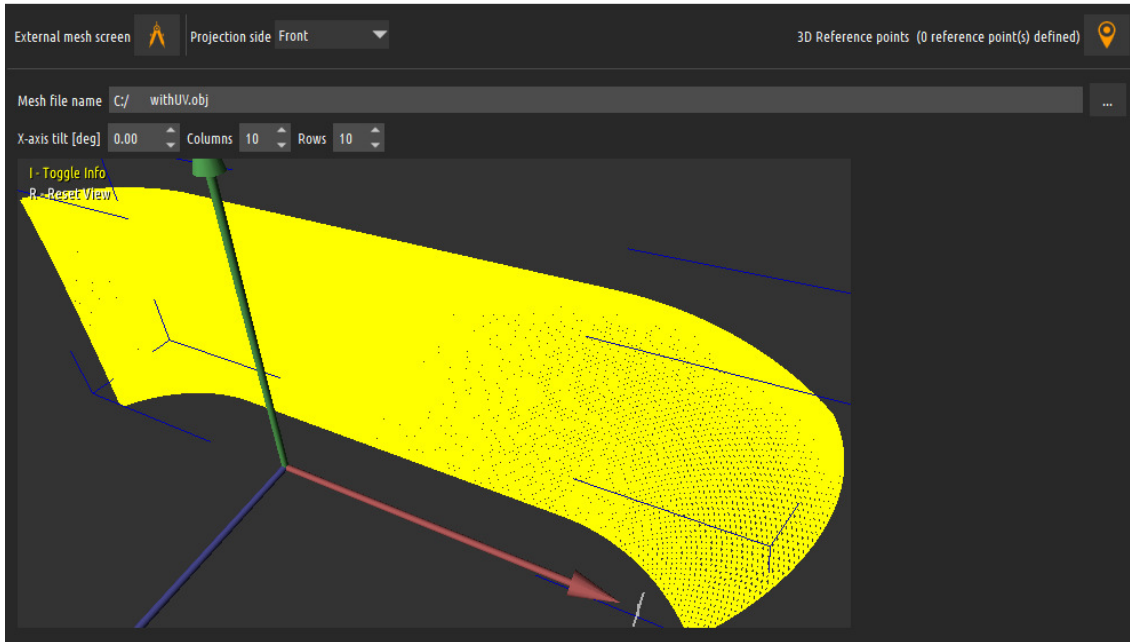
This projection screen is for the most complex and challenging setup.

Any screen shape can be modeled as an .obj model file and loaded in Immersive Display PRO.

The .obj model has to be properly prepared with correct UV mapping. This mapping will be used to calculate the auto-alignment and soft-edge blending as well as the perspective views for the multi-view projection.

Camera based alignment for this projection requires use of known 3D reference points. See the next section "External reference points"

Contact us for more info about this screen shape.

We will offer you separate consultancy services and support to use this screen shape.

6.2.3.14   External reference points

The external reference points editor can be started using the "External reference points" button   .

IN this editor users can add one or more 3D reference points defined in their 3D coordinates x, y, z. Those reference points can be used during the screen mapping into camera view when view is configured as "Map to reference point s" (Full or Partial).

The reference points have to be defined with a unique name.
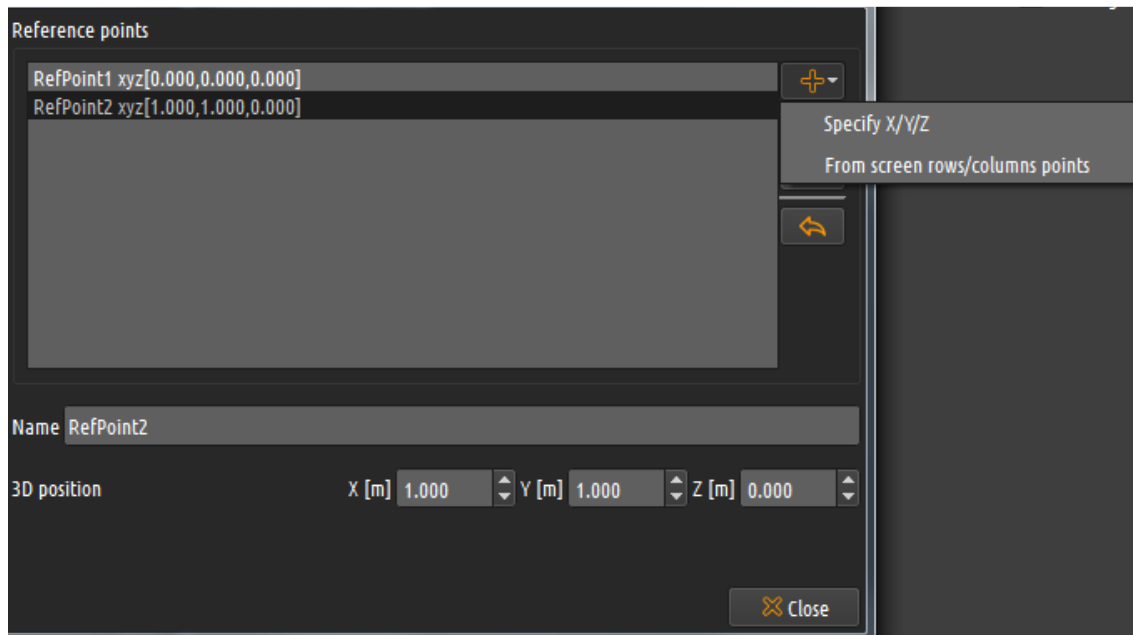
Reference points can be specified by entering their x, y and z coordinates or the x, y and z can be selected from the already define screen section markers.
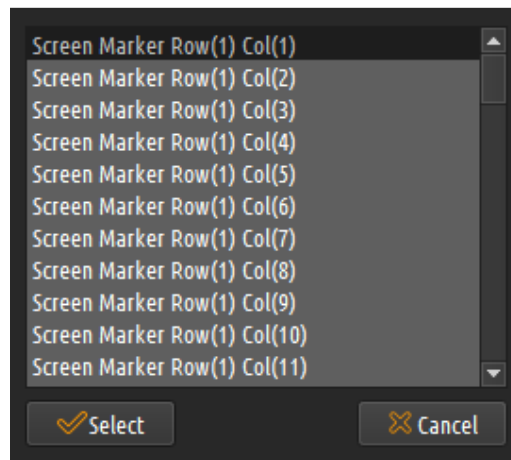
When more reference points need to be define, users can also use the "Import" to import a file that contains the reference points. The file is a text file with each line defining one reference point. The reference points name, x, y, and z values are separated by "," character.

Example:

```
RefPoint01, 0, 0, 0
RefPoint2, 0.1, 0.2, 0.3
```

6.2.4 Views configuration

Configuration of the camera views (or projector views) is the most important step for a proper multi-projector calibration.

When a single camera cannot capture the complete projection screen, multiple camera views can be used to map part of the screen and the projectors than can be seen from the particular camera view.

For each camera view the part of the projection screen that is visible in this view has to be specified.

When "Mapped to screen grid" is used, the part of the screen is specified as the screen columns and rows visible in the camera view. The Begin column is the first complete column number visible in the camera view. The number of columns is the total number of columns visible in the camera view including the first column.

Note: The first column on the projection screen is the most left column, and the first row is the bottom most row.

Accurate row values are needed for proper calibration.

When "Mapped to reference points (Full)" or "Mapped to reference points (Partial)" is used, the mapping of the view is done using a known 3D points, as specified and entered in the screen Tab.
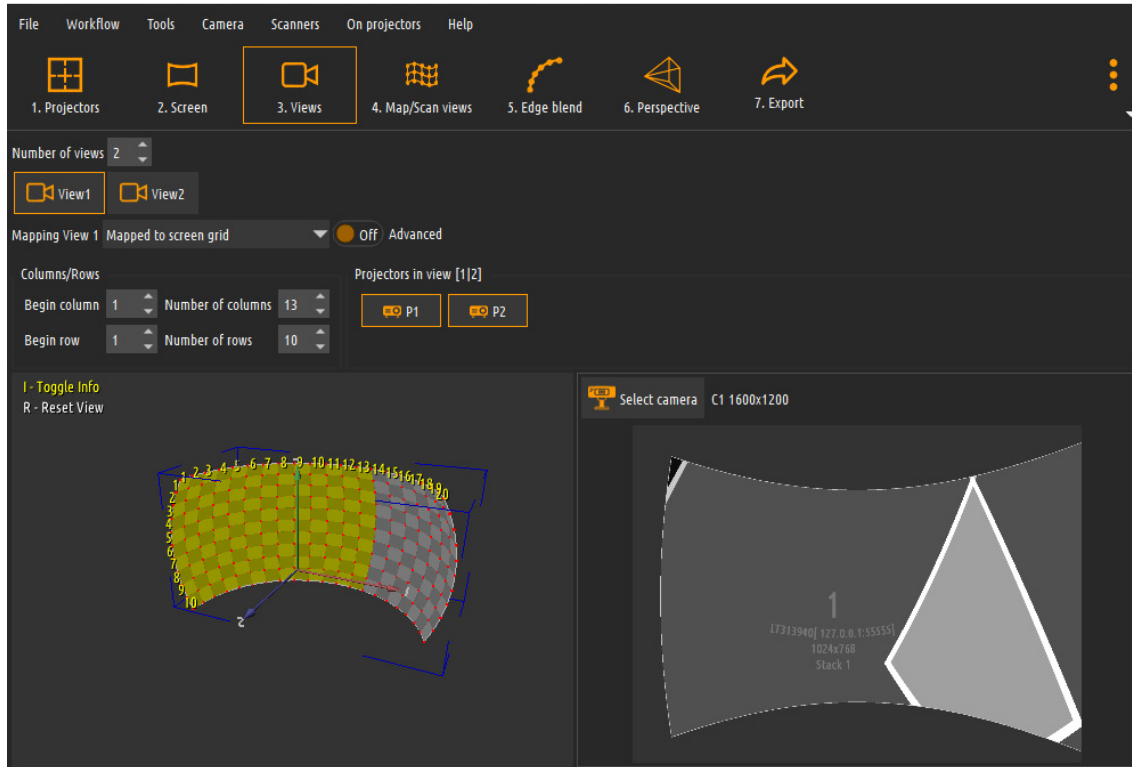
In the Views settings window user can enter the number of total camera/projector views. Each view can be selected using the corresponding view button, and for this view the values for screen mapping can be entered: Columns: Begin column, Number of columns; Rows: Begin row, Number of rows.

When a camera assisted mapping is used with multiple cameras, users can select the mapping method from map to screen grid, map to reference points, or unmapped view. The unmapped views will be reconstructed from the known points in the other overlapping views.

The camera pose (position and orientation) will be reconstructed based on the view mapped points. In the Advanced section, user can enter the estimated camera position. The pose reconstruction will use this position as initial position during the pose reconstruction.

For each camera view, the number of projectors that are completely visible in this view can be selected by using the projectors buttons.

Note: When "Map to projector" is used, a view is created for each projector and the number of the views cannot be changed. Each view is assigned a single projector.

6.2.5 Map & Scan Views

Screen mapping

The first step in multi camera views (or projector views) projector calibration is mapping the projection screen in the camera/projector view. A screen-mapping grid is available in each camera/projector view. The control points of the screen-mapping grid have to be positioned to match the columns and rows of the screen in the camera/projector view.

Select the view that will be used to map the part of the screen to this view. When the view is selected the screen mapping will be selected as the default edit mode.

For "Map to camera" mode, in order to align the screen map control points to the screen columns and rows the camera image can be used to match the screen columns and rows physical marks.
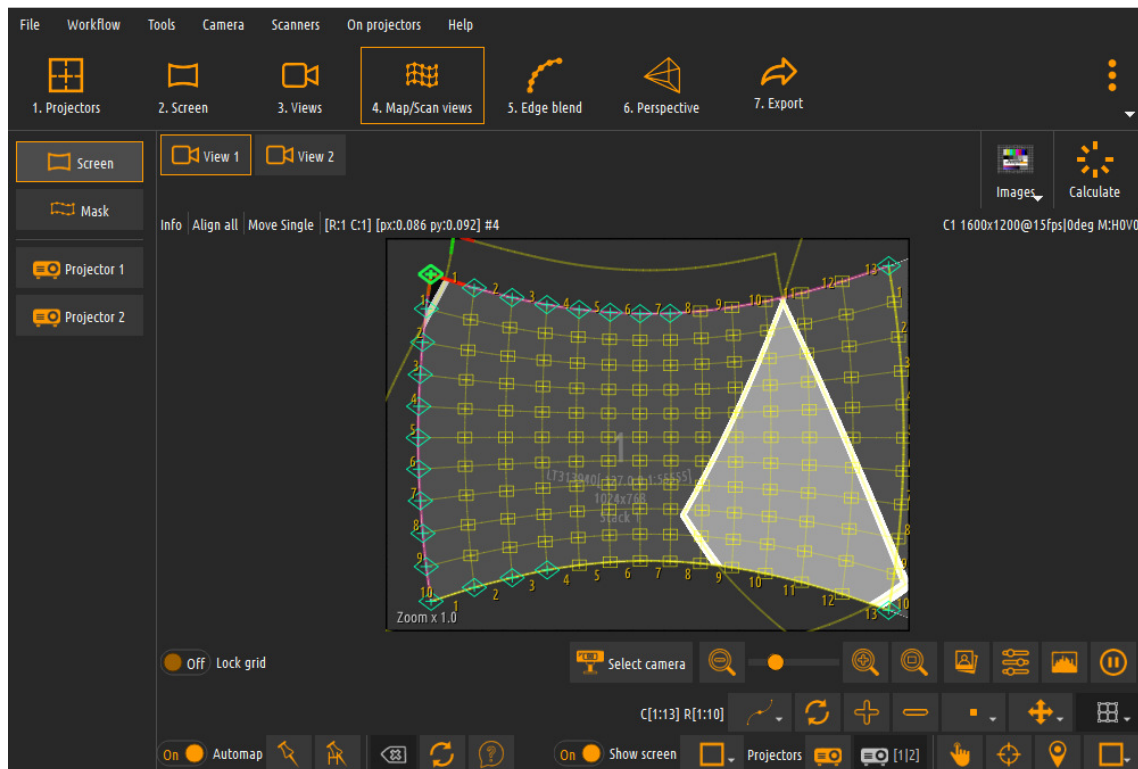
Each control point of the screen map grid has to be positioned precisely in the intersection of the columns and rows lines. This will accurately map the screen in the camera view.

In case a calibrated photo camera or calibrated web camera is used the user will only need to position only a minimum of 6 control points using the auto mapping controls. After pressing the "Automap" button, the software will accurately estimate the rest of the control points on the screen.
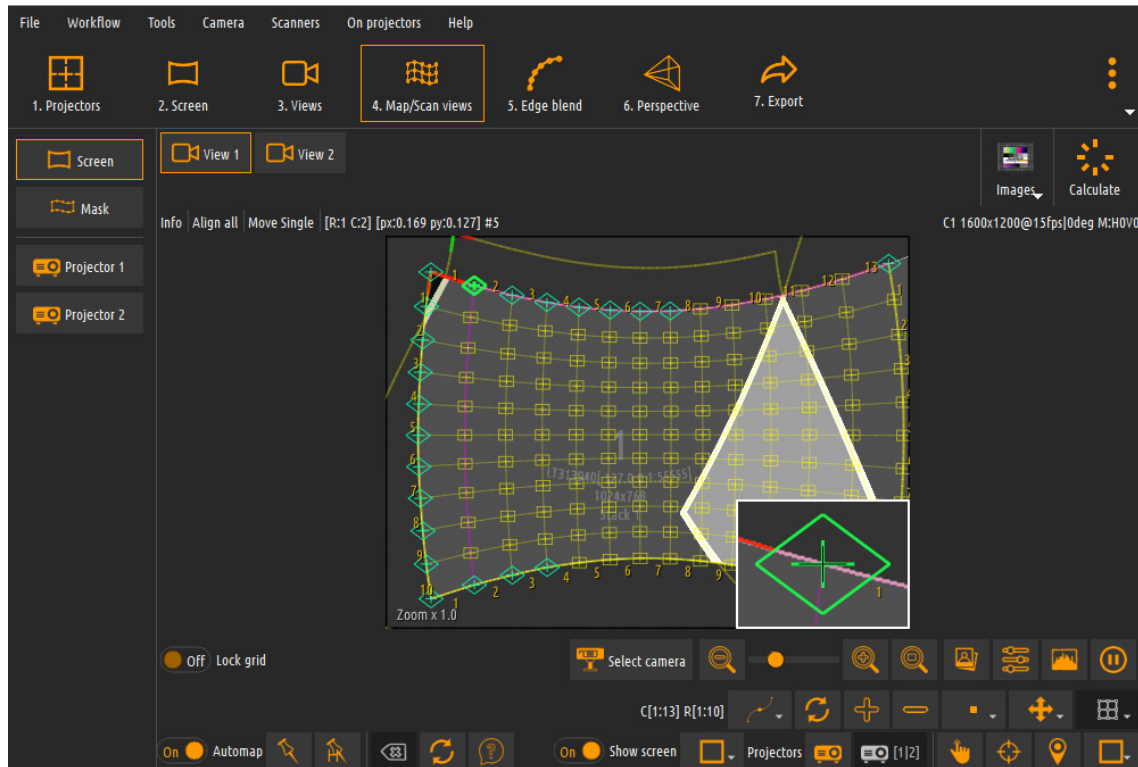
Use the mouse or keyboard control to drag each control point to mark each column and row intersection.

Dragging a control point with the *left mouse button* moves the control points with normal speed. Dragging a control point with the *right mouse button* moves the control points with lower speed. This can be used for fine movement of the control points during the mapping.

The keyboard direction buttons can be used to select the next control points in the corresponding direction.

Using the *CTRL* button with the directional buttons moves the selected control point with normal speed. Using the *CTRL+SHIFT* buttons with the directional buttons move the selected control point with high speed. Using the *SHIFT* button with the directional buttons moves the selected control point with normal speed. This can be used for fine movement of the control points during the mapping.

Note: The *Z* button in the central area toggles the zoom preview around the currently selected control point. The zoom is especially useful when mapping the screen grid to the screen markers or mapping the projectors grids to the projected circles on the screen.

When using a camera for display or projector mapping, the complete camera image can be zoomed in or out.

The mouse wheel can be used to zoom the camera image in and out. The middle mouse button can be used to pan the zoomed camera image. Double clicking the middle mouse button will reset the camera image zoom to normal. Zooming is very useful for inspection, verification and possibly manual adjustment of the mapping.

In the lower mapping control area user can use the grid editing buttons to select the grid edges mode, move mode, move constraints and edit mode.

The ⬚ button can be used to select the grid curve mode. In this mode the grid lines between the control points are curved and can follow the contours of a curved projection screen. This is the grid mode.

The ⬚ button can be used to select the grid linear mode. In this mode the grid lines between the control points are strait lines and can follow the contours of a non-curved projection screen.

The ⬚ button can be used to completely reset position of the control points in the grid.
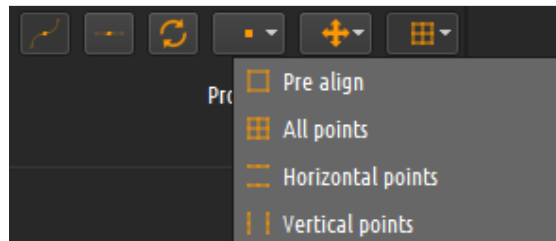
The ⬚ button can be used to select the control points editing mode. In the *Pre align mode*, only the four edges of the grid can be moved. This mode is

used for quick and rough alignment of the grid. All other grid control points will be interpolated between the edge control points.

The *Horizontal points* and *Vertical points* mode allow only the top and bottom lines of the control points (and correspondingly left and right lines of the control points) to be moved. The control points in between will be interpolated. This mode can be used for quick finer mapping of the control points when using single curved display surfaces.

In the default *All points* mode, all grid control points can be moved independently.
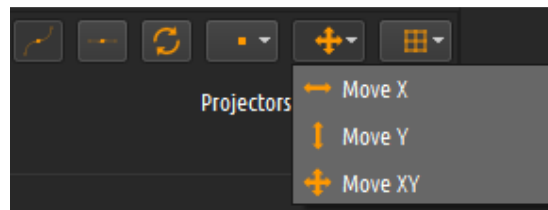
The button can be used to select the control points move constraint mode. The *MoveX* and *MoveY* modes allow movement of the grid control points in X and Y dimension only.

