Software Manual
IDEA – The Software

Version 1.1

Open Technologies Srl


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Part One

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1. IDEA - the application for Scan in a Box

The scanning software for Scan in a box is IDEA: it allows carrying out all the steps for digitizing physical objects, form capturing the range images of the object to obtaining and consequently editing its 3D model. The application is available in 2 versions: Standard [Std] and FX [FX]. The latter provides the user with a set of features additional to the Standard version, whose presence will be marked in this manual by the indication [FX].
This manual aims to describe the interface of the application, the main steps for using the scanner, the optical set-up/calibration, from the capture to the generation of the 3D digital model. To close the manual we also provide a glossary of the used terms.

1.1 Application Interface

IDEA's interface is subdivided in three main parts, as shown in Figure 1.1: the project manager panel (lower left), the 3D view panel (lower right), and the toolbar (upper row).
Every operation needed to digitize a physical object is always carried out within a *Project* that is the container into which the scan data is organized.
The project management panel shows and manages all the data collected in the project through the various steps of the digitizing process (Sect. 1.1.1). The 3D view panel shows the data of the project; most of the possible interactions with the data is performed in this panel (Sect. 1.1.2). Finally, the toolbar contains all the features provided by the application for the editing of the data (Sect. 1.1.3).

1.1.1 Project management panel

The project management panel allows to organize and manage all the data associated with a project. When the program starts, the project is empty and will then be filled with the captures and the generation of new data.

It is a good practice to name the project, saving it immediately, with the button *Save project as* , as well as frequently save with the button *Save project* during the various steps of the digitization. Each new element created within a project is represented with a name, an icon specific to the data type, and a color. The main entities of a project are the following:

- **range image**: it's the data obtained at the end of a scanning procedure and represents the part of the surface framed by the scanner at the moment of the capture;

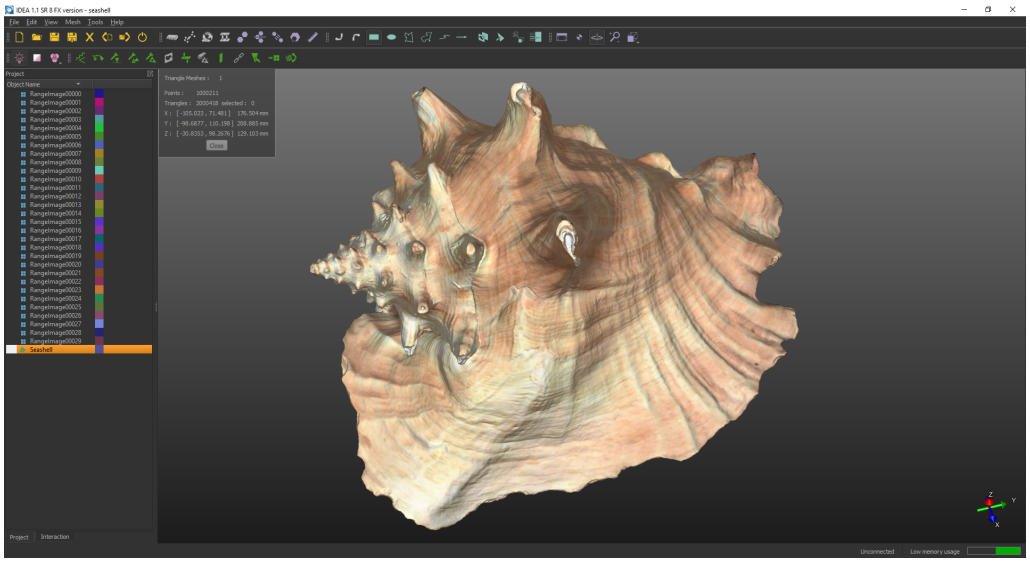


Figure 1.1: IDEA's main interface.

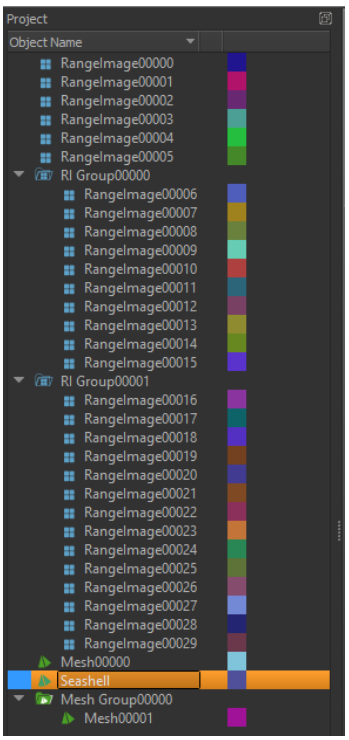


Figure 1.2: Project management panel.

- **Triangle Mesh**: 3D model representing the surface of an object through a set of triangles.

These entities may be arranged into groups that collect elements of the same kind; this allows a better organization of data, it makes it easy to visualize them and to carry out advanced procedures such as the alignment.
These groups may be:

- **Range image group**;
- **Triangle mesh group**.

IDEA is also able to manage planes:

- **planes**.

By clicking the right button of the mouse on the elements a contextual menu, specific for each type of selected object, will be visualized. Moreover, to improve the visual contrast, it is possible to change the color established by the application for each main entity.

1.1.2 3D view panel

The 3D view panel shown in Figure 1.3 allows to see in three dimensions the objects currently selected in the project management panel. Each of the selected elements is positioned within a global reference system, which orientation is shown with the axes in the lower left corner of the window.

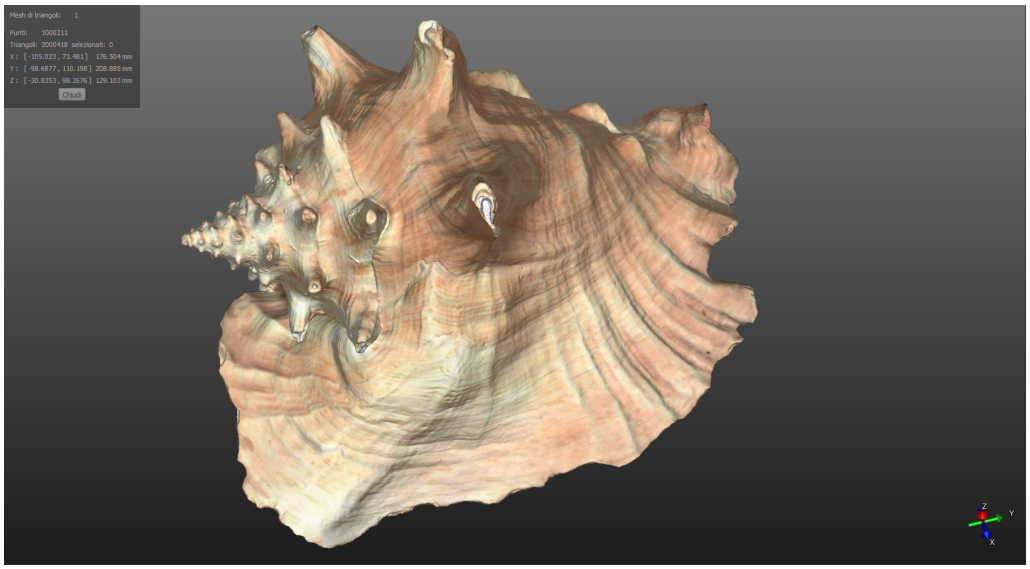


Figure 1.3: 3D view panel.

To change the view point of the currently shown scene (rotating around the object, scaling, traslation and so on) a few mouse-keybord combination can be used:

- free rotation;
- + or Alt + : free translation;
- Ctrl + : rotation bound on Y axis;
- Alt + : rotation bound on X axis;
- Shift + : rotation bound on Z axis;
- Rotation : scales the portion of data currently framed;

- : access the menu contextual to the selected data type;
- Ctrl + : changes the position of the light source in the scene;
- : with an active selection tool, allows to select part of the data, it could be used also for some features of the toolbar;
- Ctrl + : with an active selection tool it allows to deselect part of the data that was previously selected.

A few of these actions can also be activated by features of the toolbar (Sect. 1.1.3). The application establishes the barycenter of the selected elements as default rotation center. However, if the button *Rotation centered on view position*, the rotation center is positioned at the barycenter of the portion of data currently visualized. In the upper left corner it is shown a frame providing information related to the current visualization, such as the number of visualized elements, the number of points that constitutes them, and the dimension of their bounding box. In case the content of such frame was difficult to be read, due to its overlap with the visualized data, double clicking on it with the mouse allows to invert its color, improving the visualization.

1.1.3 Toolbar

The toolbar shown in Figure 1.4 collects all IDEA's tools, subdivided in colors based on their function.

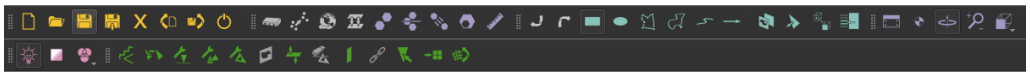


Figure 1.4: Toolbar.

1.1.3.1 Project management (orange)

Organizes the commands to open, close, save and load projects; it also allows to import and export individual elements of a project.

- **New project**: it creates a new project;
- **Load project**: it loads an existing project;
- **Save project**: it saves the current project;
- **Save as**: it saves the current project with a new name;
- **Close project**: it closes the current project;
- **Import**: loads preexisting data in the current project;
- **Export**: saves selected data outside the current project;
- **Exit**: closes the IDEA application.

1.1.3.2 Acquisition (bordeaux)

These are all the commands that regulate the acquisition process.

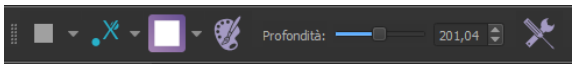


Figure 1.5: Acquisition settings.

The settings panel (Figure 1.5) will be shown after connecting the scanner with the button *open head* .

- / / / / **Surface color**: sets the threshold for the elimination of the darkest areas of the image that, in general terms, are not to be captured: the brighter the selection, the more extended the deleted areas;

- / / **Alignment**: determines the type of alignment applied at the end of the scanning process; in the first case no alignment is applied; the second in the automatic *direct alignment* [FX]; the last, *calibrated axes alignment*, is available if the turn table is present and calibrated;
- / / **Projected Image**: allows the selection of an image to project on the object. It is possible to choose between *White*, *Gray Code*, or *Phase shift*. This is useful for setting the focus of the projector;

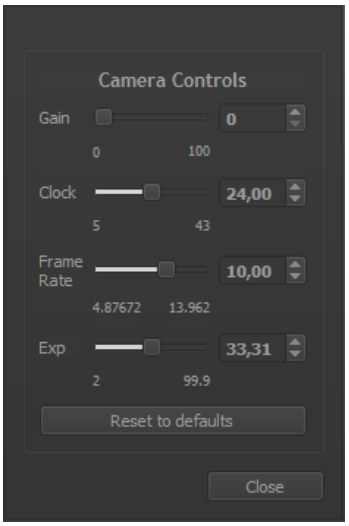


Figure 1.6: Cameras' control panel.

- **Color auto adjustment**: it allows to automatically adapt the color balance of the cameras. It requires to focus the scanner on a white sheet that has to be bigger than the scanning area;
- **Depth**: sets the maximum depth threshold (with respect to the Z axis)of the scan;
- **Measurement advanced parameters**: it sets the basic parameters of the cameras:
  - *Gain*: allows to regulate the light amplification factor;
  - *Clock*: is the timing of the acquisition cycle: higher clock value means higher speed, but if it was to be set too high it could saturate the USB bus, jeopardizing the scan;
  - *Frame rate*: is the number of images per second acquired by the cameras;
  - *Exp*: regulates the exposure time, that is the interval (in milliseconds) during which the camera sensor integrates the light: the greater the exposure time, the brighter the image but the slower the camera acquisition rate.