In the default *MoveXY* mode, the grid control points can be moved freely in X and Y dimension.
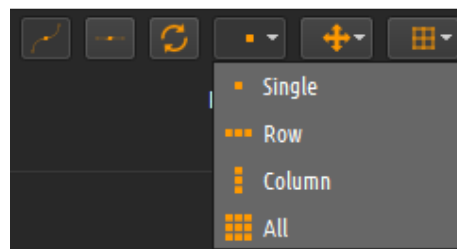
The button can be used to select the control points move mode. The *Single* mode moves a single grid control points. In *Row* and *Column* mode. The complete grid row and column are moved simultaneously.

In the *All* mode, all grid control points are moved simultaneously.

For "*Map to projector*" mode, a background image or a camera is not needed. Each control point of the screen map grid has to be positioned visually in the intersection of the columns and rows lines on the screen.

The projectors will project a test pattern that corresponds to the number of screen sections. Moving the control points will move the test pattern projected on the projector. This will accurately map the screen in the projector view.
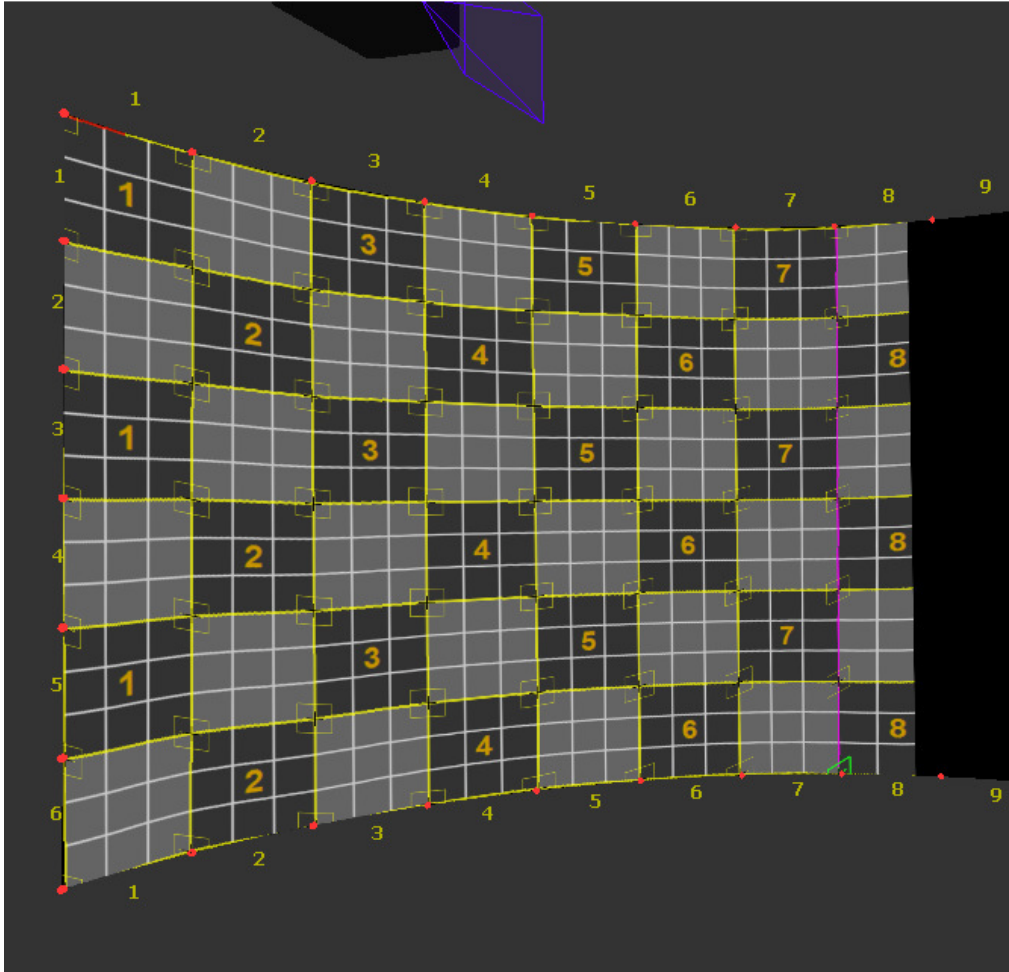
In "*Map to projector*" mode, the screen mapping control on the bottom of the screen allows scaling of the projector view to enable mapping of the screen on the projector even when the projector overshoots the screen.

For a fine tuning mapping, the columns and rows can be divided in sub-sections.

6.2.5.1 Automatic screen mapping

The automatic screen mapping greatly improves the usability and the speed of the software when using screens with known shapes and sizes. There is no need to mark and map all columns and rows of the screen individually as long as a number of columns and rows are known.

The automatic screen mapping is a feature to automatically map the screen grid on the screen based on a minimum number of known screen points. A minimum of 6 control points is needed to accurately estimate the rest of the control points on the screen. In order to minimize the mapping estimation error users is advised to select as much as possible non coplanar points on a screen.

Automatic screen mapping features are available when the **Automap** is selected from the screen mapping controls.

In the automatic screen-mapping mode user can select which control points should be manually mapped and "*fixed*" to the known screen markers.

In most common cases non-intrusive markers can be positioned on the edges on the screen marking the screen columns and rows. The "*fixed*" control points should be accurately aligned to those markers in the view (in either "*Map on projector*" or "*Map on camera*" mode).
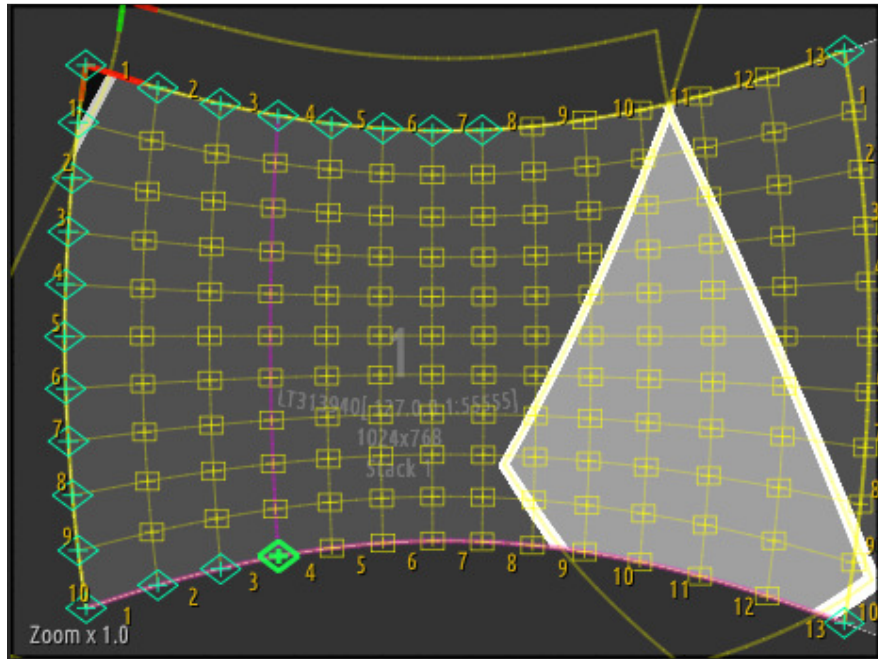
Pressing the "*Space*" button or pressing the "*CTRL+Left mouse button*" users can toggle the currently selected control point to "*fixed*" or for automatic mapping. The "*fixed*" control points will appear as green diamond shape. The rest of the points to be automatically mapped have yellow rectangle shape.

The control points for automatic mapping do not need to be manually positioned at all. Their positions will be calculated automatically based on the position of the "*fixed*" points on the screen.

The *Auto Map Screen* [icon] button will start the procedure for automatic screen mapping. The position of all control points will be estimated and the non – "*fixed*" control points will be moved to the estimated position.

After a successful automatic screen mapping, users can turn off the Automap control and continue with manual screen mapping if needed.

When the mapping cannot be estimated accurately the Undo Automap button [icon] can be used to revert the changes.

6.2.5.2   Projectors mapping

Only in "*Map on camera*" mode:

After the screen mapping is completed the next step is to map the projectors on the screen.

Projector mapping includes projection of markers on the projection screen and aligning the projection grid control point to the projected markers in the camera view.

Each projector has to be mapped in the camera view it belongs to.

Projector mapping can be done manually or can be assisted by a camera. The same camera position and settings has to be used for the screen mapping and for the projectors mapping for the same camera view.

In order to map the projector manually, an image has to be taken while projector is projecting the calibration circles. Use the *On projectors* menu to project the circles on the desired projector and take an image of the projected circles on the screen in the camera view.

Use the select camera button to select a background image containing the projected circles/marks on the screen.
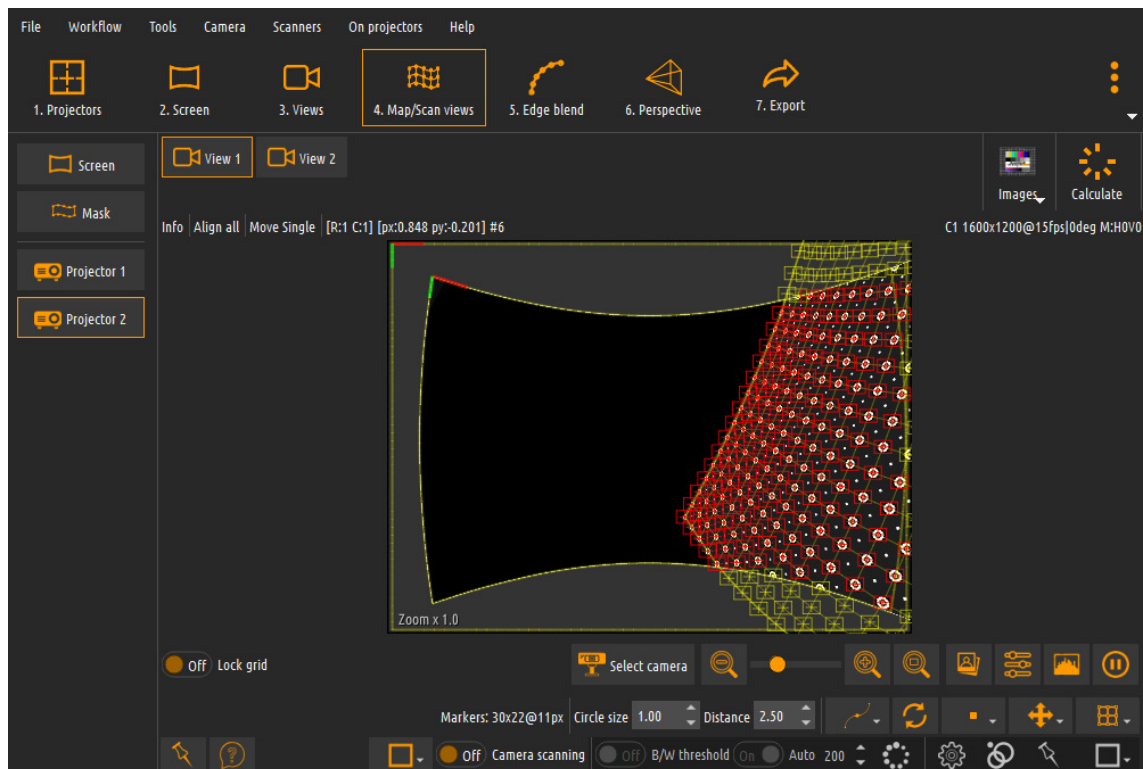
Use the mouse or keyboard control to drag each control point to match each circle center. Use the *Z button* to toggle the zoom view around the selected control point.
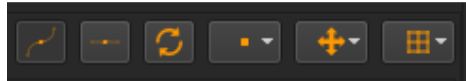
In the lower mapping control area user can use the grid editing buttons to select the grid edges mode and the grid edit mode. The buttons have the same functions as the grid editing buttons in the screen map mode.

Note: In "*Map on projector*" mode, there is no need for projector mapping. The screen is directly mapped on the projector view and projector mapping is done automatically.

6.2.5.3   Camera assisted projectors mapping

Only in "*Map on camera*" mode:
A camera can be used to automatically map the projector on the screen.
Use the select camera button to select a camera for the view.
A camera selection window will be opened to select the available cameras and the camera resolution.
The list of the available camera modes contains all available camera resolution and frame-rates in all possible camera rotation. Using the camera rotation makes it possible to rotate the physical camera and still see the un-rotated images during the calibration. In some setups cameras can be positioned to capture in portrait mode.
Select the highest camera resolution available.
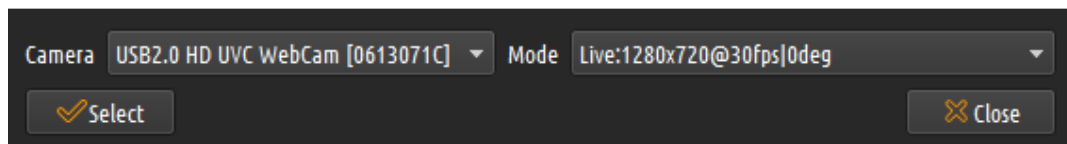
Note: The camera automatic enchantments (auto-focus, auto-zoom, white balance, etc.) have to be turned off.
When a camera is used, the *Camera* menu will become active. Using this menu user can open the *Camera properties* window to adjust the needed camera properties. The camera properties window is a window provided by the camera vendor. All available camera adjustments can be adjusted from the camera properties window.

Using the *Camera scanning* controls from the mapping control area the user can select the automatic mapping mode.
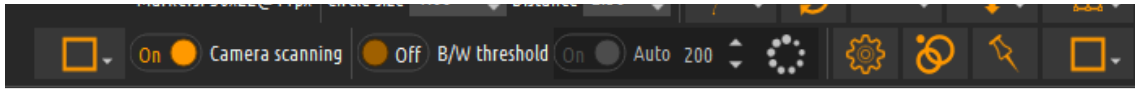
The software will command the projectors to project patterns of circles on the projection screen and will capture and analyze the images and identify and map projector automatically.
The camera will capture Black & White images.

The primary control of the camera image is the "Exposure" control. Use the Exposure to get the most natural looking camera image.
The camera image should look natural and should not be too dark, too bright or saturated. The black and darker colors and the white and brighter colors should utilize the complete camera colors range.

In order to help and facilitate the adjustments of the camera properties, the software comes with a tool called Histogram to evaluate and calculate the used camera dynamic range.

Select the Histogram button and press on the calculate button.

The software will project a number of patterns on the projection screen and will calculate the range between the dark colors and the bright colors as well as the middle distance.

Camera histogram

The camera histogram shows two peeks. The left peek is for the dark colors and the right peek is for the bright colors.

Camera histogram peeks

Use the camera properties (primarily the Exposure) to change the camera properties in such a way that the two peeks are as far as possible and that the orange line lies in the middle between those peeks.

Note: Make sure that you recalculate the Histogram each time the camera parameters have been changed.

The *B/W Threshold* field can be used to adjust the threshold of black and white. This threshold will make only the projected white circles to be visible in the camera view. The threshold has to be set as high as possible but still allowing all white circles to be visible in the camera view.

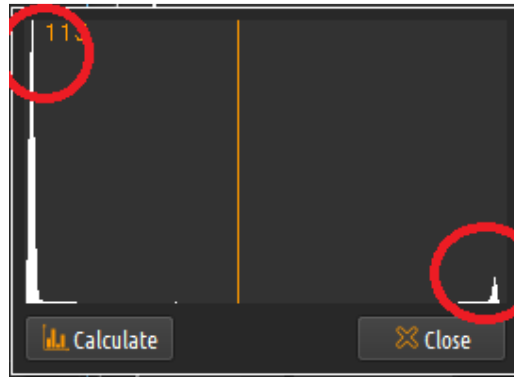Use the *Auto B/W Threshold* to let the software automatically calculate and select the threshold.

Press the *Refresh Threshold* button to refresh and automatically calulate a new value of the threshold. This is needed when the ambiental light conditions have changed or when the camera position has changed.

The *Max ratio* field can be used to adjust the sensitivity of the circles recognitions. The higher the Max ratio, the more circular shapes will be recognized as projector circles. *Max ratio* should be adjusted to allow only the projected circles to be recognized as projector circles by the camera. The

default values for *B/W Threshold* and *Max ratio* should be good for most of the projection setups.

Camera assisted projector mapping involves two steps: circles recognition and circle mapping.

The *Recognize circles* button will start a quick circles recognition procedure. The recognized circles will be mapped with green edge. Use the *Circle size and circle distance* fields and repeat the recognize circles procedure to identify as much circles as possible.
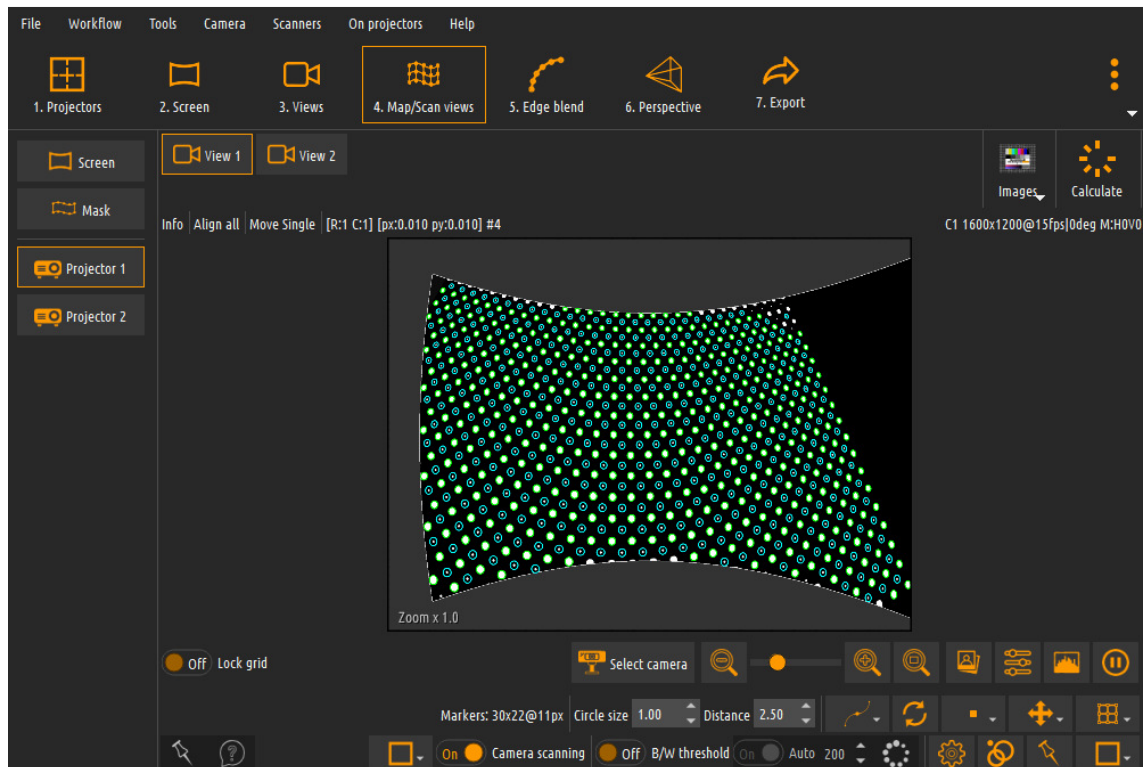
If some circles are partially visible, they can be disabled from the recognition step. Press the *Configure visible circles* button to open the widow with the configuration of the visible circles. In this window press on the circle using the left mouse button to toggle the circle visibility.
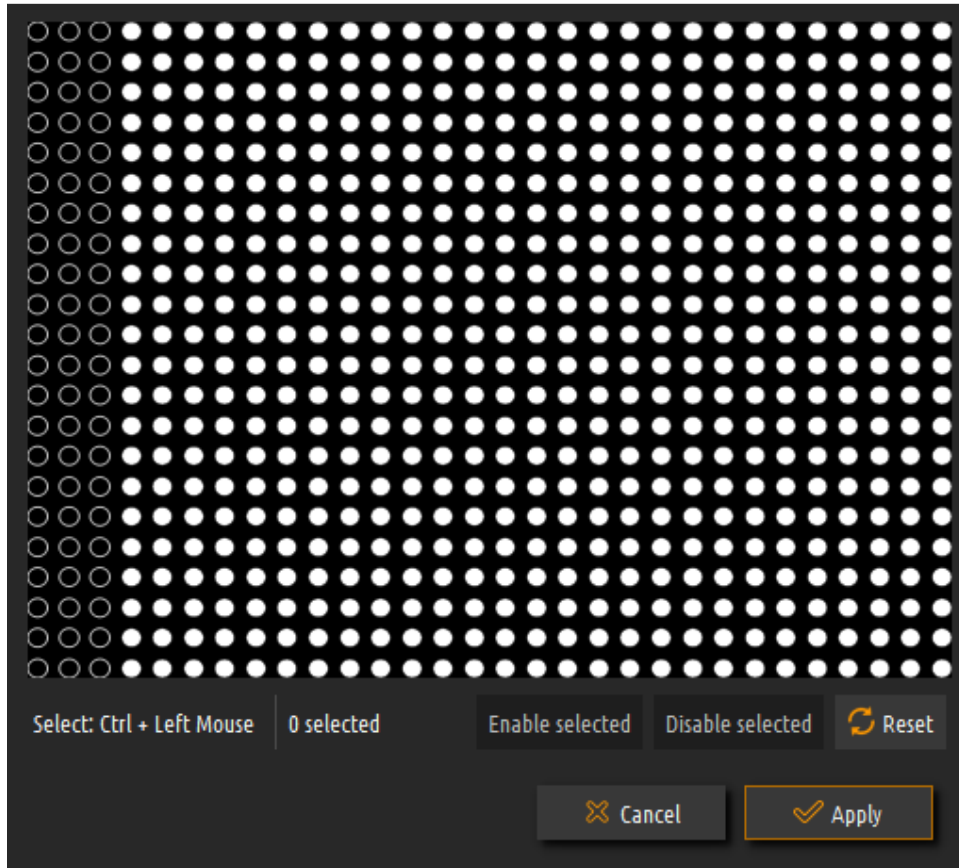
Although there are circles that are not recognized in this step, the software will take care that those circles are still automatically mapped in the next step.

The *Map circles* button will start the procedure for automatic circles mapping. After a number of circles patterns are projected on the screen and captured by the camera automatically the software will position the projector grid control points in the center of the circles.
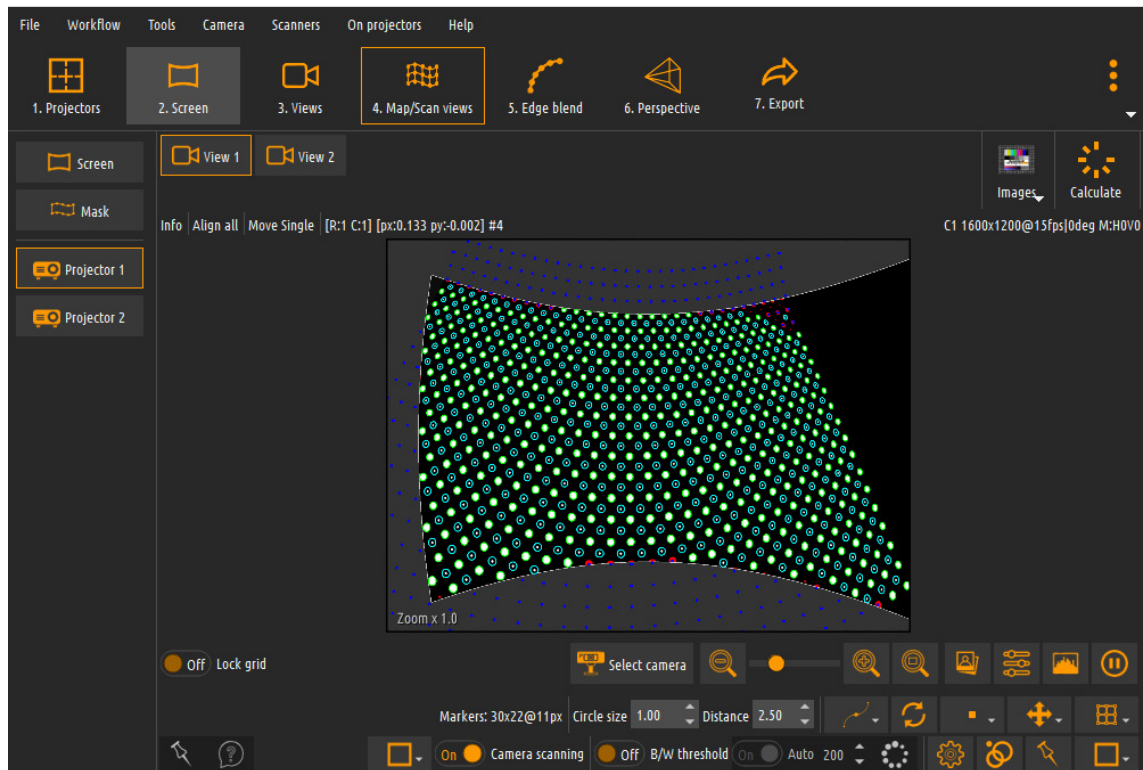
After the automatic mapping is completed, the *Camera scanning* can be disabled and the users can continue editing the projector mapping manually if needed for sub-pixel accuracy.

6.2.5.4 Camera image masking

Only in "*Map on camera*" mode:

When a web camera is used for a camera assisted projector mapping the ambient light and the reflections can cause the captured image to contain images that are not projected by the projectors. This can cause errors in the automated mapping procedure.
In order to prevent the camera to capture those reflections, the masking grid can be used to mark the area of interest for the automatic mapping.

From the *Edit grid* menu select Mask. The editing mode will switch to mask mapping.

There are 3 available camera masking possibilities: Mask Grid, Image Mask and Screen Gird.
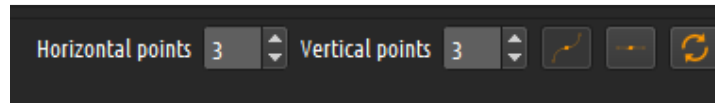
6.2.5.5　Mask Grid

In the lower mapping control area user can use the grid editing buttons to select the grid edges mode and the grid edit mode. The buttons have the same functions as the grid editing buttons in the screen map mode. User can also increase and decrease the control point along the horizontal and vertical edges of the grid.
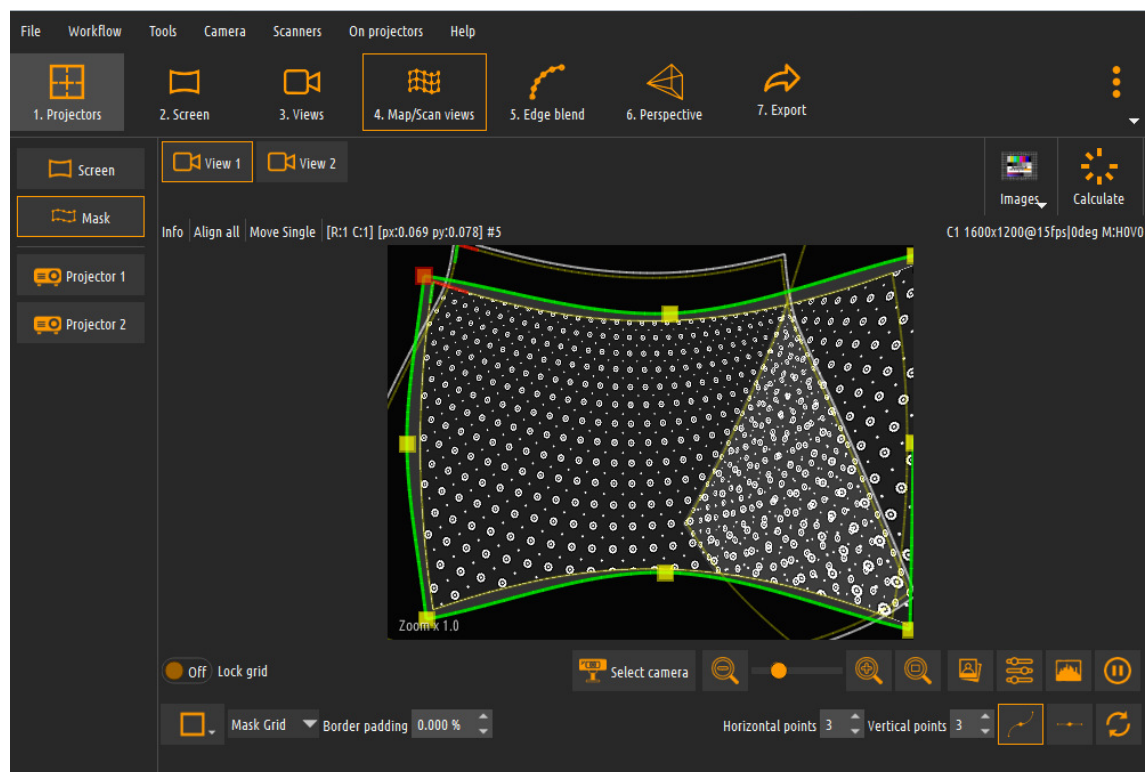
Use the mouse or keyboard control to drag the edge of the mask grid to indicate the area of the projected circles. The area outside of the projected circles will be filtered out and will not be used during the automatic mapping. This will prevent unwanted image artifacts to interfere with the automatic mapping process.

6.2.5.6   Image Mask

Select the Image Mask mode to load a black and white image to be used as a mask. The black part of the image will be used to mask the camera image. This masking is very useful when non-regular and complex areas of the camera image need to be masked. User can capture the camera image and use any drawing software to drawn the white and black regions of the mask image. This mask image can be loaded as a camera mask.

6.2.5.7   Screen Grid

Select the Screen Grid mask mode when using "Mapped to Screen Grid" camera views. The grid defined during the screen mapping will be automatically used as masking grid. Everything outside the screen region will be masked.

After the screen mapping and the projector configuration are finished, the Calculate button can be pressed to calculate the warping and blending.
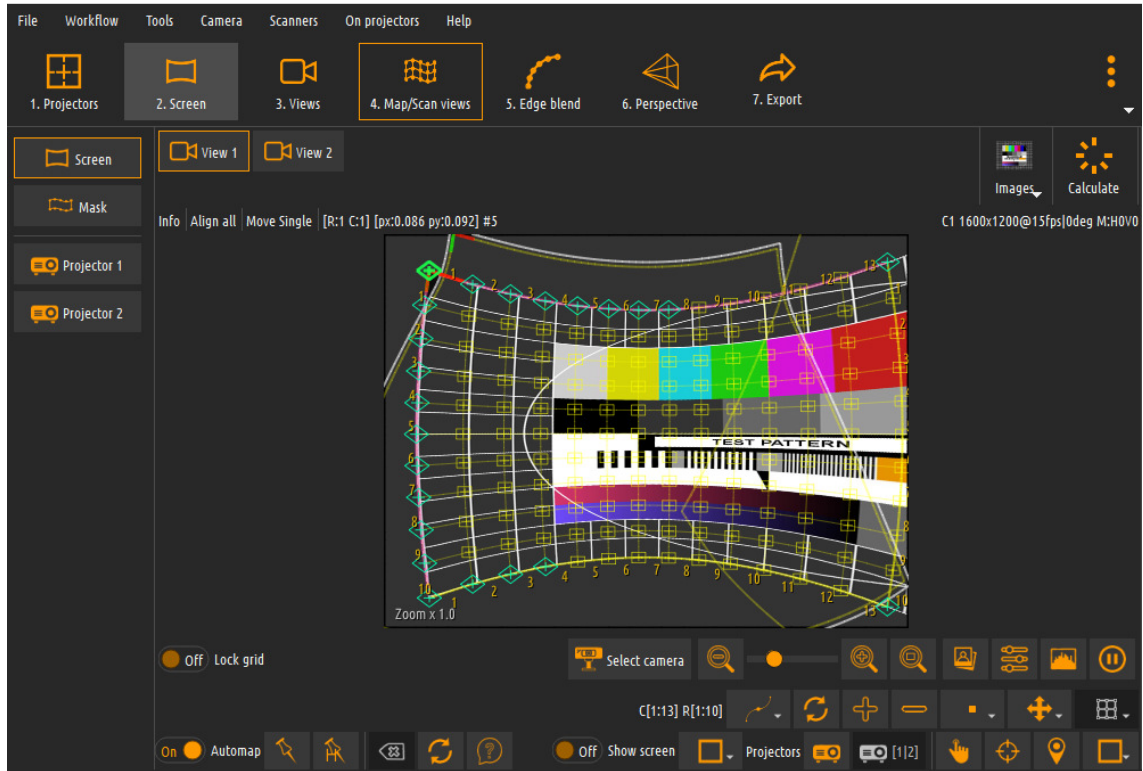
6.2.6 Blend configuration

In the Blend settings the soft edge blending can be configured for the best projectors blending.

The *Gain, Slope and Gamma*, parameters influence the fade-in and fade-out profile of the overlapping regions of the projectors. Slope parameter determines the steepness of the blend profile and *Gamma* determines the curvature of the profile.
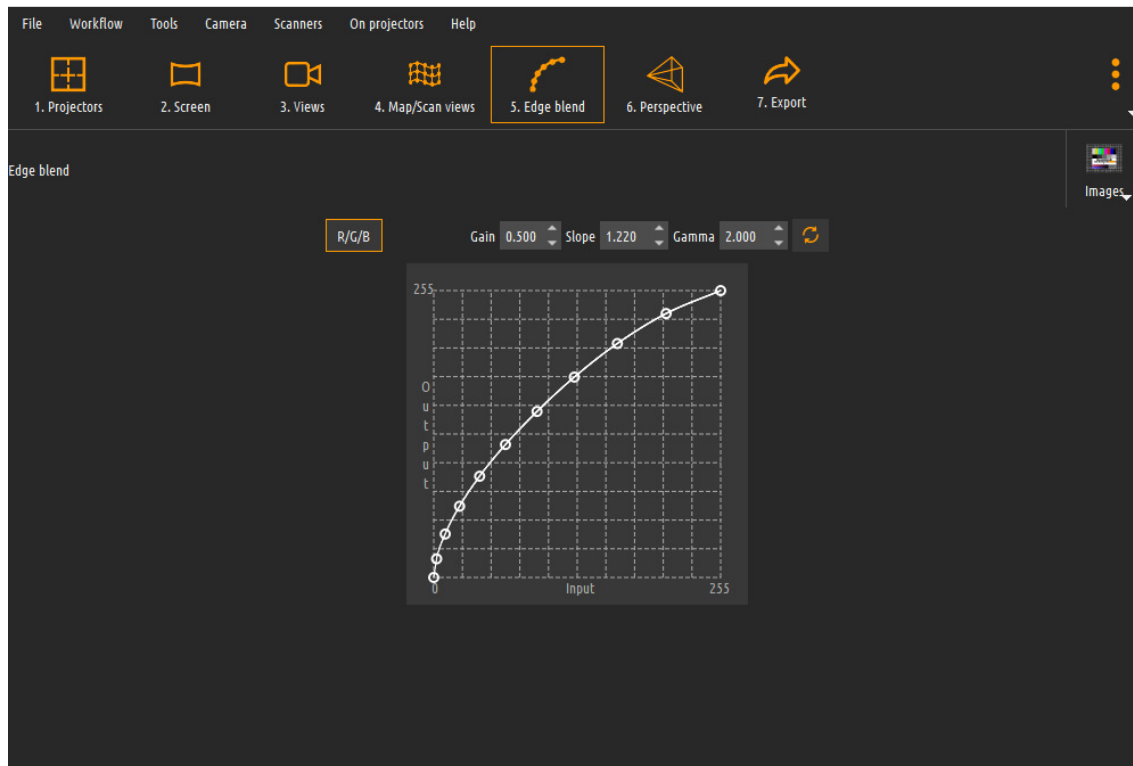
The default values for *Gain, Slope and Gamma* provide the best blending result for most of the projection environments. Depending on the color profile of the projected scene and the used projectors, slight adjustment in the Gamma and Slope settings will be sufficient for fine-tuning the blending regions.

6.2.7 Multiple perspective virtual cameras warping and blending

When a 3D scene generated by a game or a simulation engine is projected on a wide screen, the horizontal and vertical fields of view are limited to the projection transformation of the virtual camera of the game engine. Generally, the mathematics of the perspective projection allows creating undistorted images with fields of view below 90 deg. Each image with field of view larger than 90 deg will contain a fisheye distortion, which makes it impossible to project on screens with angles larger than 90 deg.

The solution for this is to define multiple cameras in the game of the simulation engine and then generate separate image for each projector from each camera. In that case each projector will project image with freed of view smaller than 90 deg.

Immersive Calibration PRO will calculate the positions, rotations and the field of view of the cameras to be setup in the game of simulation engine as well as calculate the geometrical correction and soft-edge blending for each projector.

Using multiple virtual camera projection setups can be created that project the complete 360 degrees 3D environments on omni-directional cylindrical or dome projection screens.

Note: Multi virtual camera calculation is only possible with known screen shapes. Immersive Calibration PRO supports the most common projection screens: Cylindrical screen and Dome screen.
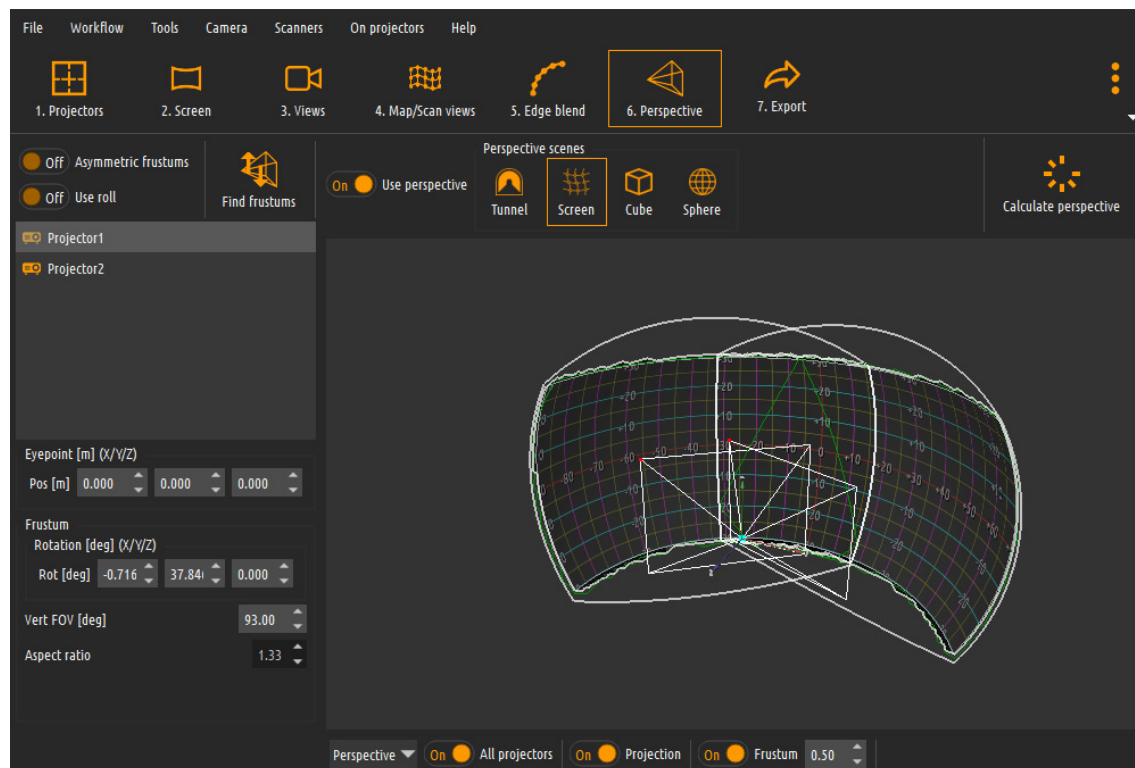
In the 3D frustums window user can adjust the virtual camera properties that will generate image for a particular projector. For each projector a frustum is available with the center of the eye-point in the game or simulation engine. User can change the rotation of the frustum along the 3 axes (x, y and z) and the vertical field. Those are needed to create the camera parameters ion the 3D engine.

The contour of the projector image on the screen has to be completely enclosed by the contour of the frustum on the screen.