The button *Reset to defaults* allows to reset such parameters to their original values.

1.1.3.3 Alignment (light blue)

Collects all the tools to align data (Sect. 2.2.3).

1.1.3.4 Selection (turquoise)

These are all the tools for the interactive selection of data parts; the provided selection tools are:

- **Rectangle selection**: draws a rectangular selection area on the surface;
- **Ellipse selection**: draws an elliptical selection area on the surface;
- **Polygon selection**: draws a polygonal selection area on the surface, setting its vertexes with the mouse;
- **Freehand closed selection**: draws a freehand selection area on the surface, creating a closed form based on the path traced by the mouse cursor;

- **Freehand open selection**: draws a freehand selection area on the surface based on the path traced by the mouse cursor;
- **Segment selection**: selects the area covered by a segment traced by the mouse cursor upon the surface; pressing down the key will allow to trace lines spaced by a predefined angle (editable through the options panel, and set by default at 45°);
- / **Pass through / not pass through selection (only for meshes)**: the first option selects all the surface areas intersected by the current selection, while the second one only those currently visible: in case more data layers overlap, the first option selects part of each layer, while the second one only selects the visible layer;
- **Dilate selection to triangles' crest (only for meshes)**: activating this tool allows to enlarge the result of a given selection starting from the selection itself to include all the connected triangles which normals form an angle (with respect to the normals associated to the triangles of the original selection) below a given threshold. This tool is particularly useful to select planar areas on the 3D model;
- **Select project data from view**: detects project items that contain part of the surface obtained trough a certain selection: it could be useful to detect, in big data groups, those elements that are badly aligned or that create areas of noise.

All of the described tools allow, pressing the right button of the mouse, to shift the current selection area; moreover, pressing the *Esc* key, it is possible to cancel the currently shown selection.

1.1.3.5 Rendering (pink)

These are the commands that modify the data rendering settings in the 3Dview window.

- / **Turn on / Turn off scene light**: activate / deactivate the scene light source;
- **Color settings**: allows to select the color policy of the data visualized in the 3D view panel. *Texture color* shows the color of the acquired object (if available); *Assigned color* applies a color that has been randomly selected by the software (which can be changed through the project management panel); *Use uniform color* applies a unique color (defined in the software settings) to all the data;
- / **Select face / vertex attributes rendering (only for meshes)**: the first option associates a uniform color to each triangle face that constitutes a mesh, while the second one diffuses the color associated to each vertex, interpolating it for each triangle face of the mesh.

1.1.3.6 General (purple)

Collects a number of general purpose tools, such as view and data scaling:

- **Frame all objects**: centers and modifies the dimension of the framed window to make it possible to completely display all the currently selected data;
- **Move view on barycenter**: moves the current visualization center to the calculated barycenter of the currently selected data;
- **Rotation centered on view position**: if active, the barycenter of the current visualization is set as new rotation center;
- **Select view area to frame**: allows to select a specific area to frame in higher detail;
- / / / / / **Change view point**: allows to change the view point in the six main directions related to the axis of the global reference system: front/back (projection with respect to the X-Y plane), top/bottom (X-Z plane), left/right (Y-Z plane);
- **Clone**: creates a copy of the currently selected scan data;
- **Move**: allows to apply a roto-translation of the currently selected data; the types of possible movements are:
  - *Complete movement*: allows to set a given rotation (in degrees) and translation (in millimeters)

Figure 1.7: Data movement panel.

to apply to the object, choosing as rotation center either the origin of the reference system or the barycenter of the object;
  - *Center of mass to origin*: the barycenter position is translated toward the origin of the reference system;
  - *Bounding Box vertex to origin*: allows to translate one of the parallelepiped vertexes (either the one with the highest coordinates, or the one with the lowest) to the origin of the reference system;
- **Scale object**: applies a scaling to the currently selected data; the scaling can be either uniform for all the three axis of the reference system or specific for each one of them.

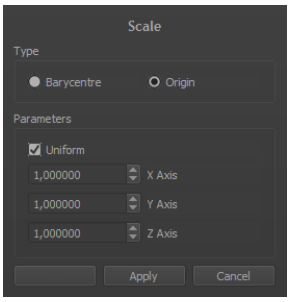


Figure 1.8: Scaling panel.

- **Data measurements [FX]**: allows to perform different types of measurement on the data:
  - Compute area: allows to compute the surface area of the mesh;
  - Compute volume: allows to compute the volume of a watertight mesh;
  - Compute distance: compute the distance between two points indicated on the currently selected data; for each selected point its coordinates are shown, as well as the coordinates of the distance vector and its length;

1.1.3.7 Features specific to range images (blue)

Includes data cleaning a conversion to mesh tools:

- **Select outliers**: allows to automatically select isolated points that are classified as not belonging to the object surface, such points can then be removed by pushing the *Del* key on the keyboard;
- **Select clusters of outliers**: allows to select small groups of isolated points, such points can then be removed by pushing the *Del* key on the keyboard;

(a) *Compute surface area and volume.* **(b)** *Compute distance.*

Figure 1.9: Data measurement panels.

- **Select outliers by angle**: select points whose normal form an angle with respect to the acquisition direction that is greater than the established threshold (the quality of a point can be expected to be better when said angle is low), such points can then be removed by pushing the *Del* key on the keyboard;
- **Generate mesh**: converts the selected range images into a mesh. The generation parameters are automatically set by the software once the user indicates the type of object to convert.

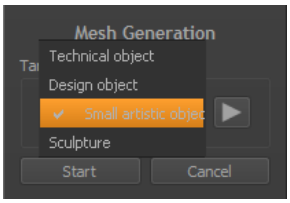


Figure 1.10: Mesh generation panel.

1.1.3.8 Features specific to triangle meshes (light green)

These are the specific tools to edit the mesh:

- **Reduce noise**: allows to reduce the noise present on the selected meshes , thus obtaining a smoother surface. In case a selection is present, the application of the algorithm is restricted to that area only. The possible smoothing methods are:
  - *Free form*: consistently smooths all the mesh.
  - *Artistic*: smooths the mesh based on the curve of the surface allowing to better preserve the details.
  - *"Conservative*: it's the most sophisticated smoothing tool to preserve the surface details.
- **Decimate**: reduces the number of triangles that constitute the mesh, optimizing the surface areas with less details. The parameters regulating this action are:

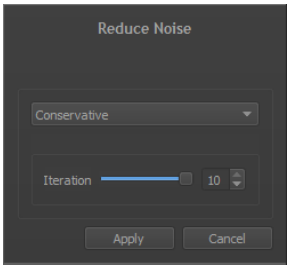


Figure 1.11: Noise reduction panel.

- *Minimum percentage of triangles (%)*: indicates the percentage of how many triangles should be retained upon completion of the decimation process, the final number of triangles indicates an estimate of the triangles number attainable after the decimation is performed;
- *Tolerance*: defines the decimation tolerance, that is how much the dec- imated mesh can be apart from the original one. If the box *Decimation in tolerance* were to be selected, the tolerance parameter will be binding as for number of final triangles;

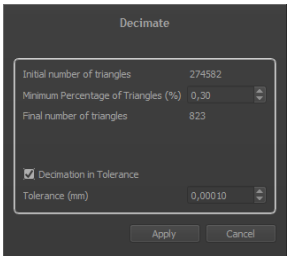


Figure 1.12: Mesh decimation panel.

- **Make manifold**: removes any topological problem as well we discon- nected components;
- **Repair intersections**: detect and repair intersections between mesh triangles, this tool control panel allows to choose among the following options:
  - *Select intersecting triangles*;
  - *Cut intersecting triangles*;
  - *Cut and fill intersecting triangles*: this option will only close holes whose border is constituted by a number of vertices lower than what indicated by the *Maximum hole complexity* parameter;
- **Fill holes**: allows to fill, totally or partially, holes detected on the mesh surface. The selection of the holes to close can be done explicitly through the list shown in the central part of the panel or through direct interaction in the 3D view panel. Once selected the hole to fill, it will be closed based on the method set in the section *Operation*:
  - *Fill whole hole*: completely fills the hole;
  - *Fill partially*: allows to indicate two vertexes placed along the hole border, splitting it into two distinct borders. At this point it is possible to indicate which of the two border is to be filled by clicking near one of them;
  - *Fill separately*: operates similarly to the previous tool, but in this case the two borders are both filled separately;
  - *Select*: allows to select a hole of interest, choosing the related entry in the panel list.

  In the hole filling list it is possible to select one or more elements, filling them simultaneously. The check-boxes *Center selected borders* and *Frame selected borders* allow visualizing immediately the selected elements in the 3D view panel. One selected the hole to fill, it's possible to proceed clicking on the *Fill* button. The combo-box *Curvature filling* allows choosing between a filling method that follows the curvature of the object or a planar filling. The triangles added in this operation will be marked as selected, therefore will be red. It's possible to cancel the last operation (Ctrl+Z to cancel,Ctrl+Y to re-apply) were the resulting filling to be unsatisfactory..

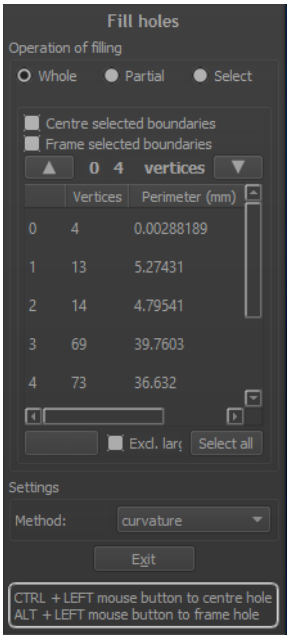


Figure 1.13: Hole filling panel.

The filling operation may fail if the hole to fill is either too big, or too complex to handle: in such a case, the tool won't generate any filling surface or, in case a partial filling is involved, it may not perform the curvature fill even though the user requested it. It is possible to bypass such problem by sectioning the hole into simpler parts, through the option *Fill partially*.

- **Approximate selection with a plane**: allows adapting a plane which passes through the area currently selected on the mesh;
- **Flip normals [FX]**: applied to a selected part or to the entire model, inverts the orientation of the surface by swapping inside and outside; it might be used in rare occasions, when certain parts of the model result inverted after the mesh-generation phase;
- **Defeature [FX]**: applied after selecting a part of the model, it performs a strong smoothing of the mesh that eliminates any geometrical detail. It can be used to rapidly remove undesired features of the mesh. This tool works only on selections, it cannot act on the entire mesh;
- **Intersect with plane [FX]**: allows to intersect the mesh with a plane by selecting one of the two identified portions. The plane is defined by means of the panel in Figure 1.14:
  The definition method of the initial plane has to be selected in the upper part of the panel; each method has a list of planes to choose from by clicking on them, or an interactive tool to define it:
  - Baricentric planes: choose one of the baricentric planes;
  - Three points: defines a cut plane for three points specified by the user by clicking with the left mouse button on the mesh; by using keys 1,2 and 3 or multiple choice on the panel it is possible to change the point to be re-selected;
  - Line: defines a plane passing through the segment traced interactively on the 3D view by pressing and releasing the left mouse button; by holding down the button it will be possible to draw straight lines that vary between them by a predetermined angle (settable through the options panel, and set by default at 45°); the segment can be retraced continuously and translated during the tracing by pressing simultaneously the right button;
  - System planes: choose one of the system planes;
  - Object datum planes: choose one of the datums associated with the mesh, if present.

  During the definition with three points or with a line, the interactive operation can be restarted with the *Esc* key. The cut and the planar fill can be performed by using the *Exit Close mesh* button. The

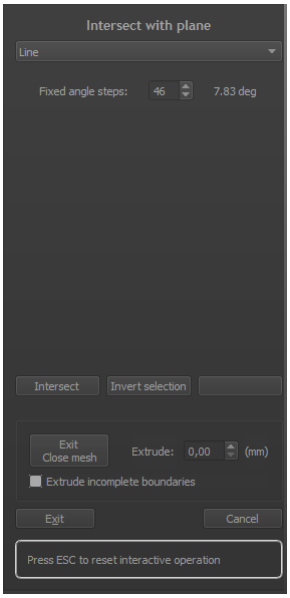


Figure 1.14: Intersect with plane panel.

hole filling will only be performed if the cut is completely on a plane or if the *extrude incomplete boundaries* option has been selected. It is also possible to extrude the mesh before the filling.

- **Catenate [FX]**: merges two or more meshes into a single one;
- **Detect undercuts [FX]**: selects all the triangles in a mesh whose normal creates an angle with respect to one of the three reference system axes that is greater than a specified threshold;
- **Convert to Range Image [FX]**: convert the mesh to a range image acquired by the current point of view;
- **Export with texture [FX]**: allows to export the model together with a high-resolution color texture, obtained from the range images used in the mesh generation step;

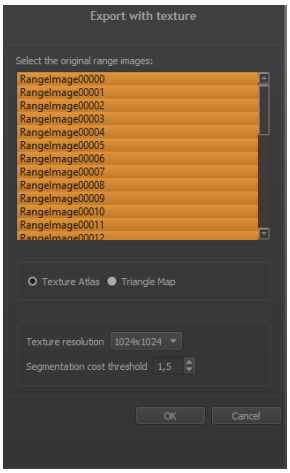


Figure 1.15: Export with texture panel.

in order to correctly reconstruct the color information, select the range images, present in the current project, from which the mesh you want to export was generated; the parameter "segmentation cost threshold" determines the number of regions and their distortion during the creation of the texture atlas.

2. Using IDEA

This chapter describes how to use IDEA the software to create a digital model of a physical object. With version 1.1 of IDEA is now possible to use the Turn Table which allows for a very high degree of automation during the acquisition and generation of the digital model. The process to configure the scanner and digitize an object is subdivided in four main steps:

1. **optical set-up and calibration (Sect. 2.1)**: relates to the physical configuration of the scanner to operate with a specific working area. It is subdivided in two steps:
   (a) **Optical set-up (Sect. 2.1.1)**: once the scanning area is chosen, the position and the orientation of the cameras, together with their focus, are to be configured;
   (b) **Calibration of the optical head (Sect. 2.1.2)**: allows obtaining the scanner's operational parameters for the chosen scanning area;
2. **Acquisition and alignment (Sect. 2.2)**: explains the acquisition methods and how to activate the alignment tool; if available the turn table, it introduces its calibration that allows the automatic alignment of object to be scanned placed on the turn table;
3. **Preparation to the model generation (Sect. 2.3)**: describes what actions need to be performed prior to the 3D model generation; such as the optimization of each individual scan's alignment, the use of the cleaning tools for the range images,and the optimization of the alignment between scans;
4. **Generating a model (Sect. 2.4)**: describes the operations linked to the generation of the triangle meshes.

2.1 Optical set-up

Scan in a box can be set to operate on the scanning areas the user chooses. Setting the scanner to operate on a specific work area is easy because it just depends on the distance between the scanner and the object. Tables 2.1 display a list of scanning areas and their relative work distance to which the scanner has to be placed in order to work, respectively for Standard (Tab. 2.1(a)) and FX version(Tab. 2.1(b)).

Together with the scanner is provided a calibration master that has to be used for the optical setup and the consequent calibration. Once chosen the working area one has to place the master as apart from the scanner as referred to in Table 2.1 and orient it so that it will be framed frontally (ref. Figure 1.4). The calibration master has 3 different patterns which are to use based on the cho- sen scanning area (ref. Figure 2.2 and Table 2.2). At this stage, the scanner can be configured to operate in the chosen scanning area.

Scanning Area (mm)	Distance (mm)
100 × 80	200
150 × 120	320
200 × 160	448
250 × 200	560
300 × 240	672
350 × 280	784
400 × 320	896
450 × 360	1008
500 × 400	1120

(a) *Standard version.*

Scanning Area (mm)	Distance (mm)
100 × 75	190
150 × 112	310
200 × 150	430
250 × 187	543
300 × 225	665
350 × 262	772
400 × 300	890
450 × 337	995
500 × 375	1100
550 × 412	1225
500 × 450	1355

(b) *FX version.*

Table 2.1: relationship between scanning area and distance.

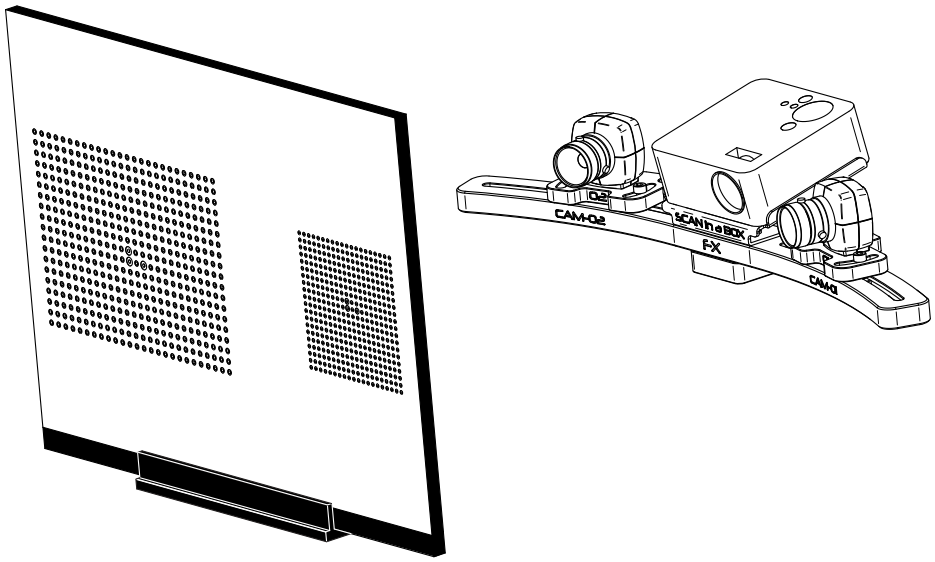
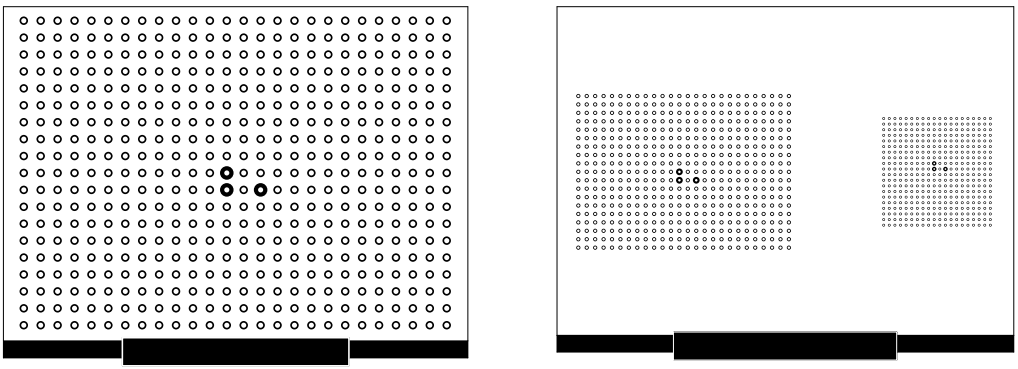


Figure 2.1: Frontal frame of the calibration master.



(a) *Pattern on the front panel 400×300 pitch 15.00 mm.*

(b) *Pattern on the rear panel 200×150 pitch 7.50 mm and pattern 100×100 pitch 5.00 mm.*

Figure 2.2: Patterns on the calibration master.

Area	Pattern
From 80 to 120 mm	100×100 pitch 5.00 mm
From 120 to 200 mm	200×150 pitch 7.50 mm
From 200 to 350 mm	400×300 pitch 15.00 mm
Beyond 400 mm	400×400 pitch 30.00 mm

Table 2.2: Relationship between scanning area and pattern on the calibration master.

2.1.1 Optical set-up mode

Whenever the scanning area changes the scanner has to be configured and then calibrated. Clicking on the button *Open head* the scanner connects to the software; *setup and calibration* mode can be activated by choosing *optical setup* in the *mode* combo-box.
The program's interface presents itself as shown in Figure 2.3. The optical setup panel (Figure 2.4) is displayed in the center at the bottom of the window.

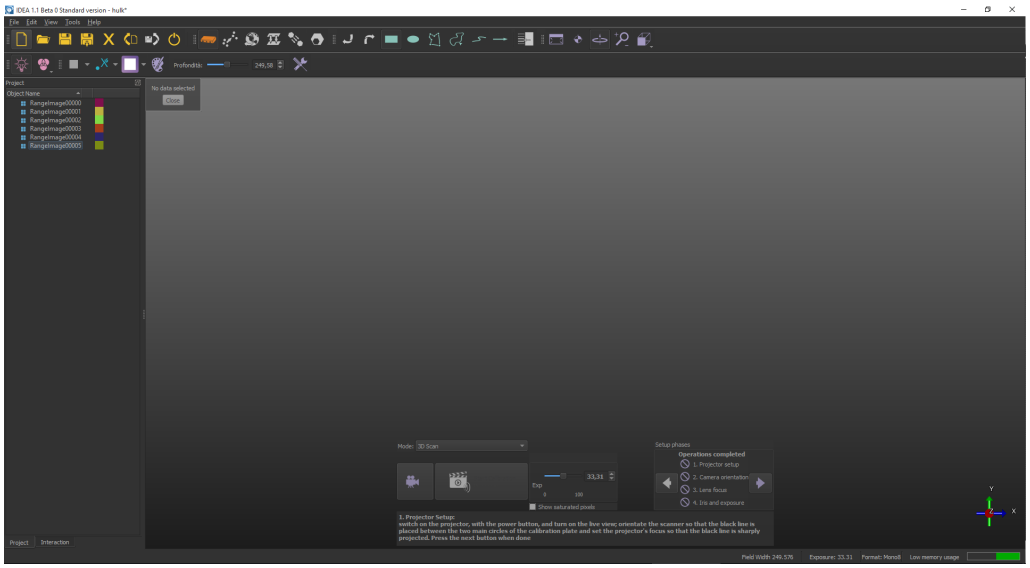


Figure 2.3: Optical setup mode.