The *Find frustums* button can be used to facilitate this process. Pressing the *Find Frustums* button the frustum will be aligned with the projected image and the field of view will be adjusted so that projected image is completely contained in the frustum.

The top part of the 3D frustums window contains buttons to control the 3D view of the projection screens and the frustums. The list of the projectors can be used to select the projector whose virtual camera will be configured. The lower part of the window contains controls to enable and disable the visualization on the projection screen.

After the virtual camera frustums are set-up use the *Calculate perspective* button to start the warping and blending calculation and the camera calculations for multiple virtual cameras. After a couple of seconds, the calculation will be finished and projectors will project images from virtual cameras of a 3D scene such that the complete projected scene will look undistorted on the projection screen. The overlapped projections will also be soft-edge blended.
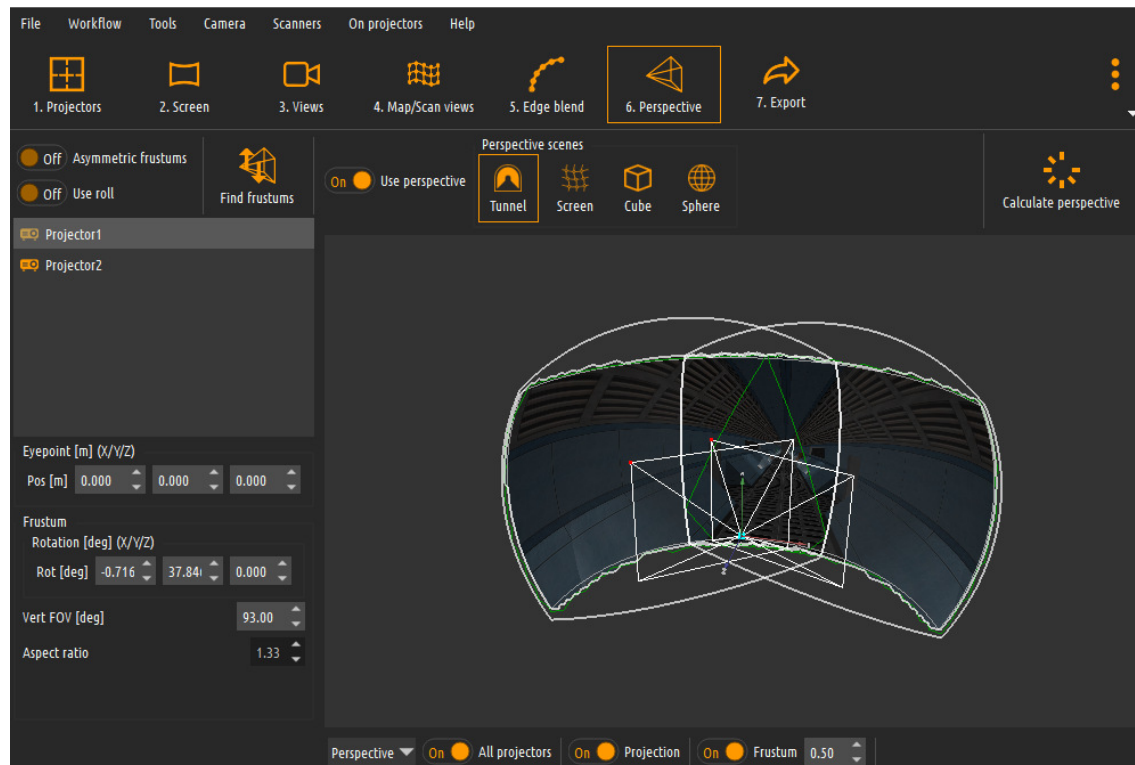
Note: Every time the screen or projectors mapping grids are changed or adjusted the Single Virtual Camera calibration has to be calculated before the Multiple Virtual Camera is calculated again.

Immersive Calibration PRO comes with 3 3D scenes that can be used to configure and evaluate the multi frustum calibration: A simple 3D tunnel scene a 3D room scene and 3D mesh scene that matches the screen shape and dimensions.

The scene can be selected from the 3D Frustum configuration screen or from the main screen (View Menu button). After the 3D multi frustum calibration is calculated, the default scene is the 3D mesh scene.

The 3D tunnel scene can be used to evaluate the calibration with respect to the perception depth and the field of view. It is a typical scene generated from a game or other 3D graphics engine.
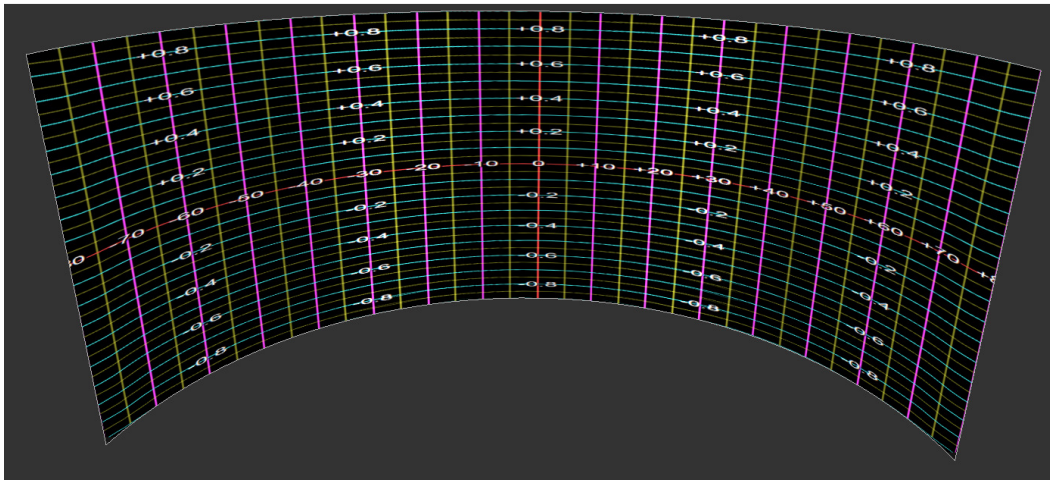
The 3D mesh scene is a special scene that resembles the projection screen viewed from the eye point. This scene contains the screen horizontal and vertical divisions (angles or height) in order to visually verify and confirm the calibration.

6.2.8 Images configuration

The Tools/Images menu opens the Images settings where the users can define one or more patter images that can be used to preview the result of the calibration. Images can be added and removed using the buttons on the left side of the list.
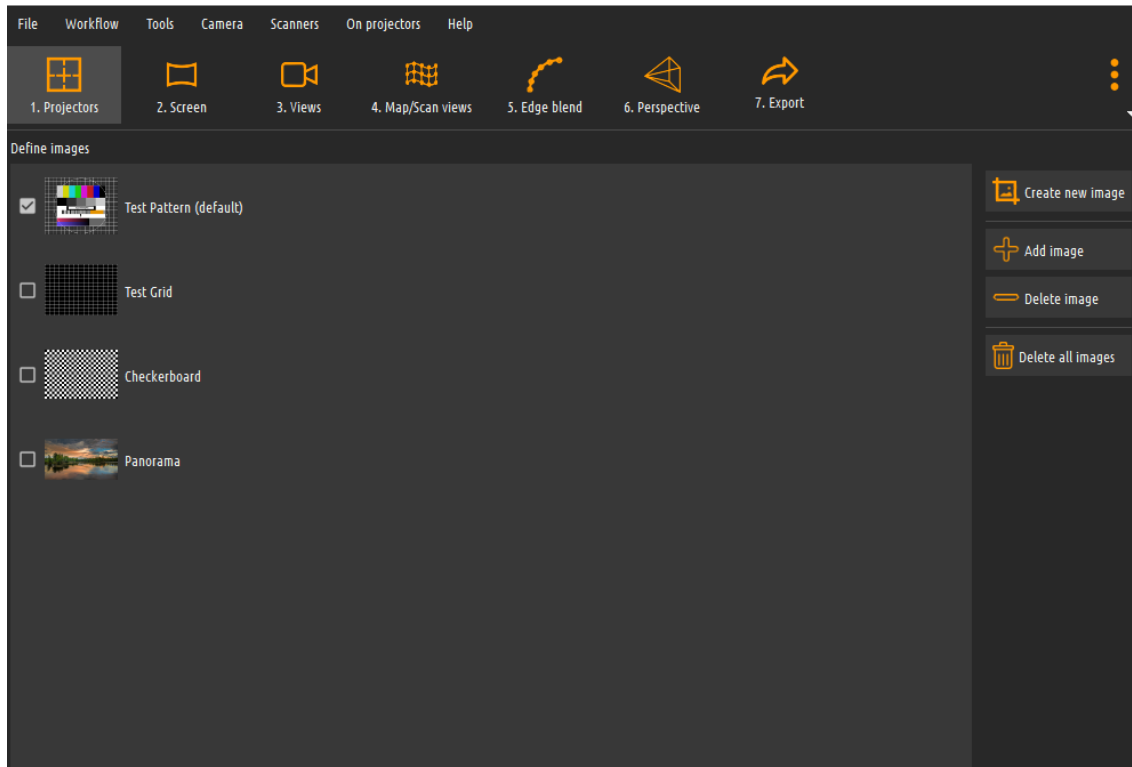
The patterns can be later selected from the "On projectors" menu.

6.2.9 Plug-ins Configuration

The Tools/Plugins menu opens the plugins configuration settings. Plugin system allows extensions of the functionality of Immersive Calibration PRO by means of external plugin modules. Different camera plugins, exporter plugins and post-exporter plugins are supported.
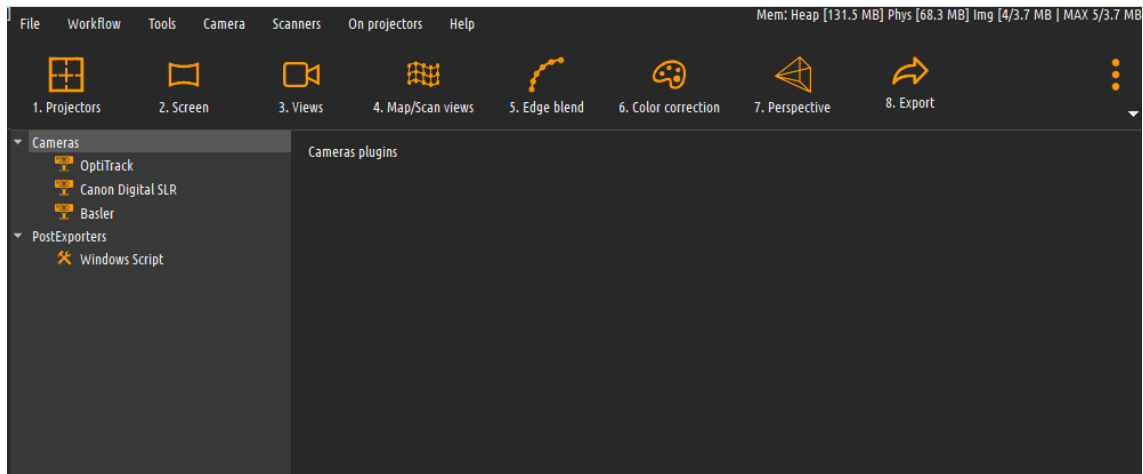
Note: When a plugin is enable or disabled, a software restart is needed to affect the changes.

Next to the built-in web camera support, the following cameras are supported by plugin:

- Cannon DSLR cameras
- Basler USB and IP cameras
- OptiTrack USB and IP cameras

The following post-exporter plugins are available:

- Windows scripting host (WSH)

The WSH exporter plugin can be configured to run a script (vbs or js) whenever a file is exported from Immersive Calibration PRO. A script can be written to be notified when a file is exported and the script can take care in distributing or copying the exported files on their destination (local PC or remote PC). This can be used for automatic the calibration process and calibration results distribution.
An example script is depicted below:

```
Script.js

function notifyExportedFile(fileType, fileName)
{
    var FSO = WScript.CreateObject("Scripting.FileSystemObject");
    //Extract the base file name (without the path)
    var baseFileName = /([^\\]+)$/.exec(fullPath)[1];
```

```
//Copy the file to the destination folder
FSO.CopyFile(fileName, "c:\\destination\\" + baseFileName);

return;
}
```

6.2.10   Projectors configuration
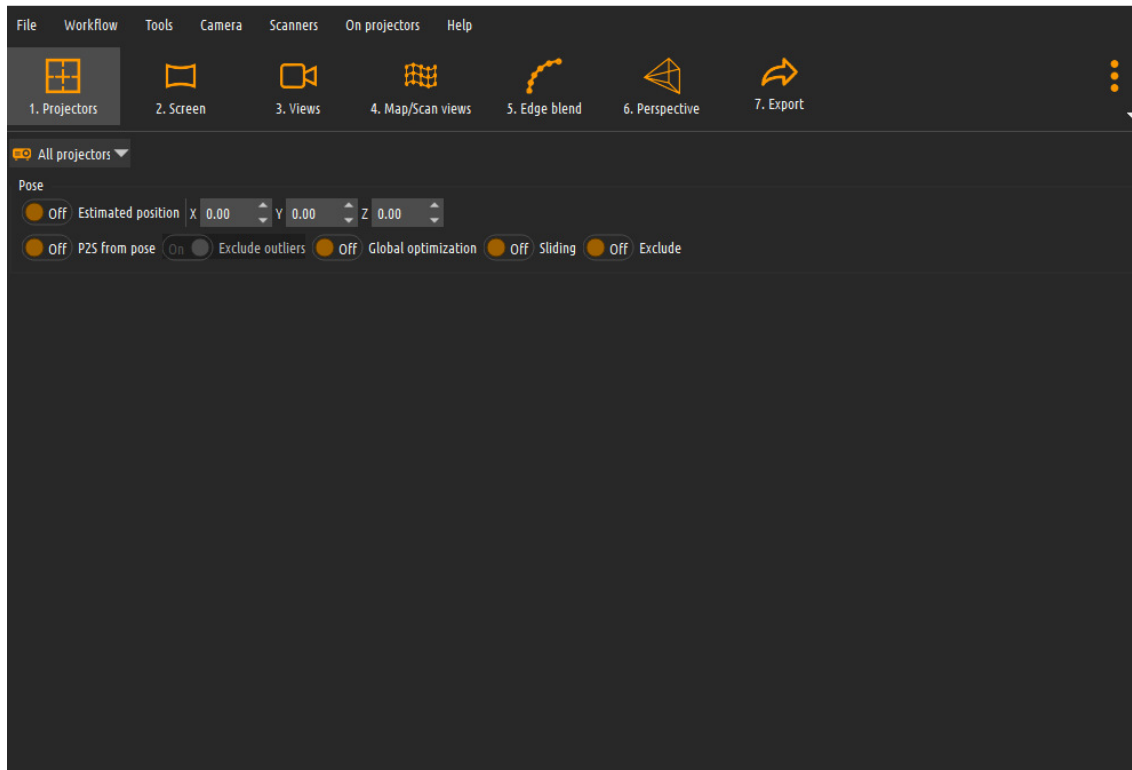
The projectors settings tab is used to configure the advanced projector settings.

- When the estimated projector position is checked and the estimated x, y and z values are entered (in meters) the software will use them as initial values for estimating the projectors pose.
- The P2S from pose can be selected to use the projector 3D pose to calculate the projector warping and blending.
- When sliding is checked, an iterative algorithm is used to calculate the projectors warping and blending.

The projectors advanced settings do not need to be used unless instructed by our support team.

6.2.11   Advanced projectors masking

When the projector image is obstructed and not the complete projector image falls on the screen than this can have negative impact when the obstructed part falls in the overlap zone.

The advanced projector masking can be used to mark part of the projector image is not visible and should be masked.

The masked projector image will not be used to calculate the warping and blending.

Use the advanced projector masking dialog to define the projector image masked regions:
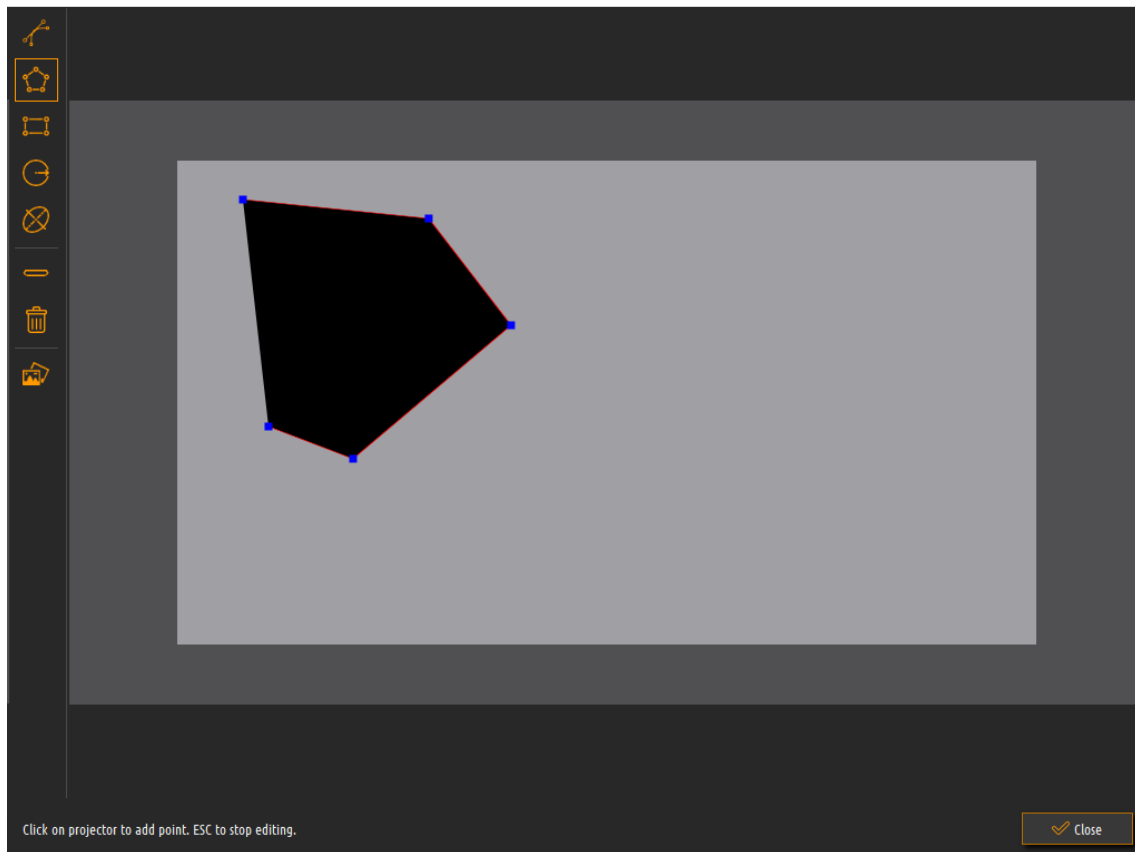
The regions palette on the left side allows definition of different polygonal shapes to match the obstruction region. While defining the region, the projector image will become while and the defined (masked) region will be

black. This allows easy definition of the regions looking on the projection surface.

Multiple projection regions can be defined and grouped to define complex shapes.