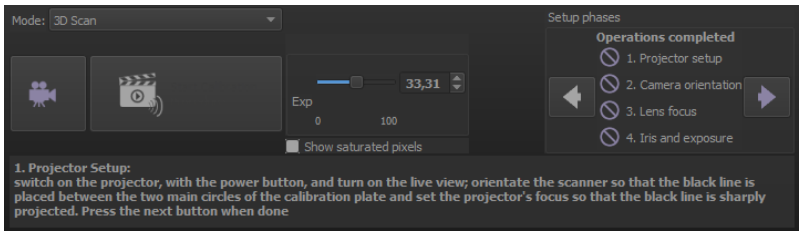
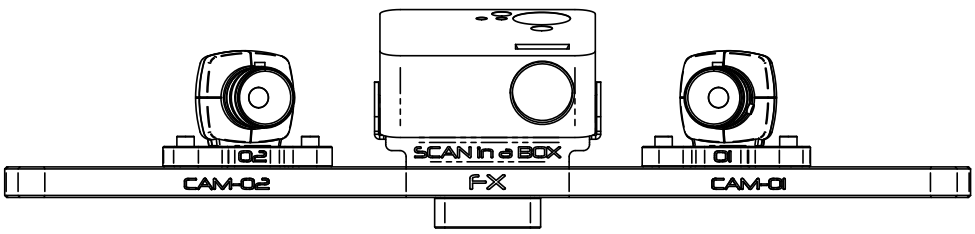


Figure 2.4: Optical setup panel.

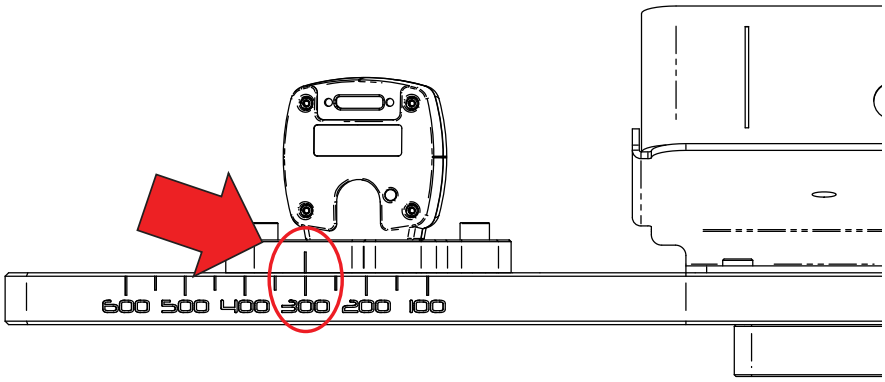
With this panel it is possible to carry out the following operations:

- / **Turn on / Turn off live**: allows to activate or deactivate the live visualization of the master framed by the two cameras; By clicking on the button *Turn on live* two windows will appear in the 3D view panel. Such windows show the surface currently framed by the cameras, together with a crosshair, as shown in Figure 2.4;
- **Start calibration procedure**: terminates the optical setup procedure and start the calibration;
- **cameras' regulation operations**:

- *Gain*: allow to regulate the cameras' gain;
- *Clock*: is the time setting of the cameras: a higher clock would signify a higher acquisition speed, that if pushed beyond a certain threshold could saturate the USB2 bus;
- *Frame rate*: is the number of images acquired by the camera per second;
- *Esp*: regulates the exposure time, which is the interval, measured in milliseconds, in which the sensor of the camera integrates the light: the higher the time of exposure, the brighter will be the image but the acquisition speed of the camera will be slower.



(a)



(b)

Figure 2.5: Setting of the position of the cameras on the support bar.

To regulate the scanner functions IDEA will guide the user to carry out the following operations:

- straighten the cameras and use the auxiliary bar to move them so that the notch on the supports coincide on the one on the bar, which should match the chosen framed area (ref. Figure 2.5);
- open the lens cover[1], switch on the projector, with the power button, and turn on the live view; the projector will cast a black line in the center of its projection pattern; orientate the scanner so that the black line is placed between the two main circles of the calibration plate (ref. Figure 2.6); set the projector's focus so that the black line is sharply projected; press the *next* button to go to the next step;
- orient the cameras so that they frame the black line of the projector in the center of the crosshair as in Figure 2.6. The cameras will so form a triangle that constitutes the base of the triangulation principle used for 3D scanning (ref. Figure 2.7); once finished regulating, tighten the screws that fix the cameras to the support bar. Press the *next* button to go to the next step;
- open the iris of the camera's lenses as wide as possible; higher the exposure time if the images of the framed master are too dark; regulate the focus of the cameras so that the circles of the master are as sharp as possible; tighten the focus screws (ref. Figure 2.8); press the *next* button to go to the next step;
- set the exposure time based on Table 2.3 and close the iris of the cameras until the images of the master are clear, equally on the left and the right, and not saturated; tighten the screws of the iris (ref. Figure 2.9). press the *next* button to go to the next step.

At this stage the optical setup is finished and it is possible to proceed with the calibration.

[1] Standard Version only

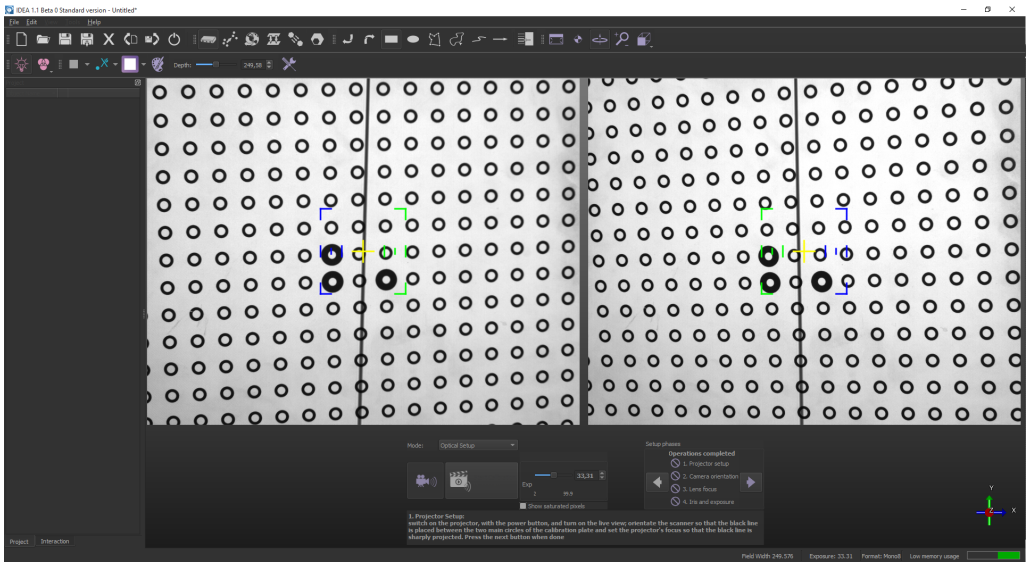


Figure 2.6: Frame of the calibration master.

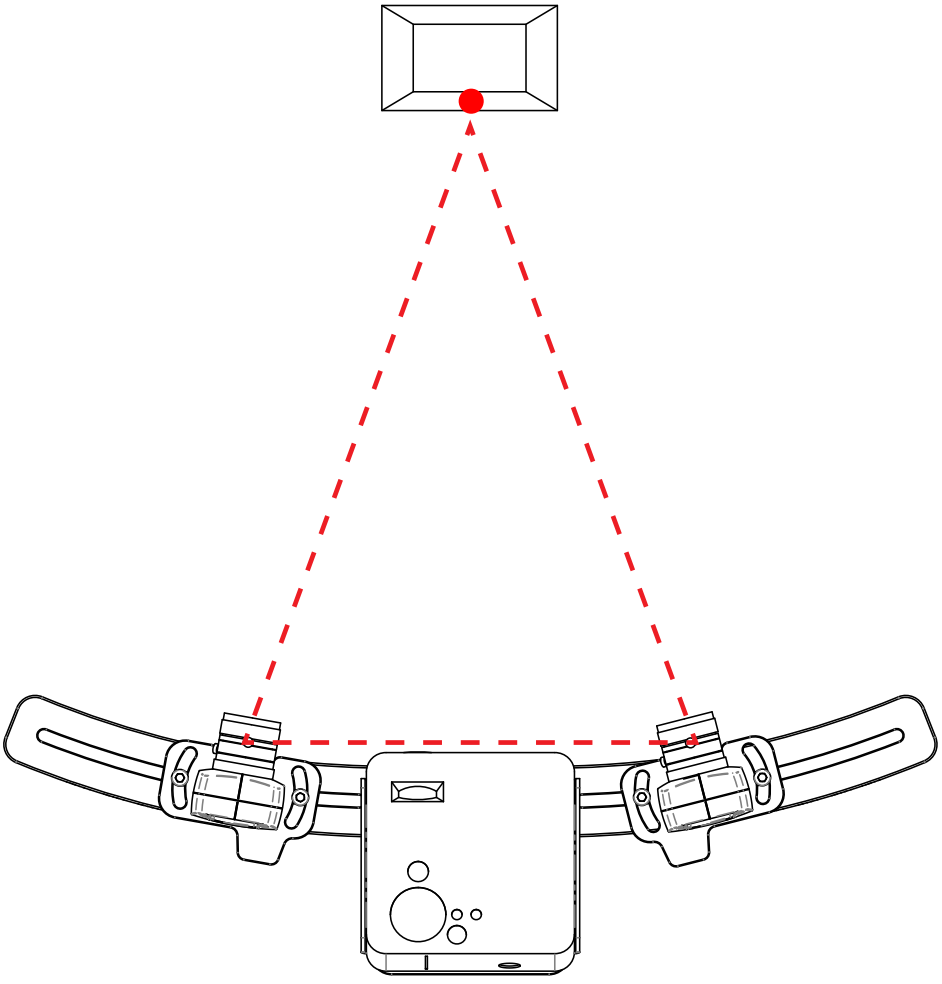


Figure 2.7: Triangulation principle.

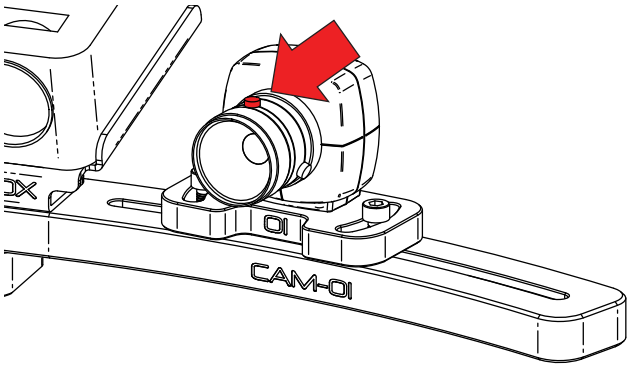


Figure 2.8: Focus setup screw.

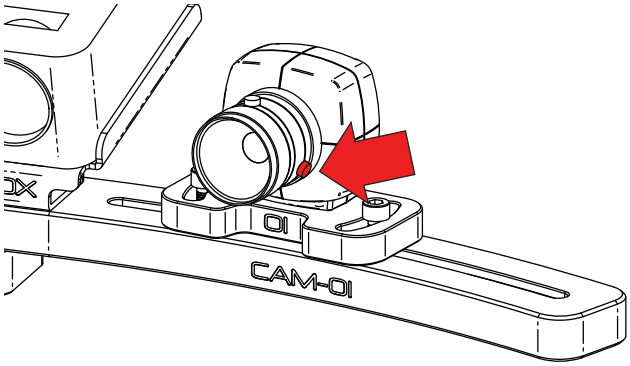


Figure 2.9: Iris' screw.

Scanning area (mm)	Exposure time (ms)
100 × 80	16.66
150 × 120	16.66
200 × 160	33.33
250 × 200	33.33
300 × 240	33.33
350 × 280	50.00
400 × 320	50.00
450 × 360	66.66
500 × 400	66.66

(a) *Standard version.*

Scanning area (mm)	Exposure time (ms)
100 × 75	16.66
150 × 112	16.66
200 × 150	33.33
250 × 187	33.33
300 × 225	33.33
350 × 262	50.00
400 × 300	50.00
450 × 337	66.66
500 × 375	66.66
550 × 412	66.66
500 × 450	66.66

(b) *FX version.*

Table 2.3: relationship between scanning area and exposure time.

2.1.2 Calibration of the optical head

After finishing the optical setup the calibration sets the functioning parameters of the scanner in its new configuration. The button *start calibration procedure*, described in Sect. 2.1.1, allows transitioning to this phase. The program shows the dialogue window *New optical head calibration* of Figure 2.10 in which the user indicates:

- the approximate framed area;
- the type of master he/she wants to use.

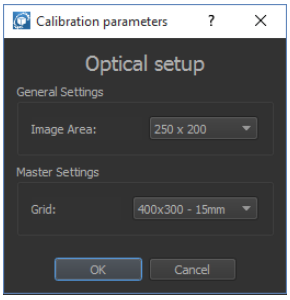


Figure 2.10: Optical head calibration settings.

Once confirmed these choices IDEA starts the *Calibration* mode as shown in Figure 2.11.The purpose of the calibration is to acquire a sequence of images to elaborate in order to produce entry data for the procedure that calculates the scanner's operational parameters.

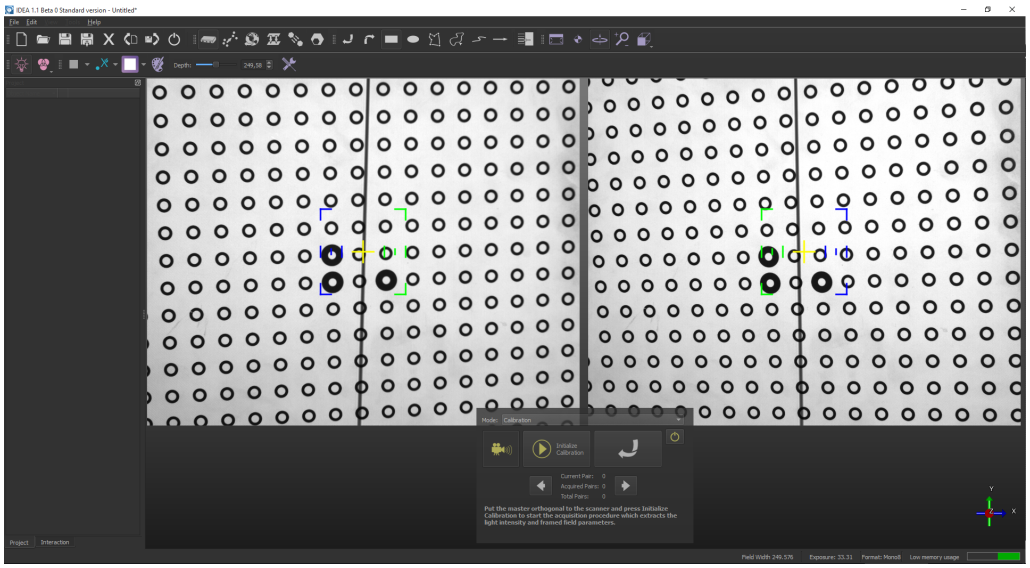


Figure 2.11: Calibration mode.

The calibration panel (Figure 2.12) is shown at the center-bottom of the page, and offers the following features:

- **Calibration/ recalibration mode**: allows to carry out either a complete calibration or a recalibration; the complete calibration determines all the operational parameters and uses at least 9 images; the recalibration only determines the parameters regarding the orientation of the camera and uses at least 3 images. Recalibration cannot be used if the scanner's optical setup has been changed.
- / **Turn on / Turn off live**: allows to activate and deactivate the visualization of the master framed by the two cameras;
- **Initialize calibration**: starts the acquisition procedure of 3 images of the calibration plate, which allows to extract the light intensity and framed field parameters;

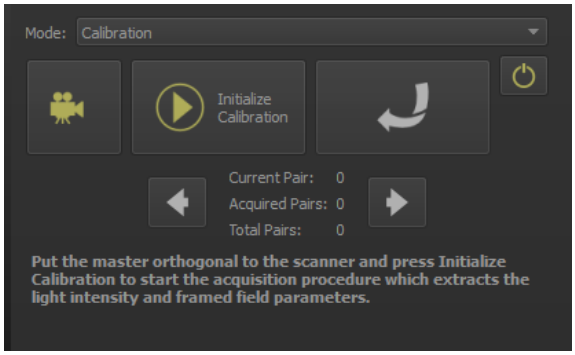


Figure 2.12: Calibration panel.

- **Grab image pair**: captures and elaborates on a pair of images of the calibration master;
- **Next pair**: goes to the next image pair that needs to be captured;
- **Previous pair**: goes to the previous image pair that needs to be acquired;
- **Erase current pair**: erases the current image pair;
- **Calibrate**: starts the calibration procedure once finished the image acquisition cycle; the procedure elaborates on the acquired data and determines the operational parameters of the scanner. On the right panel are shown the residual error stats at the end of calibration;
- **Confirm calibration**: the user confirms the calibration that is internally saved and can be used to operate with the scanner;
- **Exit calibration mode**: terminates at any moment the calibration process and gets back to the acquisition or optical setup.

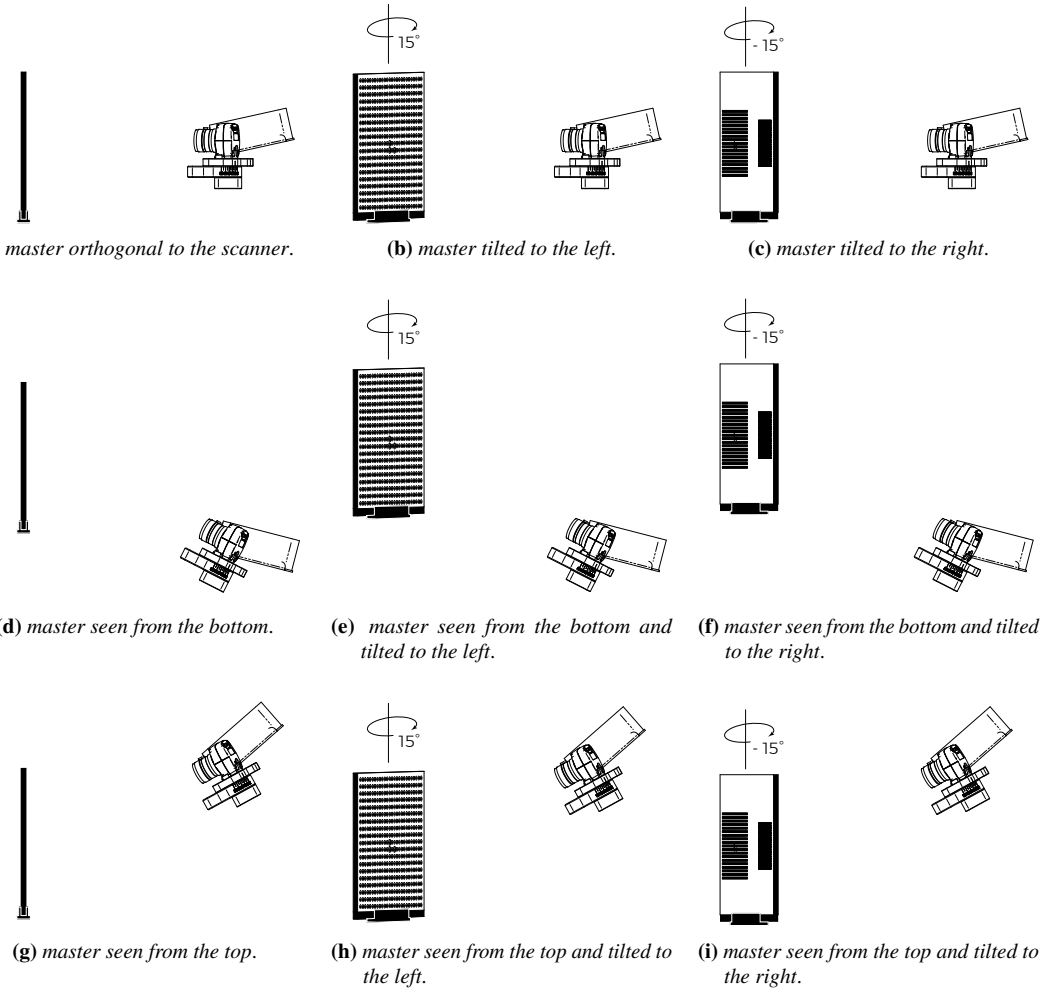
For the complete calibration procedure the user has to take images of the calibration master in 9 different positions; the user him/herself should put the master in these positions (Figure 2.13) or move the scanner to match the positions:

1. **master orthogonal to the scanner**: initially the master is in a frontal position; to start the procedure push the button *Start calibration*; the parameters of light intensity and framed field are set; to acquire the first pair of images by clicking on *Acquire images pair*; to confirm and get to the following position press *Next pair*;
2. **master tilted to the left**: tilt the master approximately 15~20° to the left, try to maintain the frame in the center of the master and acquire the second pair of images; to confirm and get to the following position click on *Next pair*;
3. **master tilted to the right**: tilt the master approximately 15~20° to the right starting from position 1, try to maintain the frame in the center of the master and acquire the third pair of images; to confirm and get to the following position click on *Next pair*;
4. **master seen from the bottom**: put the master in position 1 and lower the scanner so that it frames the master from the bottom at and angle of approximately 15~20°; try to maintain the frame in the center of the master and acquire the fourth pair of images; to confirm and get to the following position click on *Next pair*;
5. **master seen from the bottom and tilted to the left**: put the master as in position 2; try to maintain the frame in the center of the master and acquire the fifth pair of images; to confirm and get to the following position click on *Next pair*;
6. **master seen from the bottom and tilted to the right**: put the master as in position 3; try to maintain the frame in the center of the master and acquire the sixth pair of images; to confirm and get to the following position click on *Next pair*;
7. **master seen from the top**: put the master in position 1 and lift the scanner so that it frames the master from the top at and angle of approximately 15~20°; try to maintain the frame in the center of the master and acquire the seventh pair of images; to confirm and get to the following position click on

Next pair;

8. **master seen from the top and tilted to the left**: put the master as in position 2; try to maintain the frame in the center of the master and acquire the eighth pair of images; to confirm and get to the following position click on *Next pair*;
9. **master seen from the top and tilted to the right**: put the master as in position 3; try to maintain the frame in the center of the master and acquire the ninth pair of images; to confirm and get to the following position click on *Next pair*

The recalibration procedure only requires the acquisition of 3 pairs of images namely the first, the second and the third; it has to be used when the optical setup of the scanner is not modified and the user wants to perfect the operational parameters of the scanner if it has been a while since it was calibrated. The *Next pair* and *Previous pair* buttons allow to navigate through the described steps, to examine the results of the elaboration or to recapture a specific pair of images. After capturing the necessary images the calculation of the calibration can be initiated with the *Calibrate* button and confirmed with *Confirm calibration* . On the other hand, to close the mode without saving click on *Exit calibration mode* button.



(a) *master orthogonal to the scanner.* **(b)** *master tilted to the left.* **(c)** *master tilted to the right.*

(d) *master seen from the bottom.* **(e)** *master seen from the bottom and tilted to the left.* **(f)** *master seen from the bottom and tilted to the right.*

(g) *master seen from the top.* **(h)** *master seen from the top and tilted to the left.* **(i)** *master seen from the top and tilted to the right.*

Figure 2.13: Calibration positions.