6.2.12   Advanced projectors color correction

Image color uniformity on the projection surface can become a challenging issue in case the projection surface is largely non-uniform. The position and the distance of the projector to the curve projection surface can cause hotspots on the projection screens.
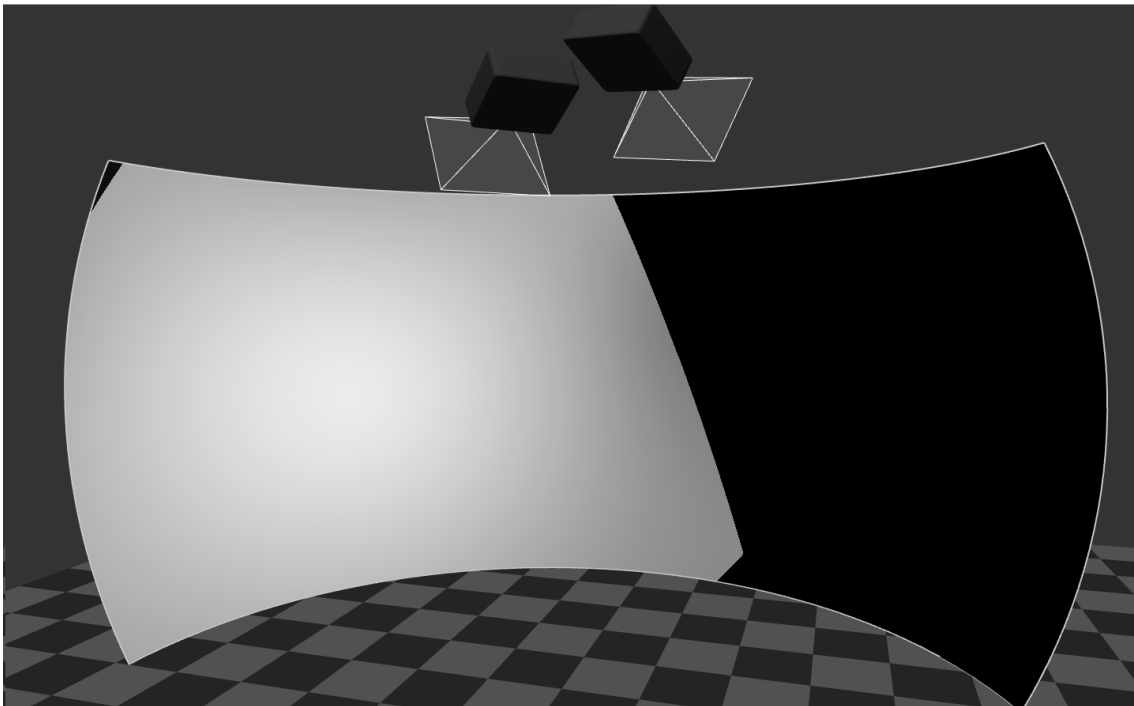
Immersive Calibration PRO offers an advanced color correction method using a spatial color correction grid.

Select the Color Correction screen.
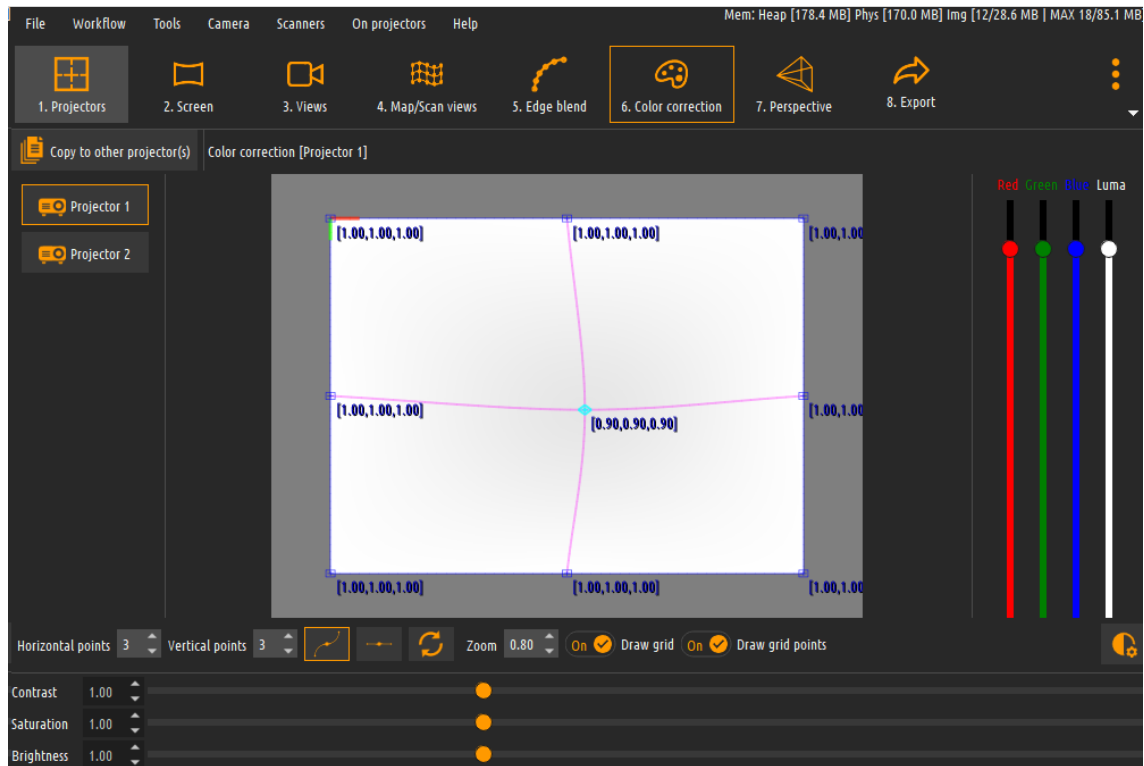
Use the gird to increase or decrease the number of individual color points.
For each point use the sliders on the right to increase or decrease the colors
to create a perfectly uniform image in the projection screen.

Additionally, user can use the Contrast/Saturation and Brightness software
controls to further fine-tune the color correction.
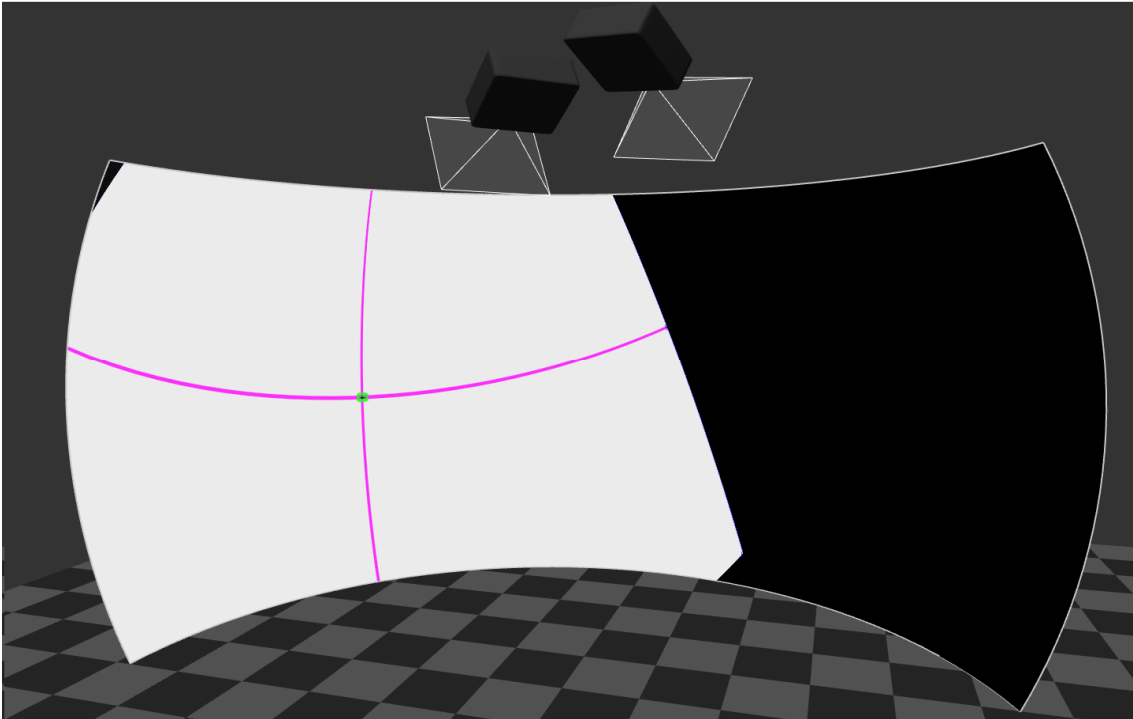
6.2.13   Advanced Configuration

The advanced configuration tab under the File/Advanced menu, contains a set of advanced configuration options that can be used in case the default options are not sufficient for successful calibration in some setups.

Users should use the default settings as much as possible. The advanced configuration options should be used after consultation and advice from our support team.

In order to provide the needed support, our support team can request a detailed diagnostic information produced during the calibration. Users can enable "Save images" diagnostics information, press the "Clear" button to clear any previous support information and perform the calibration. After that the detailed diagnostics information can be collected in a zip file and send to our support team.

Note: Enabling the diagnostic information will slow down the calibration and mapping process and will produce a large amount of data in the DIAG folder. This option should be disabled, except when the diagnostic information is requested from our support team.
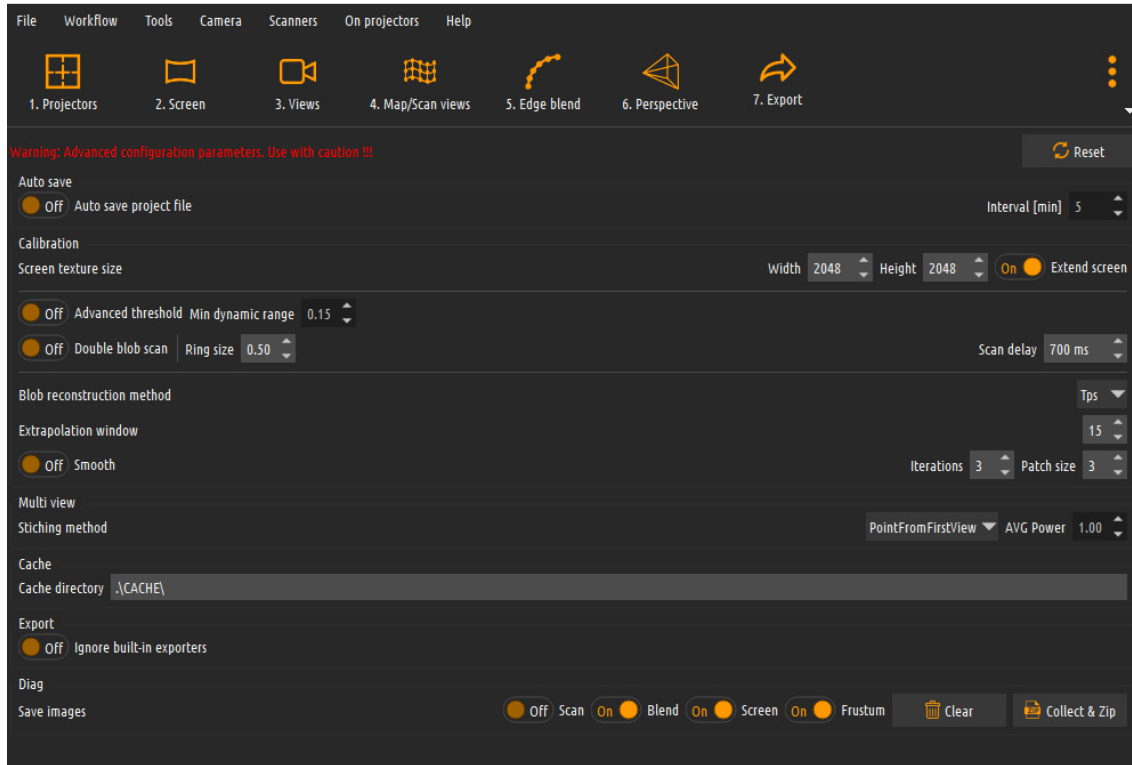
6.2.14   Post calculation warping

In some cases, after the Single Virtual Camera and optionally Multiple Virtual Camera warping and blending is calculated, the user can apply a fine grained manual post warping in order to perfectly match the calibration results.
Use the Tools/*Post warp* menu to open the warping window per projector.
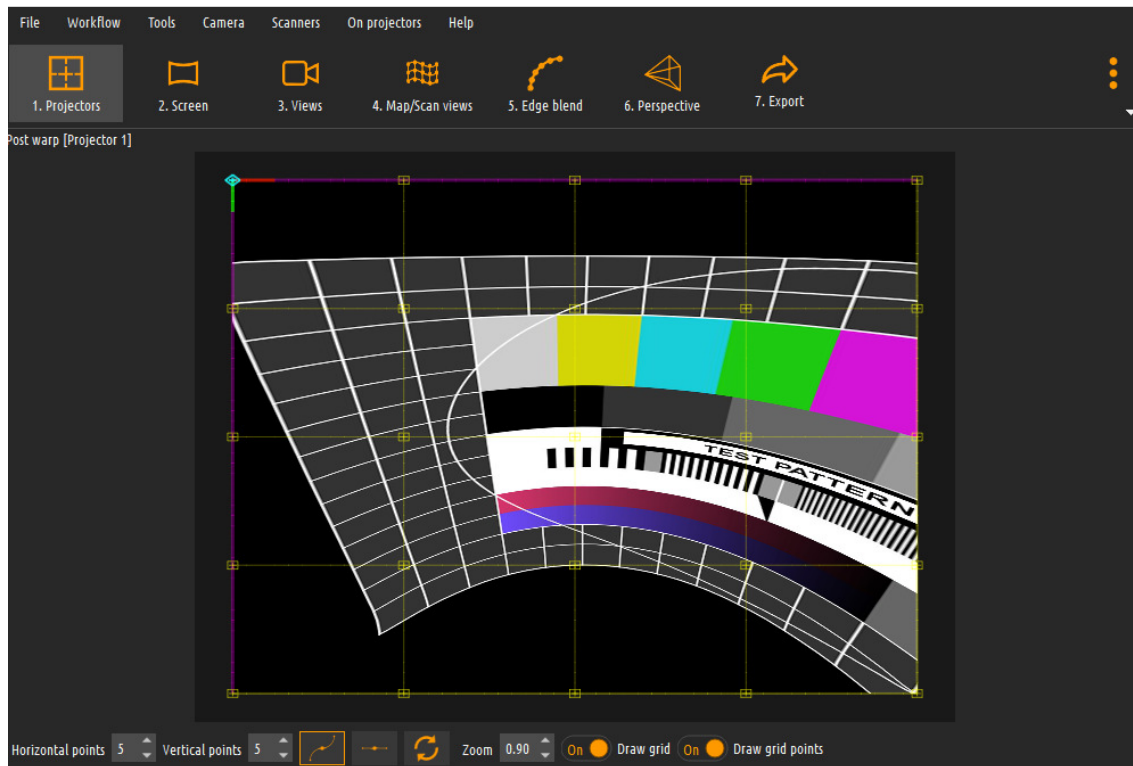
Using the warping grid, users can apply slight post warping.
 Note: This post warping is not meant to be used to correct an unsuccessful calculation. Use this step only for very slight adjustments to compensate for imperfection in the projection screen shape, the cameras and the projectors.

6.2.15   Exporting the calibration results

After Single Virtual Camera and optionally Multiple Virtual Camera warping and blending is calculated the calibration results can be exported to one or multiple files.

Use the *Export Calibration Result* button to open the Export.
If needed change the default export location and the file prefix of the exported files (bottom of the page). Initially the exported files will be saved into the "./export" directory and will be prefixed with "data".
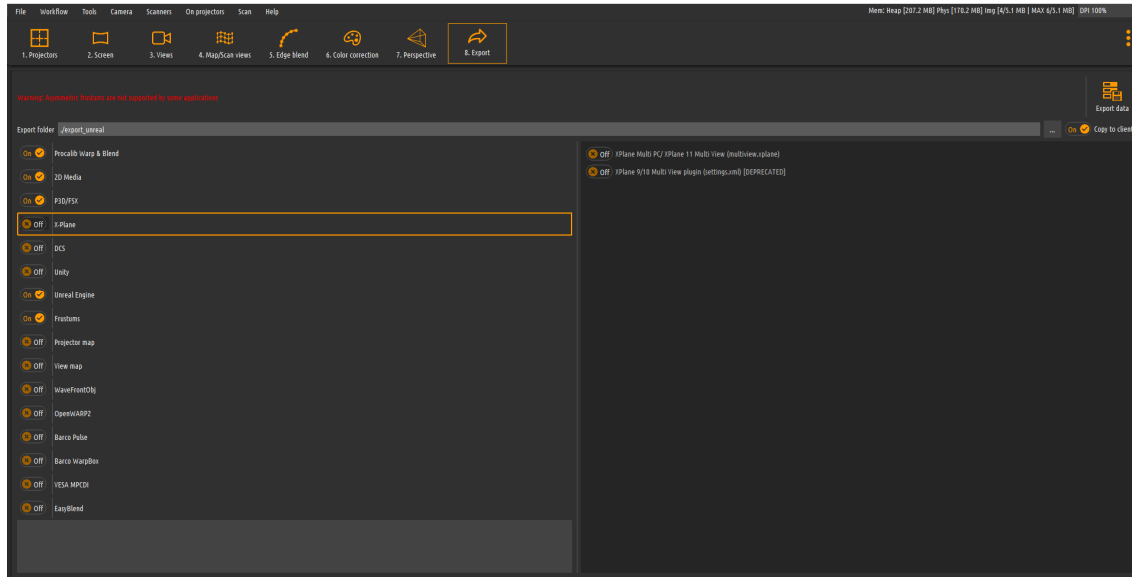
For each remote display the _single.procalib_ file contains the geometrical and blending information to project computer desktops, movies, animations or other 2D content.

For each remote display the _multi.procalib_ file contains the geometrical and blending information to project the images from the virtual cameras from the 3D games or simulation engines. This file will only be created when multiple virtual cameras is available.

Next to the _.procalib_ files, the virtual cameras settings files will be created to configure the 3D engines.

Note: Depending on the selected Frustum settings (Symmetric or Asymmetric frustum) when calculating the frustums in the multi-view widow), some of the exporters will not be available if the 3D engine does not support Asymmetric frustums.

The _.frustums(xml)_ file contains a general description of the virtual cameras per projector. The file contains the camera frustum parameters that can be directly applied in the 3D engines using the standard DirectX or OpenGL API.

Additionally to the The _.frustums(xml)_ file, the users can provide a template to export the virtual camera information for the 3D engines and image generators. The provided template file contains keywords that will be replaced by Immersive Calibration PRO software with the calculated values for the

virtual camera. The following section contains more details for the template files.

One of the exported *.procalib* files can be loaded in Immersive Display PRO to do the geometrical correction and soft-edge blending of the video output before the output is sent to the projector.

The list of supported third party exporters increases from release to release.
The software supports exports for the most common formats that can be used directly in a projector or through the warping box.
Additional licensing is required to enable the third party exporters.
Contact us for more info.

Select the External calibration from the projector configuration menu in Immersive Display PRO display. A file dialog will be opened to select a *.procalib* file. This file contains the projection setup for the display and all the needed geometric correction and soft-edge blending information. This will override the manual calibration in Immersive Display PRO. In Immersive Display PRO the users can still adjust the profile of the blending curves and the color profiles of the projectors. However, when using external calibration file the geometrical correction cannot be adjusted manually.
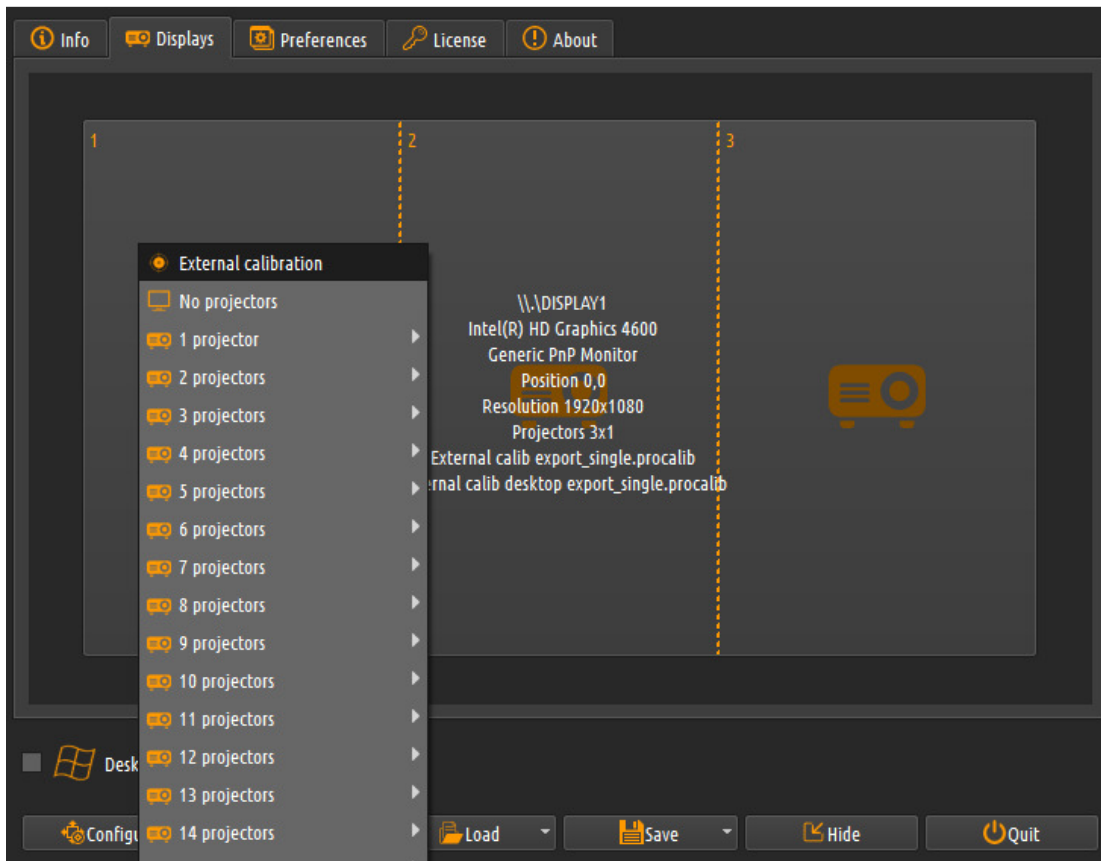
Note: Additional license is required for Immersive Display PRO to be able to use the *.procalib* result file. If no license is present the "Unregistered version" watermark will be overplayed on the output when using the *.procalib* result file.