2.2 Capture and alignment

The first step of the procedure that allows to create the 3D model is the acquisition of a set of range images. Similarly to what happens for a photo set, each of the scans need to be acquired varying the position of the

object (or the scanner), so that the entire surface of interest is covered. The positioning of the object in front of the scanner can be performed by the Turn Table, when available. Moreover it is very important for every range image to be aligned with the others: with this purpose IDEA provides two alignment tools that make it easy to reconstruct the scanned data (ref. Sect. 2.2.3.1 and Sect. 2.2.3.2). Alternatively the alignment is fully automated by the use of the Turn Table. The next sections will intruce the use of Scan in a Box in free mode and thereafter describe the use in combination with the Turn Table.

2.2.1 Free mode acquisition

When the acquisition procedure is initiated, with the *Open head* button  , it will be displayed the interface shown in Figure 2.14.

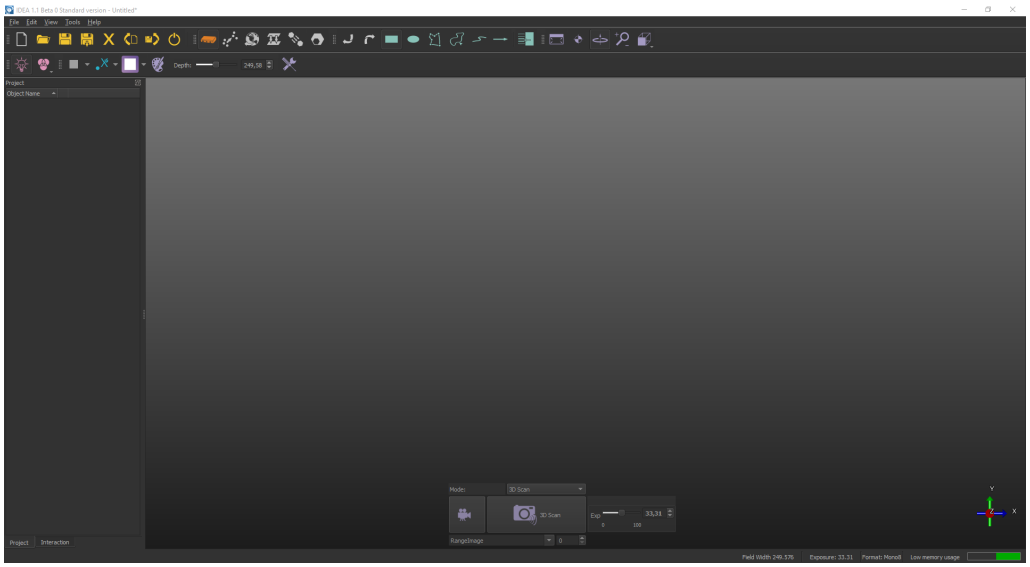


Figure 2.14: Acquisition interface.

The scan panel (Figure 2.15) shows a combo-box by which the following options can be chosen:

- **3D Scan**: allows to perform 3D scans in free mode, described in this section;
- **Optical setup**: allows to go back to the physical configuration of the scanner (ref. 2.1.1).

Keep the selection *3D Scan* to perform the 3D acquisition of the framed area of the object; the scan panel shows also the following buttons:

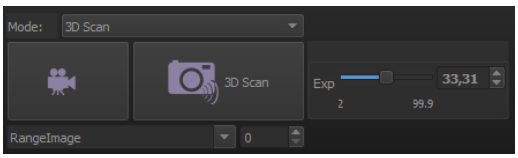


Figure 2.15: Scan panel.

-  /  **Turn on / Turn off live**: allows to activate and deactivate the visualization of the object and to place the scanner at the appropriate distance;
-  **3D Scan**: launches the acquisition of the part of data currently framed by the cameras;

In the lower part of the panel it is also possible to set the name of the scans, as well as set the initial value of their progressive numeration.

 In case the progressive numeration is decreased, the new acquisitions will replace the ones already existing.

The acquisition settings' tools, displayed in Figure 2.16, allow to modify the parameters related to the acquisition (ref. Sect. 1.1.3.2).

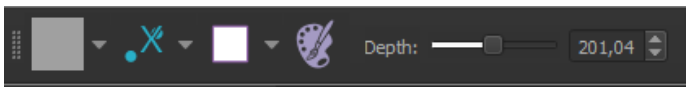
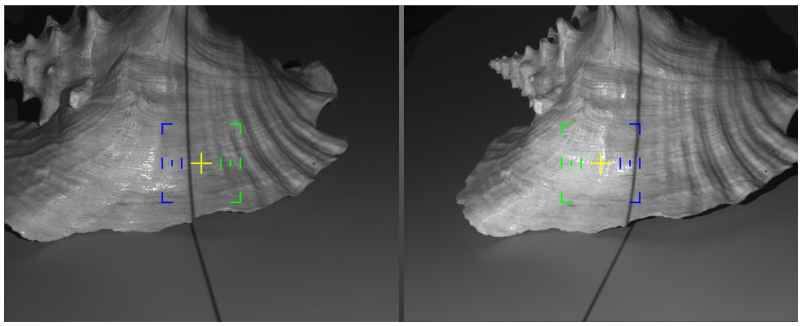
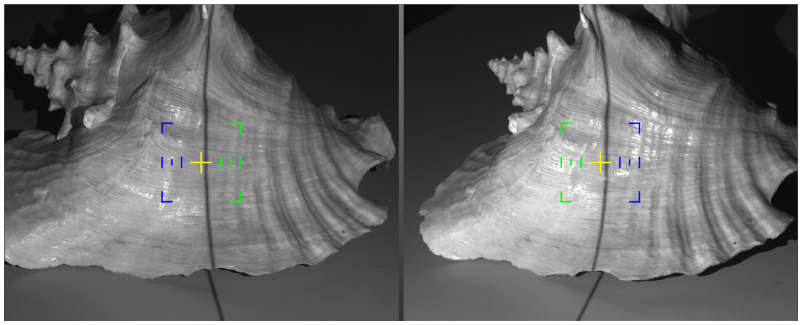


Figure 2.16: Acquisition settings panel.

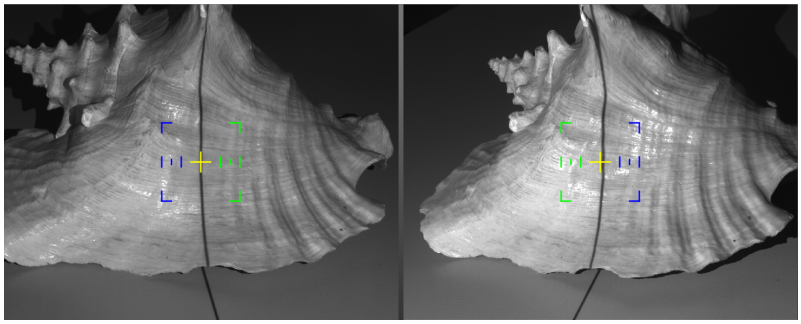
Before launching the 3D scan it is necessary to go through a sequence of operations (ref. Figure 2.17):



(a)



(b)



(c)

Figure 2.17: Preparation to acquisition.

- **Live activation**: clicking on the button *Turn on live* two windows will appear in the 3D view panel. These windows display the surface currently framed by the cameras, as well as a crosshair;
- **White pattern projection**: make sure that the projection of the *white* pattern of the drop-down menu located in the acquisition settings section is activated (Figure 2.16), so that the scanner projects on the object with white light a vertical black line in the center of the projection, as shown in Figure 2.17.a;
- **Color auto adjustment (optional)**: to obtain a good coloring of the scan, this button allows to automatically adapt the parameters of the camera to better the color balance. To proceed the scanner

has to frame either the master or a white sheet bigger than the framed area; this setting is automatically established during he scanner calibration and therefore could be treated as an optional step;

- **Alignment type [FX]**: the FX version of IDEA further expands the application's potential by integrating an advanced alignment feature, called direct alignment, that can be exploited directly during acquisition. This tool allows to proceed very naturally in the acquisition process, easily identifying, acquiring and aligning the surface areas not yet acquired. The acquisition policy is described in more detail in (ref. Sect. 2.2.3) and can be set through the drop-down menu in the acquisition settings panel, which allows you to choose between *No alignment* and *Direct Alignment*.
- **Distance regulation**: to obtain an optimal acquisition the scanner must be placed at an appropriate distance form the object: this is reached when the vertical line projected by the scanner passes through the center of the crosshair: if the line is closer to the left side (blue) of the crosshair (see Figure 2.17.a), the distance between object and scanner must be reduced, whereas if it's closer to the right side (green), it must be increased. When the line passes trough the yellow center(see in Figure 2.17.b), the work distance is appropriate;
- **Projector's focus regulation (optional)**): if the black vertical line appears not to be sharp enough (as shown in Figure 2.17.b) set the projector's focus to obtain a satisfying definition (ref. Figure 2.17.c).

It is now possible to scan the surface of interest through the button *3D Scan*. At the end of the scan the acquired data is displayed in the 3d view window as in Figure 2.18.

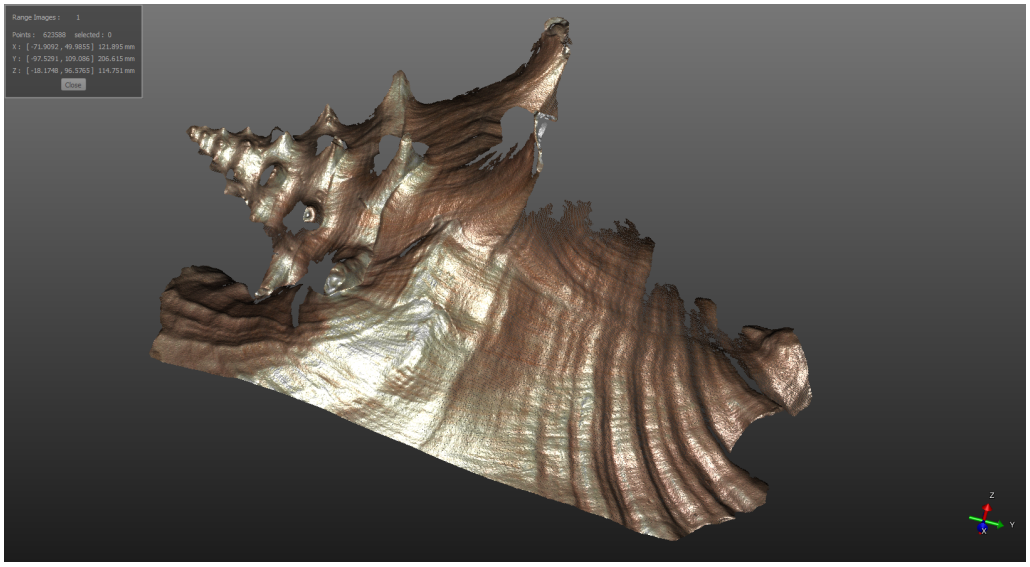


Figure 2.18: Result of an acquisition procedure.

2.2.2 Turn Table acquisition mode

The availability of the turn table allows to perform acquisitions, object positioning in front of the scanner and alignments in a completely automatic manner. Upon opening the connection with the scanner with the button *Open 3D Scanner*, the IDEA interface will appear as in Figure 2.19.
The presence of the turn table adds new options to the combo-box of the scan panel (Figure 2.20):

- **3D Scan**: allows to perform single 3D scans orienting the object by means of the turn table;
- **Optical Setup**: allows to return to the physical configuration of the scanner (ref. 2.1.1).
- **Batch Turn Table 3D Scan**: allows to perform multiple acquisitions through a single scan command; the object will be automatically oriented by the turn table;
- **Turn Table Calibration**: allows to calibrate the turn table rotation axis, enabling the option to automatically align the scans.

IDEA also allows to operate with an uncalibrated turn table. This is the case, for example, during the first use of the turn table, every time the turn table is moved from the position at which it was originally calibrated, or if the scanner is moved. In such cases it is possible to perform both single as well as multiple scans, however

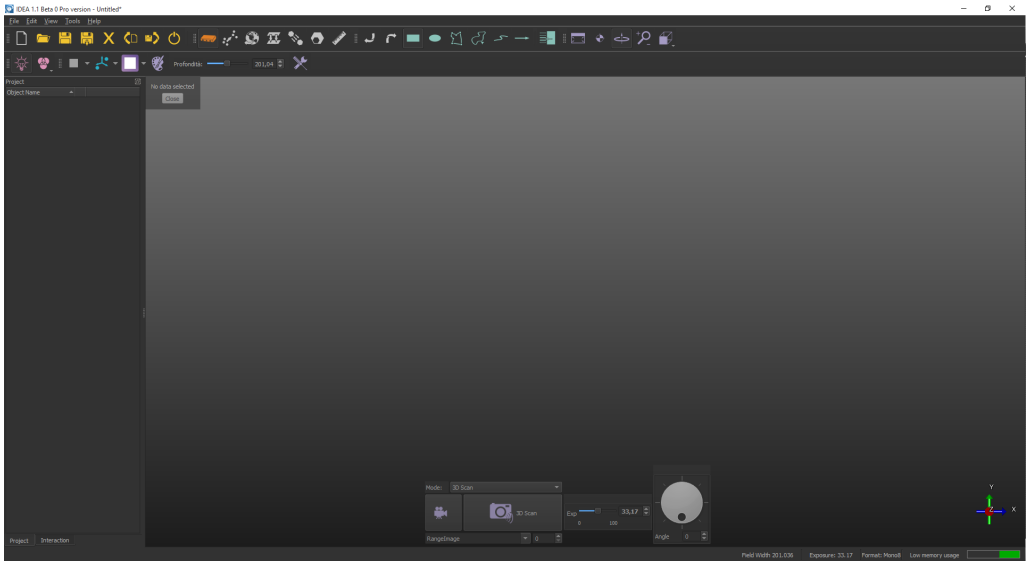
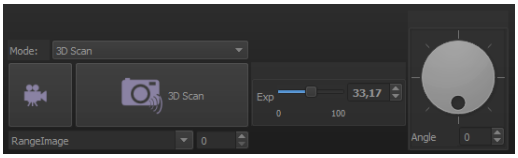
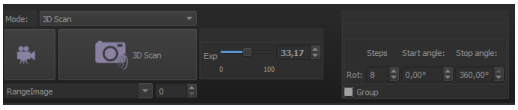


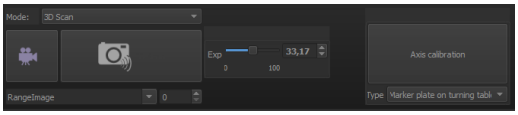
Figure 2.19: Acquisition interface with the Turn Table.



(a)



(b)



(c)

Figure 2.20: Scan panel: (a) single 3D Scan with Turn Table, (b) multiple 3D Scan with Turn Table, (c) Calibration of the Turn Table.

losing the automatic alignment of the scans based on the calibrated axis. The *direct alignment* is available in the FX version, but it is recommended to calibrate the turn table by selecting this mode in the combo-box of the scan panel (Figure 2.20.(c)) and proceeding as follows:

1. **Choice of the framing**: place the object on the turn table and frame it with the scanner at the correct working distance;
2. **positioning of the calibration plate**: remove the object and place the calibration plate on the turn table; if the scanner frames the turn table at an angle greater than 30° the plate must be laid on the turn table plate, otherwise the calibration plate must be mounted upon its support so that it can be properly framed by the scanner; in fact it is important that the small black circular markers of the calibration plate are adequately framed by the scanner;
3. **axis calibration**: press the button *axis calibration* and wait that the procedure is completed; IDEA will signal either a positive or negative outcome; in the first case it is possible to proceed to the scan phases. In the second case it is necessary to make sure that no error has been committed and the procedure must be repeated.

Once this calibration phase is completed, IDEA gets automatically configurated in *Batch Turn Table 3D Scan* mode, the scan panel is shown as in Figure 2.20.(c) and the alignment mode is set to *calibrated axes alignment* (ref. 1.1.3.2).

In this mode on the right part of the panel it is possible to specify:

- the total number of steps, that is the number of desired scans to be performed; the default value is 8;
- the start and end angular position; the predefined values define a trajectory between 0° and 360°.

Pressing the button *3D Scan* the multiple scan procedure is launched, which will orient the object in front of the scanner and provide a scan result aligned in an automatic manner as in Figure 2.21.

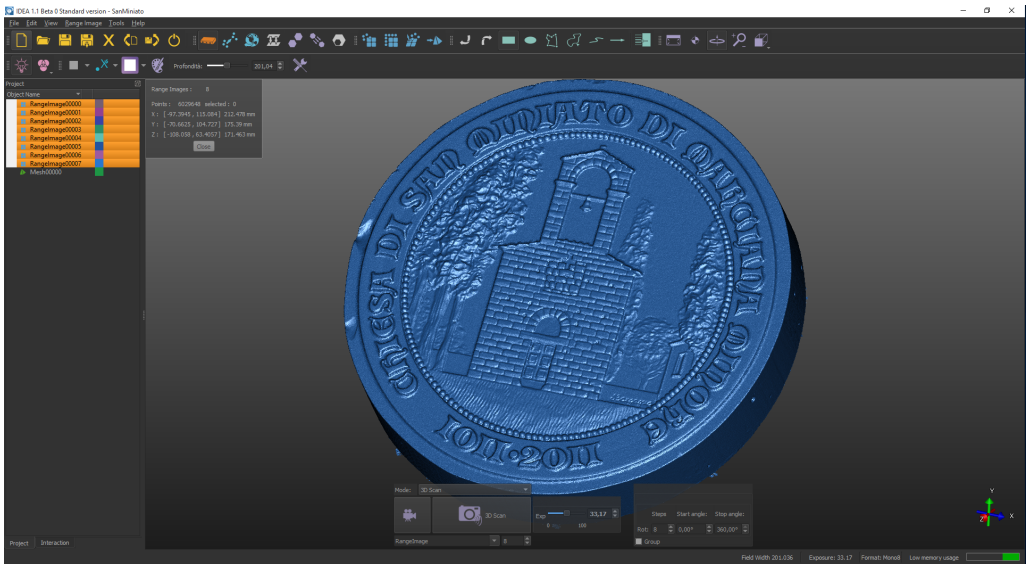


Figure 2.21: Result of multiple 3D Scan with the Turn Table.

It is always possible to activate the single scan acquisition mode: in this mode to the scan panel (Figure 2.20.(a)) already described in 2.2.1 a knob is added that regulates the rotation angle of the turn table: by acting upon it, it is possible to manually specify the angular position to orient the object in front of the scanner to perform single scans, which shall be automatically aligned.

2.2.3 Alignment tools

IDEA provides two *Incremental Alignment* tools that allow to align a single scan with each other; these tools are designed to facilitate and automate as much as possible the reconstruction of the 3D model based on the scanned data:

- **Direct alignment [FX]**: automatically aligns each scan, using only information present on the shape of the object;

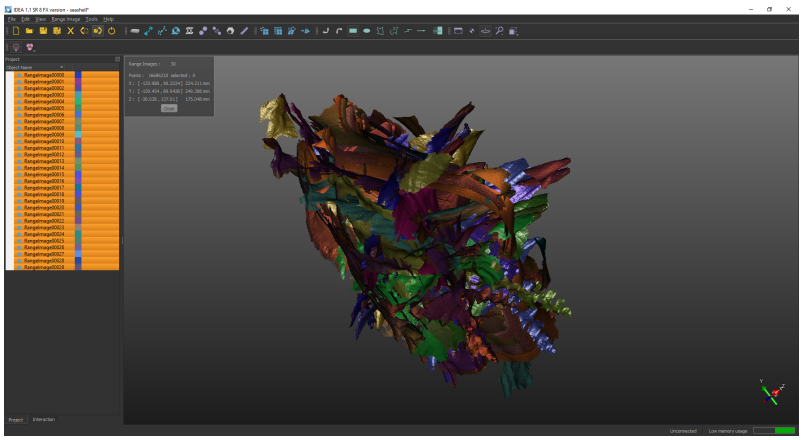
- **Manual alignment**: this tool allows you to manage the most complicated alignment scenarios, taking advantage of some indications provided by the user.

The procedure *Global alignment* can be used once all the scans have been aligned to each other with the manual alignment tool, and the undesired parts of data have been removed. This tool allows to overall optimize the undesired parts of data. This tool allows to globally and simultaneously optimize the position of a set of scans. Finally, the *Datum alignment* tool allows, once finished the generation and consequent editing of a mesh, to modify its position in the global reference system.

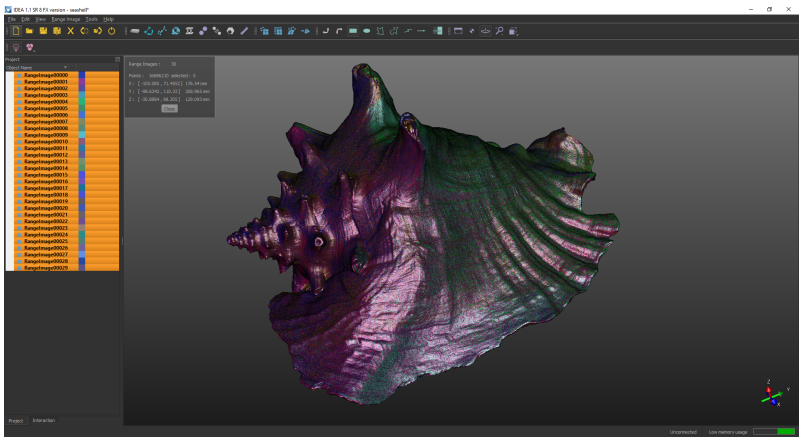
2.2.3.1 Direct alignment (FX)

The direct alignment procedure allows to automatically align the scans (without requiring user intervention), exploiting the presence of details such as edges, curves or engravings detected on the surface of the object so as to put in correspondence the acquired scans.

The use of this approach to alignment is recommended only if the surfaces have clearly distinguishable details (e. g. edges, curves or engravings): in the absence of these requirements, the procedure may fail or in rare cases incorrect alignments may be obtained which will have to be corrected by means of the *manual alignment*.



(a)



(b)

Figure 2.22: Example of use of the direct alignment procedure.