6.2.15.1 Template file virtual cameras

Immersive Calibration PRO software provides the most flexible integration with any 3D graphics engine and Image Generator software.

Users can define and provide their own text based template files in the format of the 3D engine. Immersive Calibration PRO will search for specific "keywords" in this template file and replace them with the calculated values for each projectors virtual camera. This can be also used to generate code that can be automatically compiled into the graphics engine when needed.

The template file is based on the CTemplate engine and follows the CTemplate syntax. The "keywords" are put into double curly brackets. Ex {{KEYWORD}}. The {{!ANYTEXT}} indicates a comment and will not be expanded in the generated file.

A special comment {{!PER_PROJECTOR}} must be used at the beginning of the template file to indicate that one file needs to be generated per projector. If this comment is omitted, one file will contain the file of all projectors data.

After the optional {{!PER_PROJECTOR}}

, the template file must contain the tags {{#PROJECTORS_LOOP}} and {{/PROJECTORS_LOOP}}. Everything between those two tags will be generated per projector. All the known keywords must be placed between the {{#PROJECTORS_LOOP}} and {{/PROJECTORS_LOOP}} tags.

Here are the supported keywords known by the software. Each keyword will be replaced by the calculated value.

{{NAME}}	The name of the projector. Will be replaced with Projector1, Projector2, etc.
{{VIEWPORT_X}}, {{VIEWPORT_Y}}	The viewport origin of the virtual camera.
{{VIEWPORT_WIDTH}}, {{VIEWPORT_HEIGHT}}	The width and the height of the virtual camera image. The same as the projectors resolution.
{{VIEWPORT_ASPECT}}	Aspect ratio (width/height) of the projectors.
{{HFOV_DEG}}, {{HFOV_RAD}} {{VFOV_DEG}}, {{VFOV_RAD}}	The virtual camera horizontal and vertical field of views (in degrees and

	radians respectively). Those are valid when a symmetric frustums have been used.
{{LEFT_DEG}} {{LEFT_RAD}} {{RIGHT_DEG}} {{RIGHT_RAD}} {{BOTTOM_DEG}} {{BOTTOM_RAD}} {{TOP_DEG}} {{TOP_RAD}}	The virtual camera frustums are defined by the left, right, bottom and top angles relative to the center. Those angles (in degrees and radians respectively) are calculated in both symmetric and asymmetric frustums. Ex OpenGL users can use glFrustum(l, r, b, t, near, far_ to define the camera frustum.
The following keywords contain information to define the position and orientation of the virtual camera in the 3D engine. The software calculates those values for both right handed coordinate system and left handed coordinate system. The right hand coordinate system is defined by the x-axis pointing to the right, y-axis pointing to up and z-axis pointing outside of the screen. The left hand coordinate system is defined by the x-axis pointing to the right, y-axis pointing to up and z-axis pointing inside of the screen. The following keywords are available for right handed coordinate system.	
{{POSITION_RH_X}} {{POSITION_RH_Y}} {{POSITION_RH_Z}}	The X, Y and Z position of the virtual camera (in meters). Those are the same as the position of the eyepoint.
{{LOOKAT_AXIS_RH_X}} {{LOOKAT_AXIS_RH_Y}} {{LOOKAT_AXIS_RH_Z}} {{Y_AXIS_RH_X}} {{Y_AXIS_RH_Y}} {{Y_AXIS_RH_Z}}	The orientation of the virtual camera can be defined by the look-at axis and the Y axis of the camera in the world coordinate frame. Those vector are unit vectors. Ex:OpenGL gluLookAt can be used with the position, lookAt and YAxis to define the position and orientation of the camera.
{{ROTATION_RH_X_DEG}} {{ROTATION_RH_Y_DEG}} {{ROTATION_RH_Z_DEG}} {{ROTATION_RH_X_RAD}}	Alternatively, the orientation can the defined in the Euler angles rotations. The rotation order is YXZ. The rotation

{{ROTATION_RH_Y_RAD}} {{ROTATION_RH_Z_RAD}}	angles can be defined in degrees or radians respectively.
The same keywords (only containing LH) are available for left handed coordinate system	
{{POSITION_LH_X}} {{POSITION_LH_Y}} {{POSITION_LH_Z}} {{LOOKAT_AXIS_LH_X}} {{LOOKAT_AXIS_LH_Y}} {{LOOKAT_AXIS_LH_Z}} {{Y_AXIS_LH_X}} {{Y_AXIS_LH_Y}} {{Y_AXIS_LH_Z}} {{ROTATION_LH_X_DEG}} {{ROTATION_LH_Y_DEG}} {{ROTATION_LH_Z_DEG}} {{ROTATION_LH_X_RAD}} {{ROTATION_LH_Y_RAD}} {{ROTATION_LH_Z_RAD}}	

This is an example of a template file that can be used to generate C code for setting up the virtual cameras using OpenGL.

```
////////////////////////
{{#PROJECTORS_LOOP}}
//Frustum for {{NAME}}
glViewport({{VIEWPORT_X}},{{VIEWPORT_Y}}, {{VIEWPORT_WIDTH}}, {{VIEWPORT_HEIGHT}});
glMatrixMode(GL_MODEVIEW);
glLoadIdentity();
gluLookAt(  {{POSITION_RH_X}}, {{POSITION_RH_Y}}, {{POSITION_RH_Z}},
                    {{POSITION_RH_X}}+{{LOOKAT_AXIS_RH_X}},
                    {{POSITION_RH_Y}}+{{LOOKAT_AXIS_RH_Y}},
                    {{POSITION_RH_Z}}+{{LOOKAT_AXIS_RH_X}},
                    {{Y_AXIS_RH_X}}, {{Y_AXIS_RH_Y}}, {{Y_AXIS_RH_Z}});

float _near = 0.1f;
float _far = 100.0f;
float _left = tan({{LEFT_RAD}})*_near;
float _right = tan({{RIGHT_RAD}})*_near;
float _bottom = tan({{BOTTOM_RAD}})*_near;
float _top = tan({{TOP_RAD}})*_near;

glMatrixMode(GL_PROJECTION);
glLoadIdentity();
glFrustum(_left, _right, _bottom, _top, _near, _far );

//Draw the scene for {{NAME}}
Draw();

{{/PROJECTORS_LOOP}}
////////////////////////
```

When export is completed, the following file will be generated:

```
//Frustum for Projector1
glViewport(0, 0, 1024, 768);
glMatrixMode(GL_MODEVIEW);
glLoadIdentity();
gluLookAt(  0, 0, 0,
                    -0.612062, -0.013827, -0.612062,
                    -0.00846378, 0.999904, -0.0109339);

float _near = 0.1f;
float _far = 100.0f;
float _left = tan(-0.960481)*_near;
float _right = tan(0.960481)*_near;
float _bottom = tan(-0.820305)*_near;
float _top = tan(0.820305)*_near;

glMatrixMode(GL_PROJECTION);
glLoadIdentity();
glFrustum(_left, _right, _bottom, _top, _near, _far );

//Draw the scene for Projector1
Draw();
...
...
```

6.2.15.2   Prepar3D v3.3+ camera settings

Prepar3D v3.3 introduced a feature named View Groups. On multi display systems, View Groups can be created to easily configure views across multiple displays using the View Group Management window.

http://www.prepar3d.com/SDKv3/LearningCenter/getting_started/view_system/display_configuration.html

There is no more need for modifying the flight files (fxml files) for creating correct geometry for multi-projection systems.

One important feature of View Groups is the possibility for asymmetric frustums (camera). This allows Immersive Calibration PRO to calculate the best frustum fit and ensure minimum pixel loss and minimum image stretching.

In Immersive Calibration PRO make sure that the option "Asymmetric frustum" is enabled when calculating the frustums for each projector view.
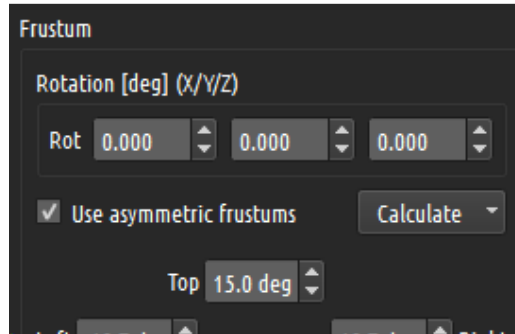
When using asymmetric frustums, the calculation of the frustums will be optimized to minimize the pixel loss and maximize the projector image usage on the screen.

This will export a file ViewGroups.xml that can be copied into the P3D configuration folder.
Open the folder "%APPDATA%\Lockheed Martin\Prepar3D v3". The easiest way is to press WIN + R keys, type %APPDATA% and press enter. This will open the "%APPDATA%\ folder. Open the underlying Lockheed Martin\Prepar3D v3 folder.
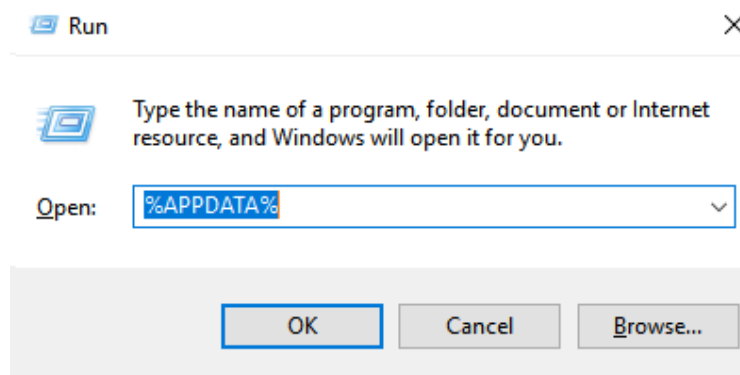

Rename/backup the existing ViewGroups.xml file and copy the exported ViewGroups.xml file in this location.
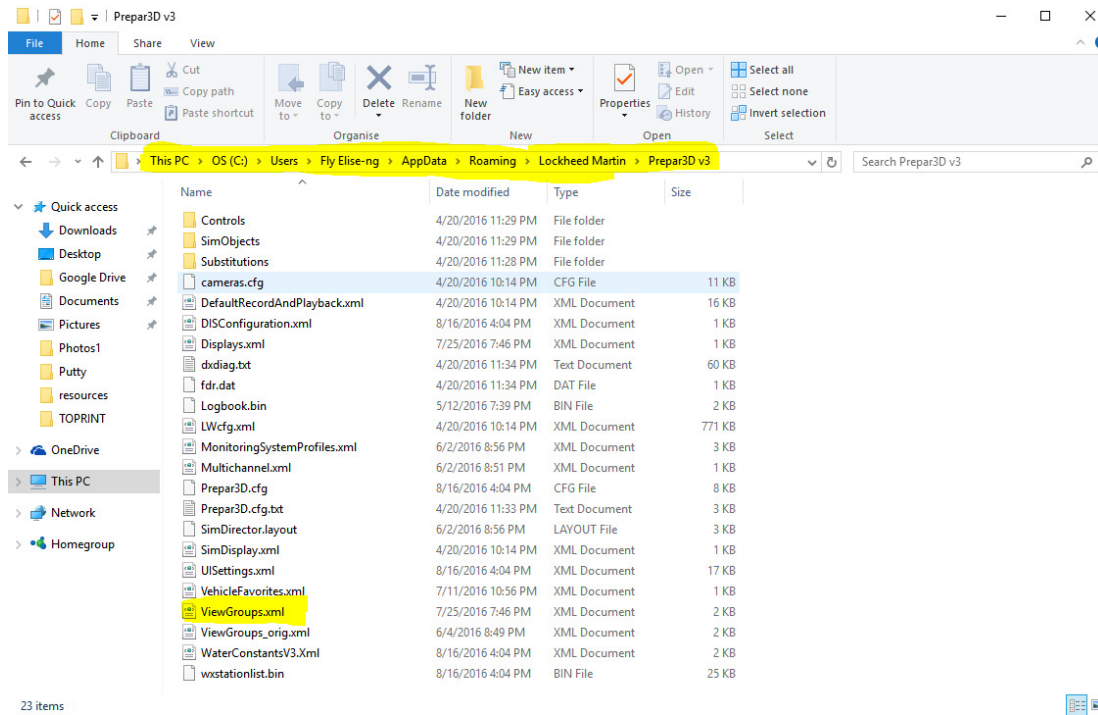
When P3D is restarted it will load the exported ViewGroups.xml.
Open the P3D View menus and select View Group Management.

Note: Latest versions of P3D v3 moved the configuration data to the global location C:\ProgramsData\ Lockheed Martin\Prepar3D v3. If this folder exists, copy the exported ViewGroups.xml file in this location.

Note: Latest versions of P3D v4 moved the configuration data to the global location C:\ProgramsData\ Lockheed Martin\Prepar3D v4. If this folder exists, copy the exported ViewGroups.xml file in this location.
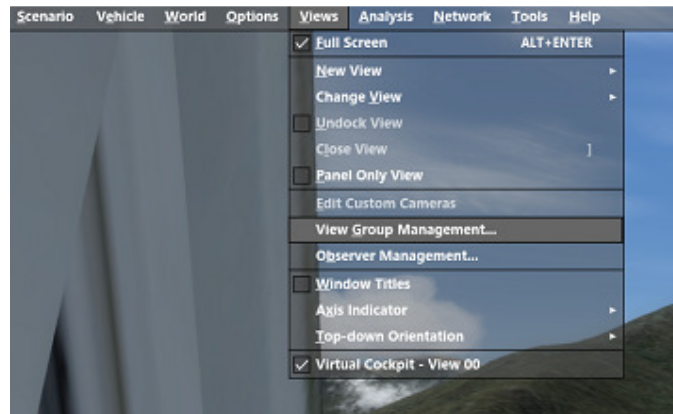
Just make sure that the enumerated displays and graphics cards on your system match the DisplayID exported in the ViewGroups.xml file. If they do not match, assign them the correct DisplayID using the View Group Management window.
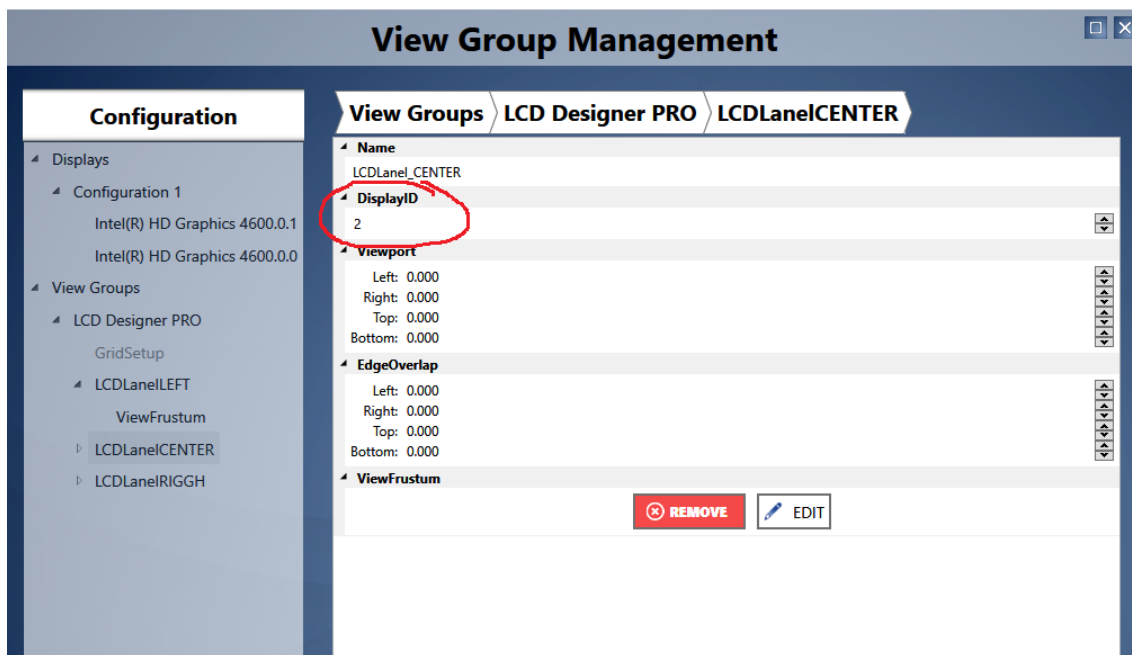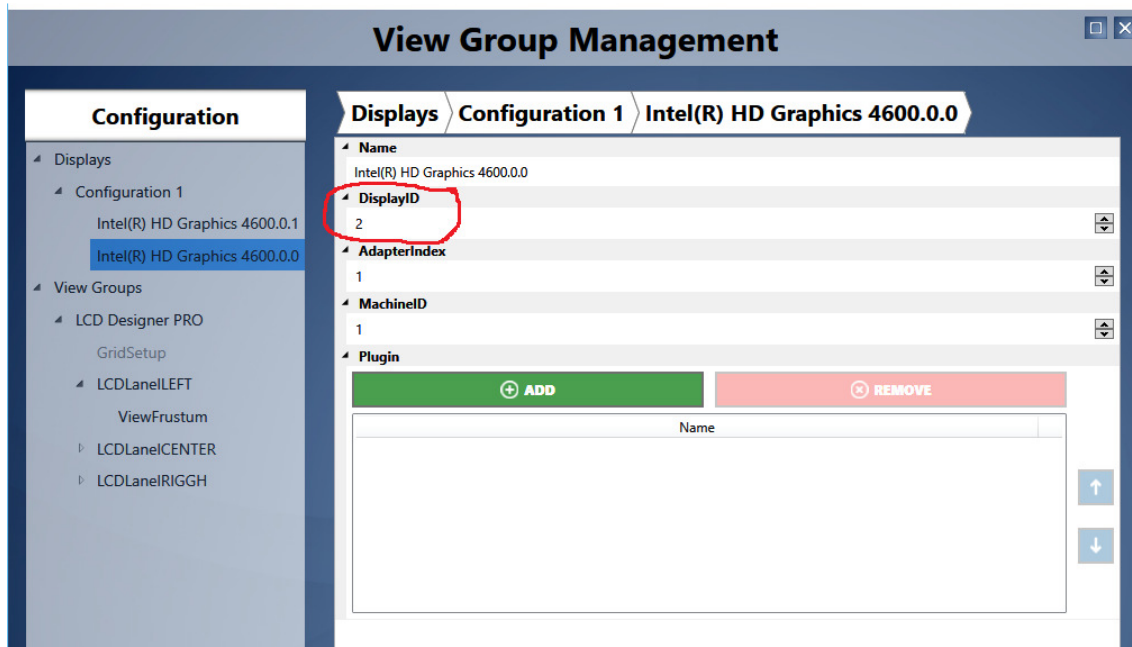

Now you can start any flight in cockpit mode or virtual cockpit mode.

Use the right button and click on the current view (not the View Menu) and select View Groups, then click on Immersive Calibration PRO. This will create the position the views on the corresponding projectors.

Note: When using the ViewGroups.xml file, there is no need to update the flight fxml files. The ViewGroups.xml file will make sure that the view are positioned on the correct projector.

Start Immersive Display PRO. For each ungrouped display, click on the display, select external calibration and chose the exported _multi.procalib file. Now restart P3D and select the View Groups/Immersive Calibration PRO.
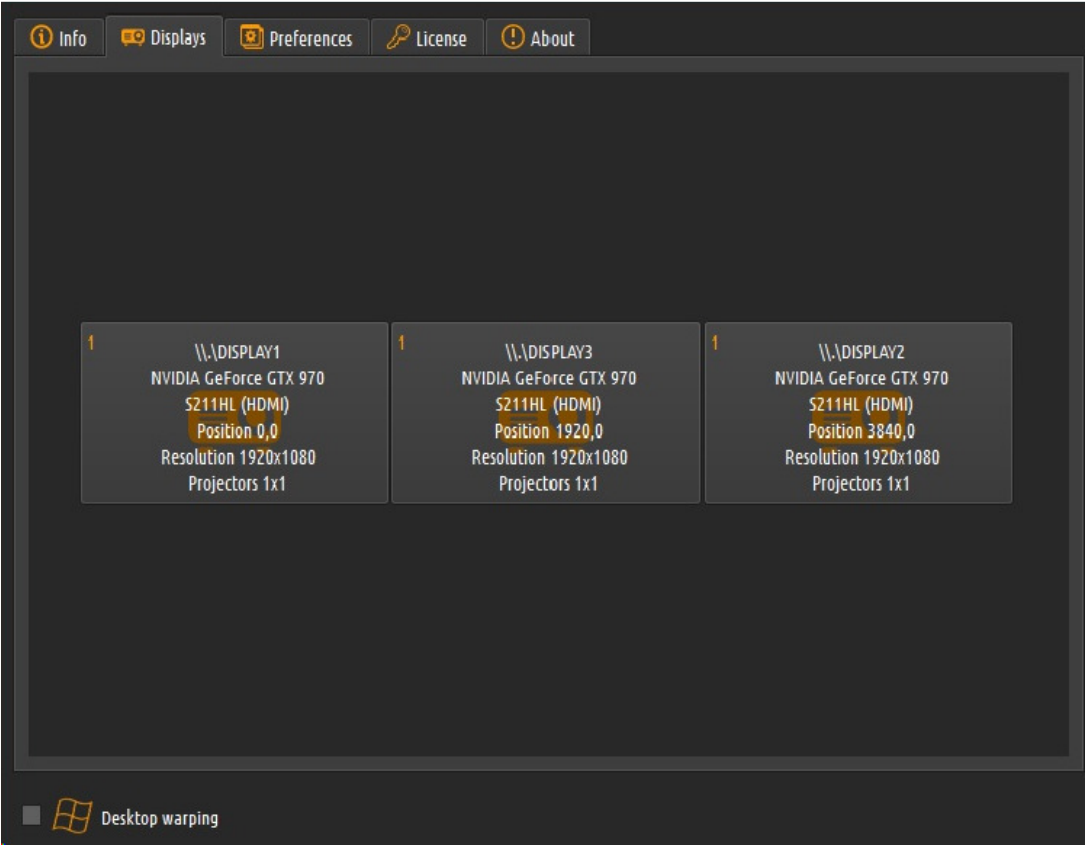
6.2.15.3 FSX/Prepar3Dv2+ camera settings

The exported *.fsx* file contains a description of the FSX/Prepar3D outside views and the corresponding view camera settings. This file has to be copied in the .flt file.

Open the FSX/Prepar3D .flt file and delete all [Window.x] and [Camera.x.x] sections. Copy the content of the .fsx file inside the .flt file at the same place as the original [Window.x] and [Camera.x.x] sections.

Note: Make sure that the file %APPDATA%\Microsoft\FSX\fsx.cfg (or %APPDATA%\Lockheed\Prepar3D\prepar3d.cfg) contains the following entry: WideViewAspect=True

Note: In Prepar3D v2 the WideView settings is available in the settings screen. Also make sure that the model.cfg file of the aircraft that is used does not contain the interior. Comment out the interior part by putting // before the interior section in the file.

In Prepar3D version 2.x, the format of the flight file has been changed in *.fxml* file. This is an xml file that contains the same information as the previous *.flt* file format. For a convenience Immersive Calibration PRO generates *.fxml* file that contains a description of the Prepar3D v2.x outside views and the corresponding view camera settings. This file has to be copied in the Prepar3D v2 saved *.fxml* file.

Note: When using Multiple Virtual Cameras the *_multi.procalib* has to be loaded as external calibration in Immersive Display PRO.

6.2.15.4 X-Plane Multi View settings

The exported *.settings.xml* file contains configuration data for X-Plane MultiView plugin to enable multiple views from a single running instance of X-Plane. Each view has it's own camera settings provided by the *settings.xml* file.

Out of the box, X-Plane does not provide functionality to create multiple individual views from a single running instance of X-Plane. This makes it

impossible to create true 180 deg (or more) projections from single X-Plane view frustum.

We developed the MultiView plug-in for X-Plane 9 and 10 (32bit and 64bit) that creates multiple views from a single running instance of X-Plane.

Using the MiltiView plugin and using Multiple Virtual Cameras the _*multi.procalib* as external calibration in Immersive Display PRO, users can create true immersive projection from a single X-Plane computer with multiple projectors.

6.2.15.5   Dome master *video* projection from a single PC

The exported *single.procalib can be used to playback a standard definition, high definition or ultra-high definition dome master video content. Dome master video contains 180 degree video usually taken by a fisheye camera. The video image size is square (width==height)
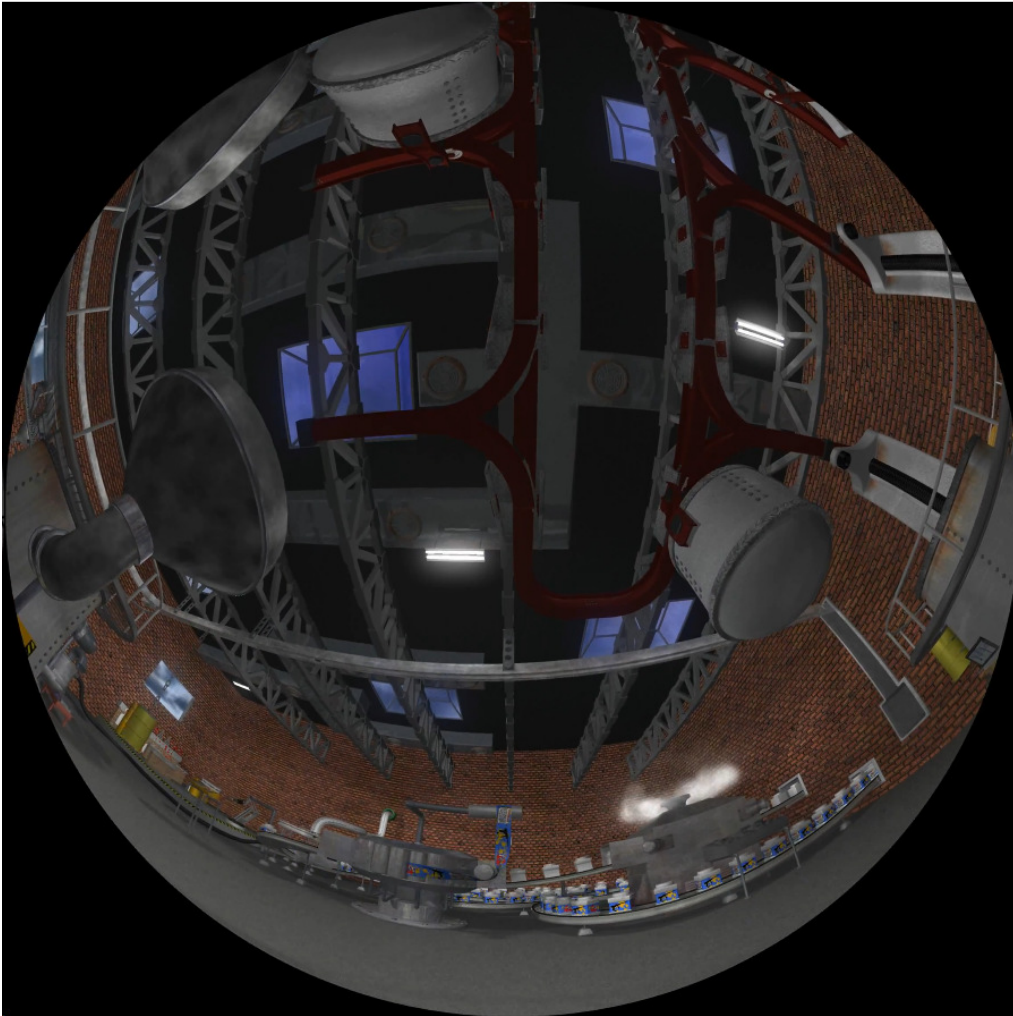
Start Immersive Display PRO, go to Display Tab and click on the display. From the drop down menu select "External calibration" and load the *_single.procalib file.
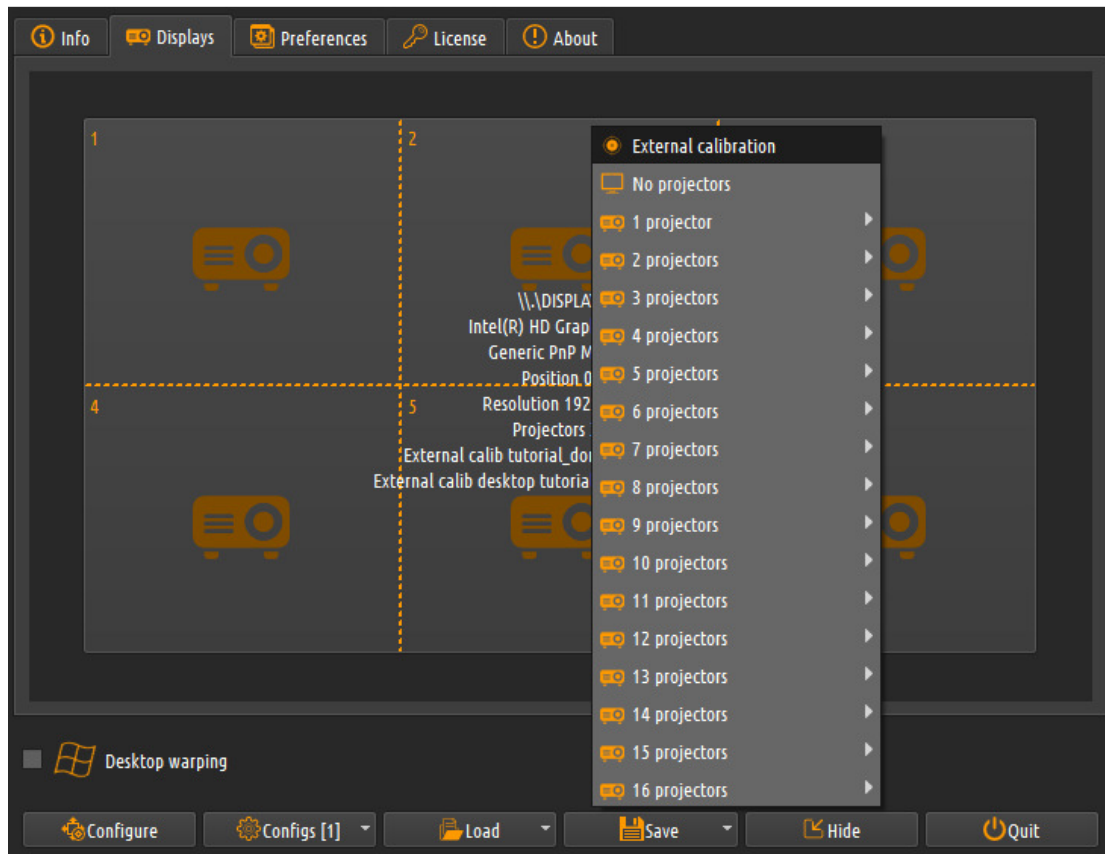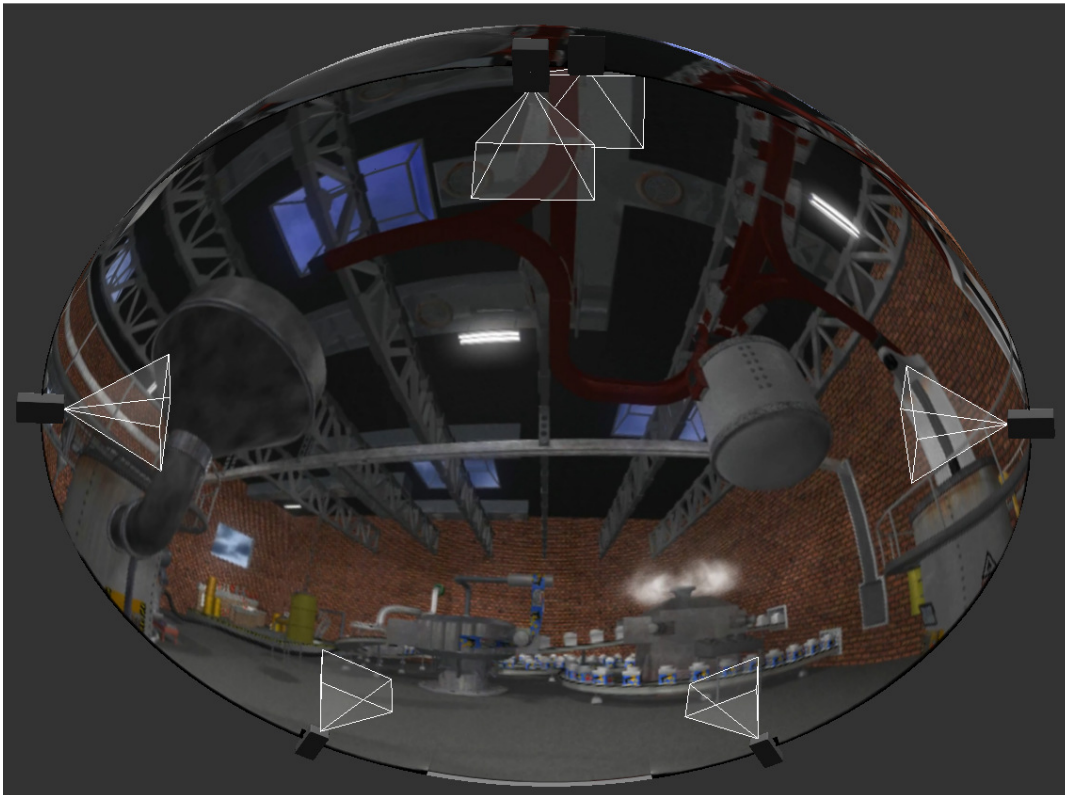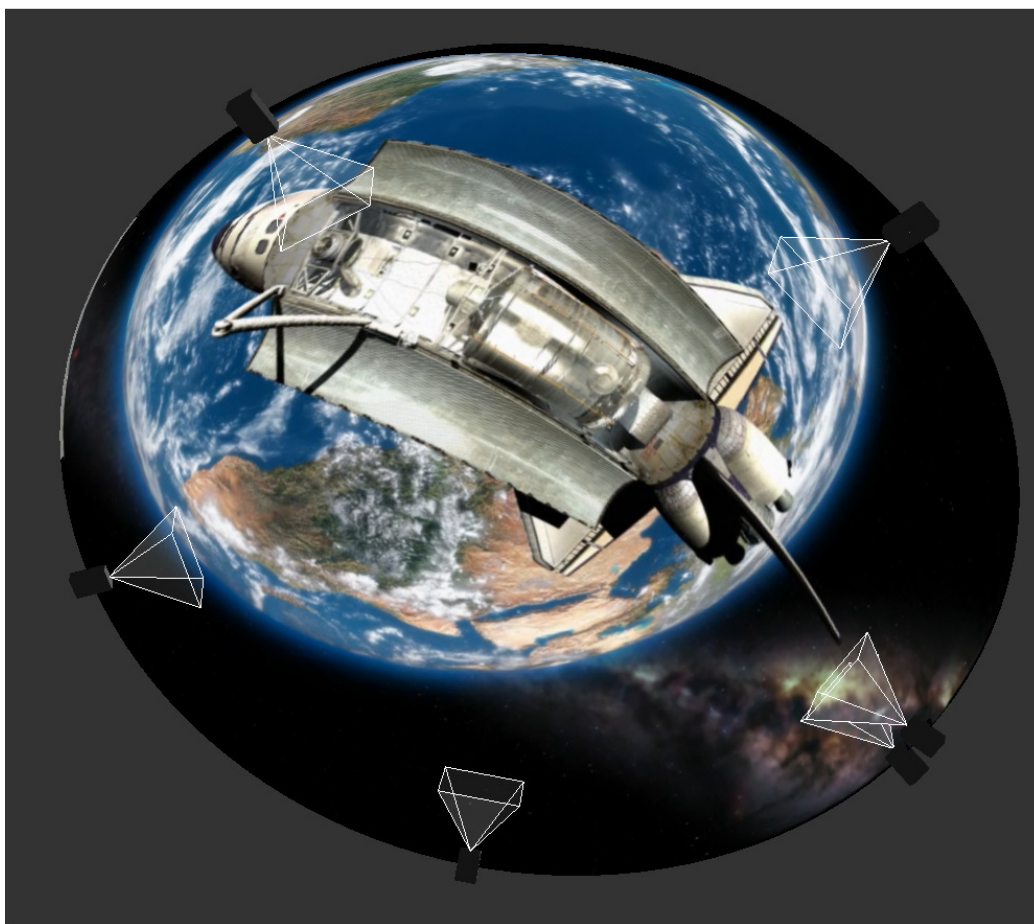
Now start the video player and load and start a dome master video file

The video will be started and will open on all 6 projectors. Each projector will display the part of the video needed for the part of the screen covered by the projector.
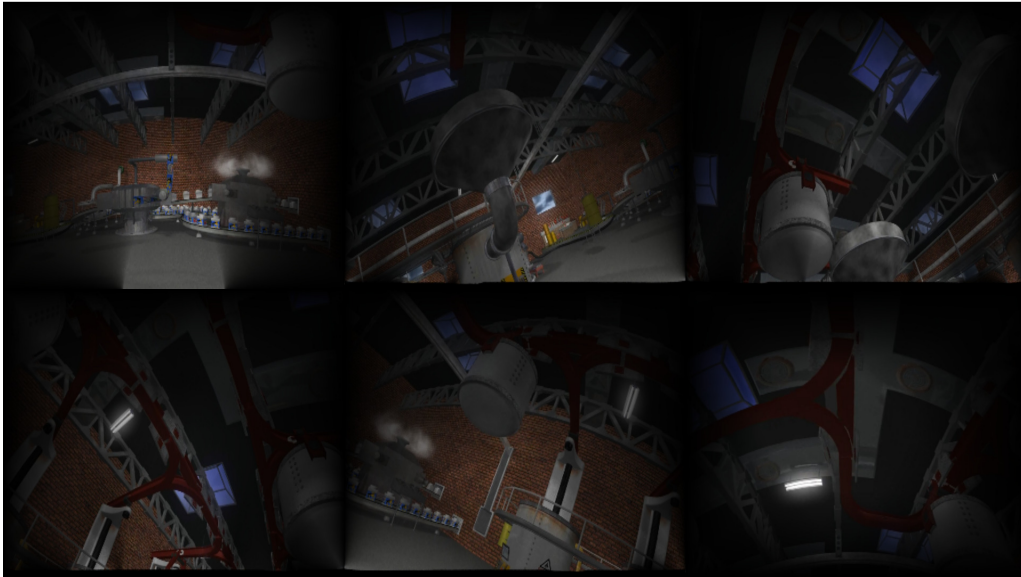
The projected image on the dome projection screen will be perfectly aligned and soft-edge blended.

6.3 Camera calibration

Only in "*Map on camera*" mode:
Standard digital camera and web cameras use optical elements (lenses) that distort the image. Depending on the camera sand the optical elements the distortion can be manifested on the taken images in form of curved shapes at the edges of the captured image. When a straight lines scene is captured with such a camera, the captured images show curved lines especially at the edges of the image.
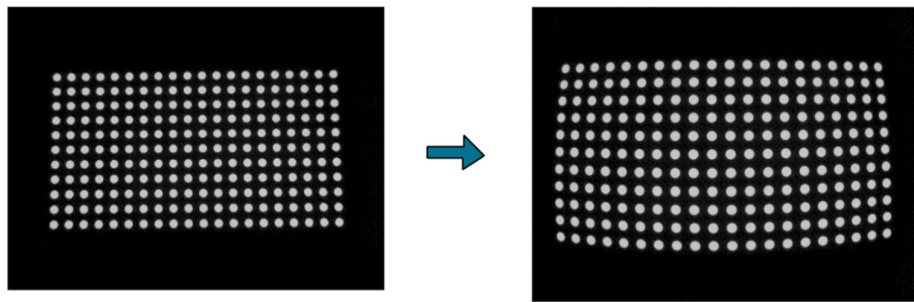

Camera Calibration is an essential step in the preparation for automatic screen mapping.
After the camera calibration, the camera distortion parameters are estimated and are used for rectifying the camera image. The calibrated camera images can be used for automatic mapping of the screen grid points on the screen.
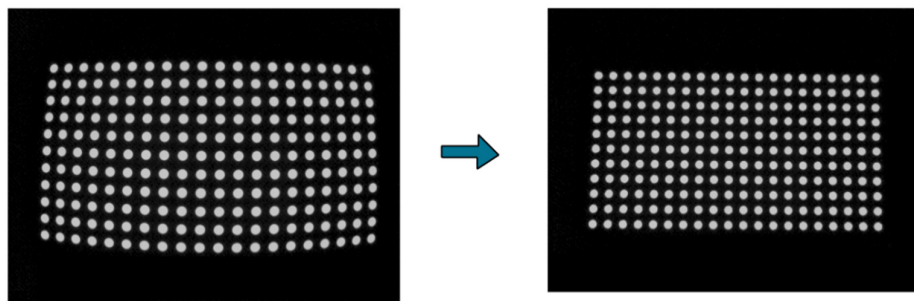

For the calibration procedure the user has to capture a well-known calibration grid (e.g. chessboard) several times from different positions and camera distances. The estimated points from the grid and the knowledge about the original points are used to estimate the radial/tangential/affine distortion parameters of the camera and its intrinsic parameters.
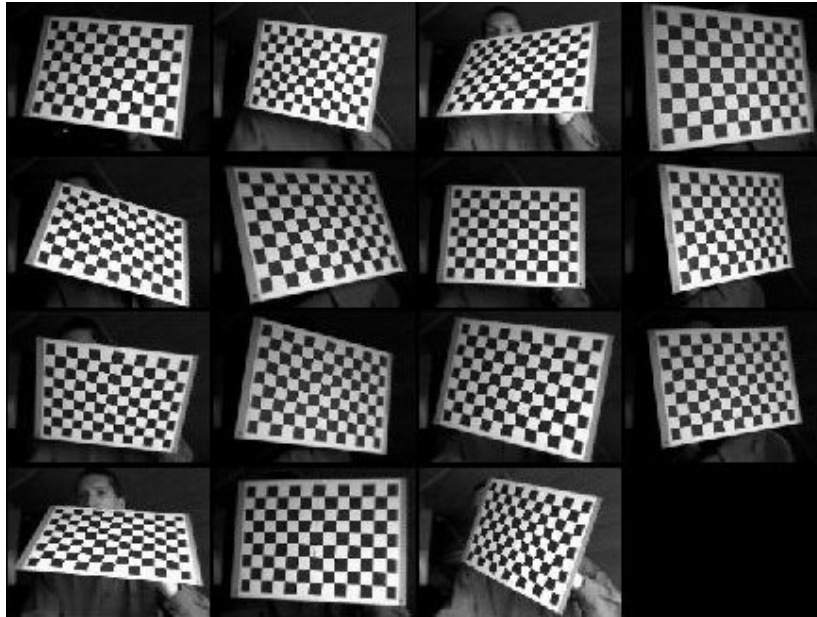
10 or more images are required from different locations and angles in order to accurately estimate the camera distortion parameters.
A special chessboard grid pattern should be used for camera calibration. The pattern is divided is horizontal and vertical black and white boxes.
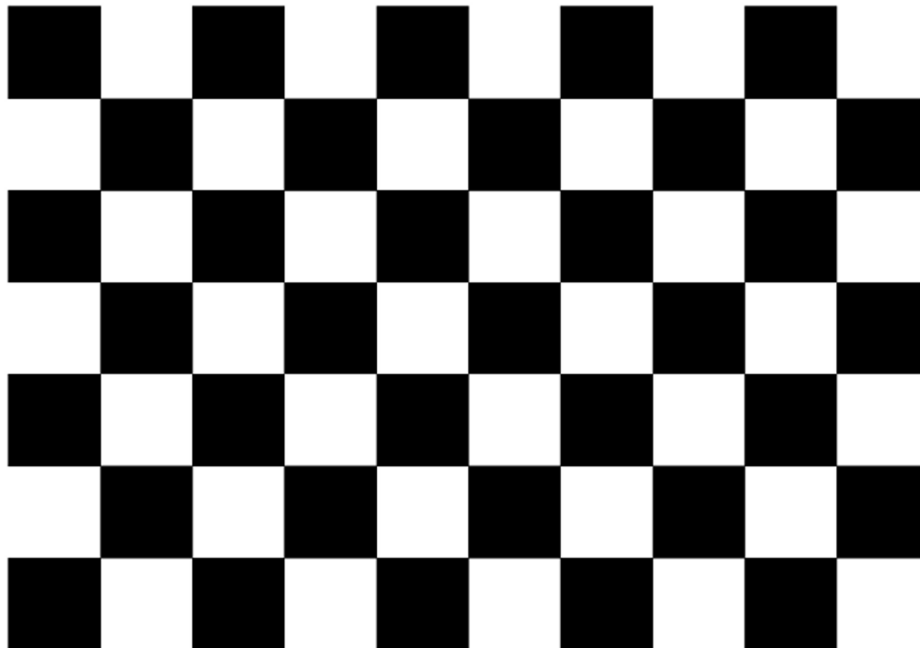
The camera calibration needs to know the number of internal horizontal and vertical crossings. The software will try to "recognize" the crossings from every image and will estimate and calculate the camera distortion.
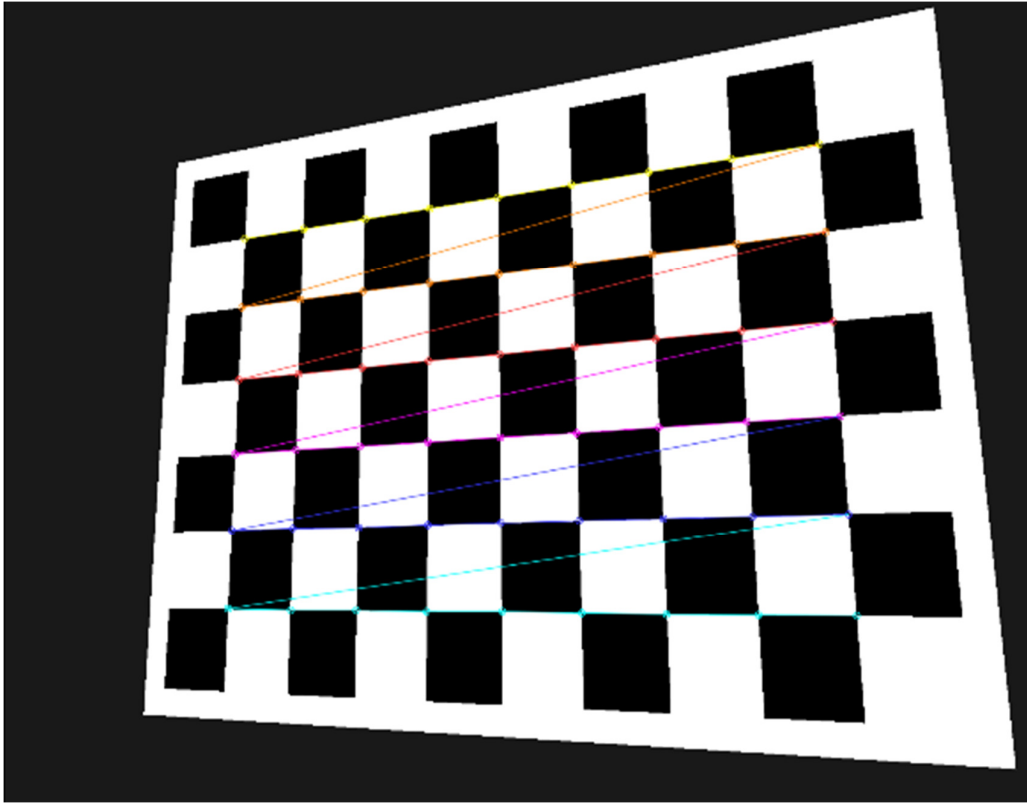
Immersive Calibration PRO offers two tools for camera calibration: *Calibrate Live Camera* and *Calibrate Photo Camera*.

After the camera is calibrated and the camera calibration data is saved, the calibration data will be used to correct the image from distortions and to show the undistorted image in the view window.

When the camera image is corrected and the camera calibration data is used, the view window will show "*Calibrated*" in the top left part of the window.
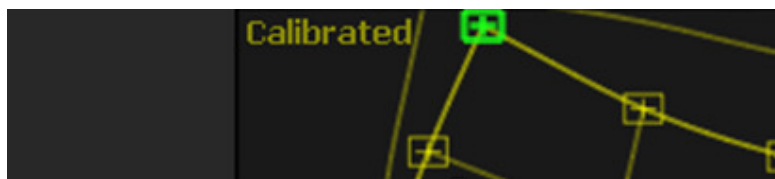
The camera calibration data can be unloaded at any time by selecting the appropriate camera calibration tool and pressing the *Remove calibration data* button.

Immersive Display PRO installation contains a *pattern.pdf* file with a calibration pattern of 9x6 internal intersections.
This *pattern.pdf* file has to be printed out on an A4 paper without any printer scaling and fittings. The width and the height of the black and white boxes have to be the same.

6.3.1 Live camera calibration

Only in "*Map on camera*" mode:

Pressing the *Calibrate Live Camera* button from the *Camera menu* will open the *Calibrate Live Camera* tool window.
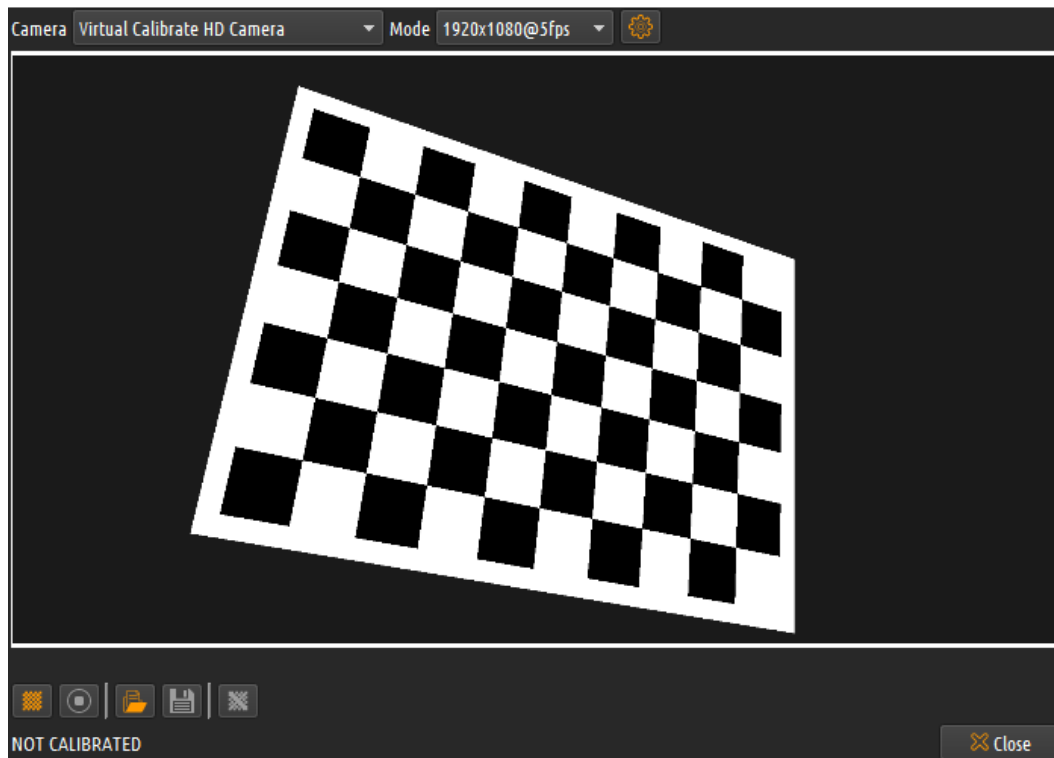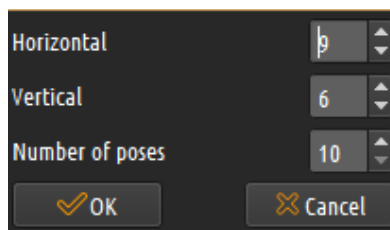

On the top of the Calibrate Live Cameras screen user can select the available web cameras and the available camera mode.

Note: The camera automatic enchantments (auto-focus, auto-zoom, white balance, etc.) have to be turned off. If one of the camera optical parameters changes (focus, zoom, etc.), the calibration procedure has to be repeated.

The calibration process will start after pressing the *Start calibration* button.

Before the calibration can start the user has to enter the number of internal horizontal and vertical intersections and the number of images to be taken.

We provide a calibration pattern with 9x6 internal intersections. A number of 10 or more images is required for the best and most accurate calibration result.

After calibration results is started the users has to move the calibration pattern (mounted on a flat rigid surface) in front of the camera in different poses and distances so that the different poses occupy the complete camera view.

Each time the software will recognize the calibration pattern an image will flash and image be taken. The software will continue to search for another pattern until all required patterns are recognized.

After the calibration is completed and the camera distortion is estimated, a File Save dialog will pop up and ask the user to save the calibration data. The calibration data is stored in a separate *.camera* file. After saving the project this calibration file is opened automatically when the project is opened.

When the camera is calibrated the Calibrate Live Cameras screen shows the file name that contains the camera calibration data.

During the live calibration, the calibration can be canceled using the ▣ *Cancel calibration* button.

The camera calibration data can be saved to a *.camera* file using the 💾 *Save calibration data* button. This file can be loaded later using the 📂 *Load calibration data* button.
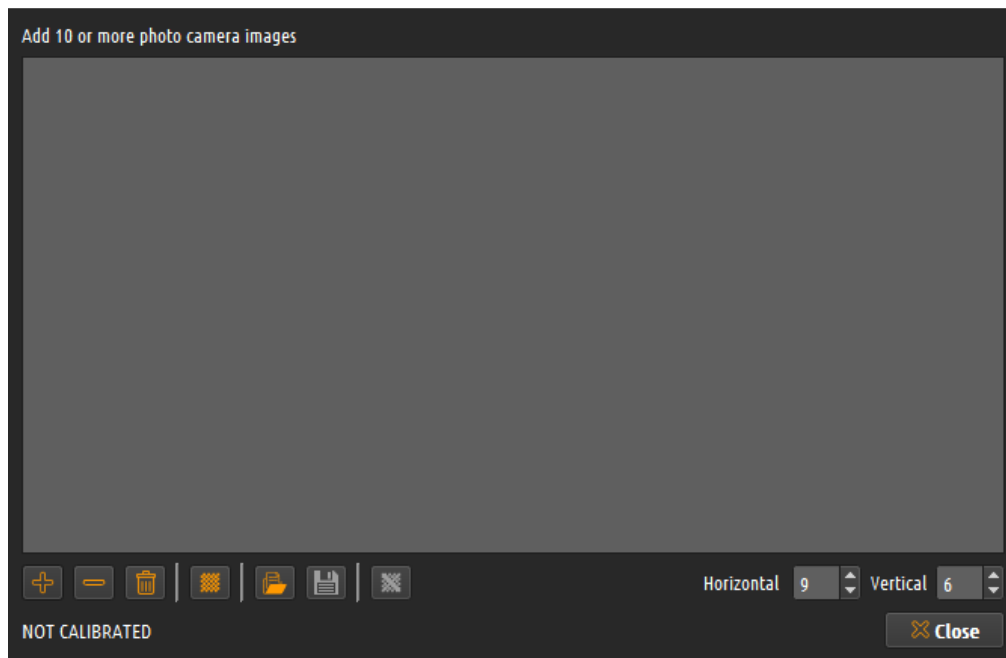
The camera calibration data can be unloaded pressing the ▨ *Remove calibration data* button.

6.3.2 Photo camera calibration (offline)

Only in "***Map on camera***" mode:

Pressing the *Calibrate Photo Camera* button from the *Camera menu* will open the *Calibrate Photo Camera* tool window.

The photo camera calibration tool works similarly to the live camera calibration.

Using a photo camera user should make photos of the calibration chessboard pattern from different perspectives. A minimum of 10 images is needed for the calibration process.

Note: The camera automatic enchantments (auto-focus, auto-zoom, white balance, etc.) have to be turned off. If one of the camera optical parameters changes (focus, zoom, etc.), the calibration procedure has to be repeated.
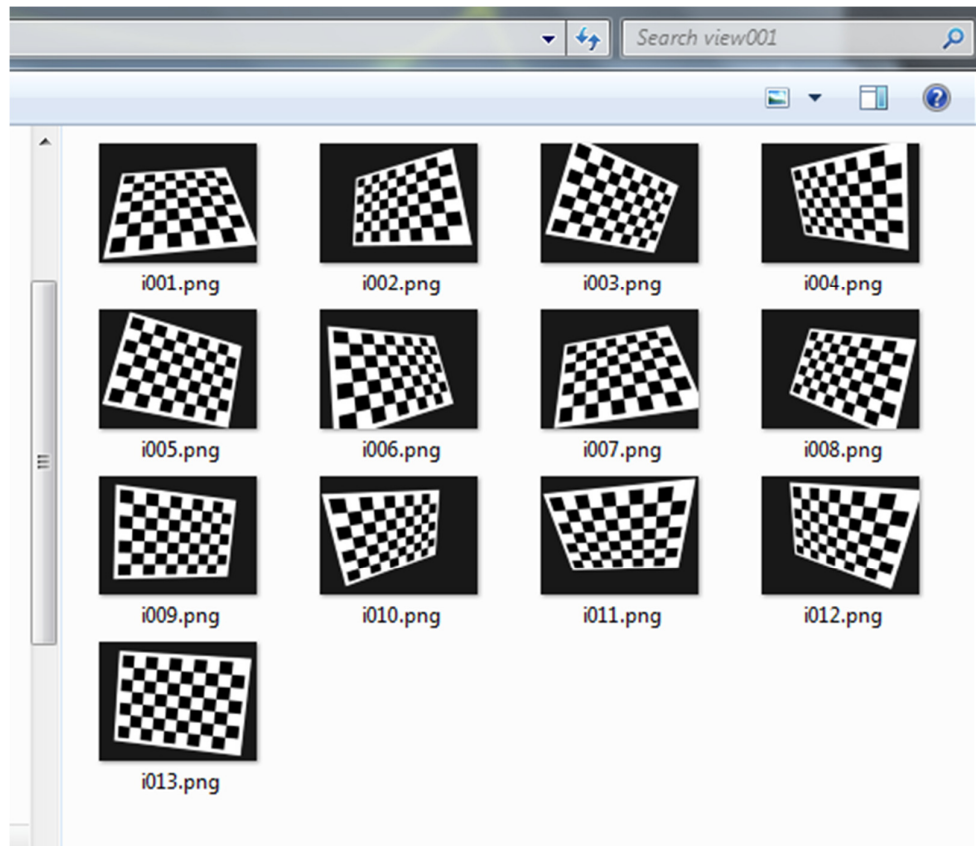
Using the [icon] button one or more images can be added to the list of images to be used for calibration.

The [icon] button and the [icon] button remove one or all images from the list of the images.

Before the calibration can start the user has to enter the number of internal horizontal and vertical intersections.
We provide a calibration pattern with 9x6 internal intersections.

The calibration process will start after pressing the *Start calibration* button.

The photo camera calibration data can be saved to a *.camera* file using the *Save calibration data* button. This file can be loaded later using the *Load calibration data* button.

The photo camera calibration data can be unloaded pressing the *Remove calibration data* button.

After the calibration is completed and the camera distortion is estimated, a File Save dialog will pop up and ask the user to save the photo camera calibration data. The calibration data is stored in a separate *.camera* file. After saving the project this calibration file is opened automatically when the project is opened.

When the photo camera is calibrated the Calibrate Photo Camera screen shows the file name that contains the camera calibration data.

7 License agreement

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