This tool can be used at the same time as the acquisition procedure, as described in Sect. 2.2 or at any other time on the scan data already present in the project; in combination with the scan command, it makes the alignment operation of the new scan data completely automatic; in the second case, the application of the

direct alignment on a selected set of scans will cause the algorithm to attempt to align each of the views of the set, as shown in Figure 2.22: all successfully aligned scans appear in green in the project management panel, otherwise their color will not change.
There are cases (particularly when the object to be digitized requires the acquisition of many views, or is composed of several parts) where it can be convenient to group the scans of a project into separate groups through the *group* command, which can be invoked from the contextual menu of the project management panel. The group is a project entity that behaves as a single range image for the purpose of the direct alignment: if several groups have previously aligned range images by means of direct alignment inside them, the groups can be aligned as shown in Figure 2.23:

- in Figure 2.23.(a) the range images of a first group already aligned with the direct alignment are selected and displayed;
- In Figure 2.23.(b) the scans of a second group aligned with each other are selected, but not with the scans of the first group;
- To align the scans of the two groups with each other, it is possible to open the context menu for one of the two groups (right mouse button), press the item *Direct alignment with*, and choose the name of the group with which you want to perform the alignment: if the procedure succeeds, all the scans will be moved within a single group, and they will be aligned with each other, as shown in Figure 2.23.(c).

It may rarely happen that the direct alignment procedure has been found to have achieved a correct result, although it is clear from a visual inspection that it has failed. In this case, you will need to cancel the alignment and proceed with the manual alignment procedure. Once manual alignment is complete, you can add the depth image to those aligned with direct alignment via the context menu *set as direct aligned*.

2.2.3.2 Manual alignment

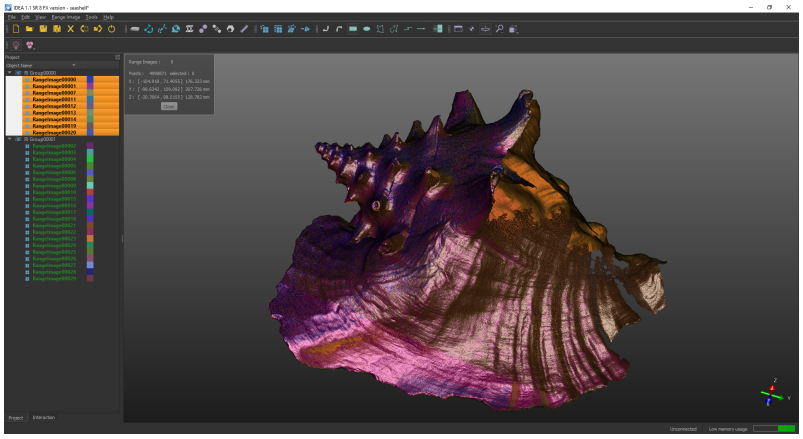
The *Manual alignment* tool tool allows to face and solve even the most difficult alignment issues, asking the user to give some directions to guide the alignment process. Once selected the scans and launched the tool, the manual alignment interface is displayed as in Figure 2.24:
In the center of the left column appear two lists with the names of the selected scans: the upper list allows to select the scans that will remain fixed during alignment, whereas the bottom one allows to select the ones that will change, that is, the ones that will be moved during alignment. To align select at least one fixed scan (in the top list) and one moving (in the bottom list). When an element is selected in one list it will become impossible to select it in the other, and its name will be marked in red (ref. Figure 2.25.a). Once selected the fixed and moving scans, the interface will present itself as in Figure 2.25.b: the central area of the display, divided in three panels, shows to its upper left the fixes scans in red, on its upper right the moving ones in green, down below all scans.
In this stage it's necessary to provide to the algorithm at least three common points in the two scan sets to obtain a first approximate alignment: proceed selecting three points in the upper left panel, and three corresponding points in the upper right one, as showed in Figure 2.26.(a).

⚠ To best tackle the issue it is very important that the point are not placed in the same straight line, but that they rather create a triangle as wide as possible.

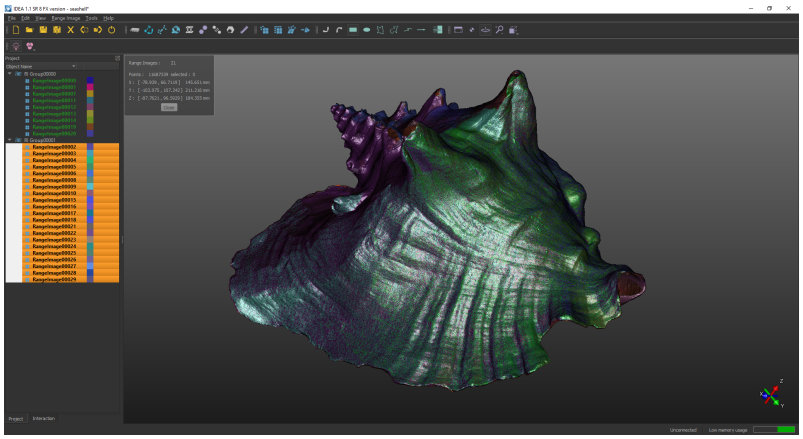
Once obtained the approximate alignment, IDEA will be able to refine it automatically: clicking on the button *Align* the position of the two scans will be optimized, and the descriptive values of average and standard deviation regarding the distance between the two surface are displayed (ref. Figure 2.26.(b). Moreover, to ease the process of selecting the common points is possible to select the box *use texture color* to visualize the texture associated to the object one has to align. After aligning the scans it's possible to continue aligning the remaining scans clicking on the *Next* button, that will automatically integrate the moving scan (now aligned) in the set of the fixed views, so that it is easier to select new moving scans.

2.2.3.3 Global Alignment

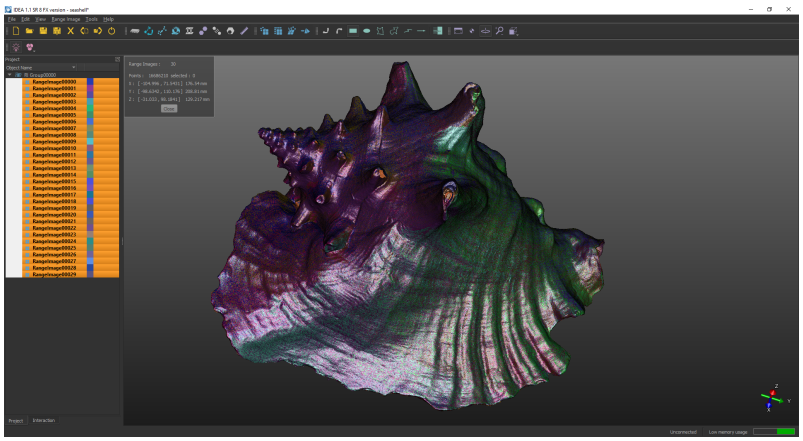
The *Global alignment* tool allows to simultaneously optimize the position of each scan with respect to the other ones Figure 2.27: this allows to obtain a lower general error compared to what would generate the direct or the manual alignment tools.
At the end of the *Global alignment*, up to the right are displayed the statistics regarding the quality of the obtained alignment. This statistics regard the alignment of the scans before and after using the tool. Apart form the descriptive values, the statistics also show in detail the average and standard deviation of each scan.



(a)



(b)



(c)

Figure 2.23: Example of use of direct alignment between two groups.

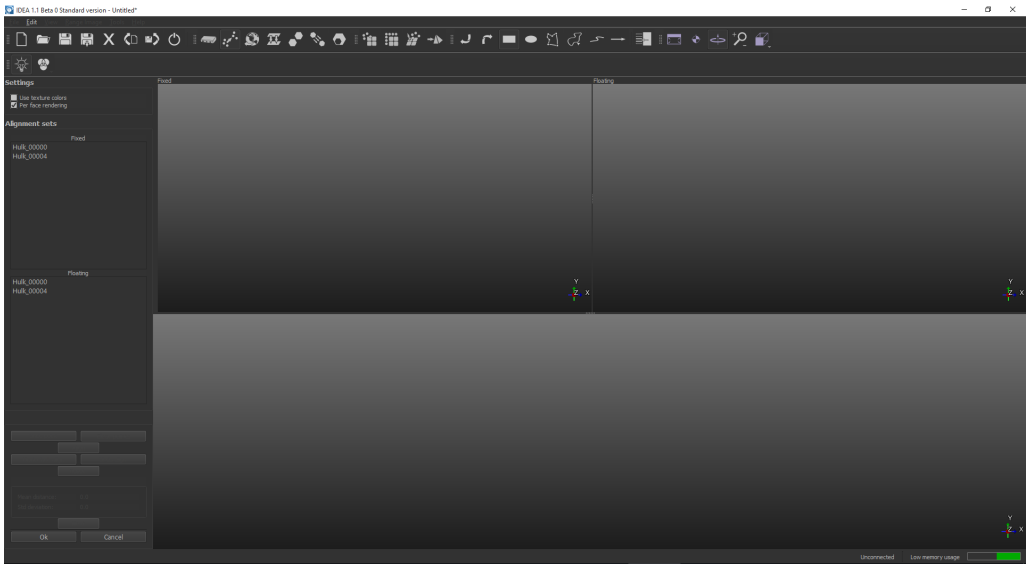


Figure 2.24: Manual alignment procedure's interface.

This allows to easily identify situations in which a scan was not appropriately aligned: if so, the distance value associated to that scan will be significantly higher that the others.

⚠ Given the complex issue, the global alignment procedure is one of the most complicated in terms of time consumption, especially for the projects containing many different scans.

If the alignment was to be interrupted by the user (with the *Stop* button placed in the lower bar that appears launching the tool) the improvements made until that moment are automatically applied to the processed scan set.

2.3 Preparing to generate the model

Before generating the 3D model it is necessary to check that this conditions are respected:

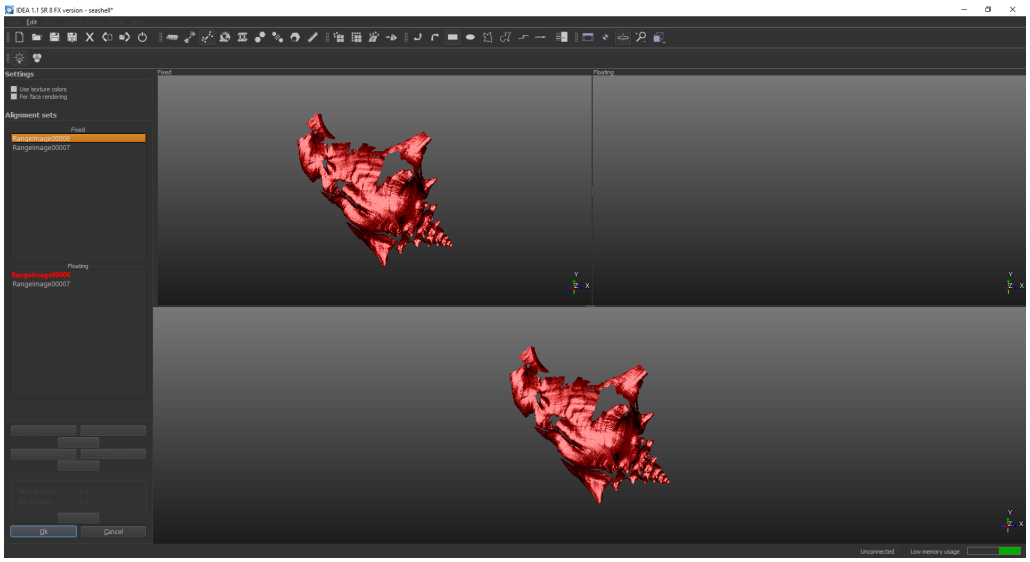
- all scans must be appropriately aligned;
- all scans must be clean: remove the outliers and the framed parts of data that one does not want to include in the final model; the outliers are parts of the range images that don't' belong to the surface of the object (they may be caused by poor light conditions, or if the material of the object does not cooperate with the light). To remove the undesired elements, IDEA provides a number of manual tools, described in Sect. 1.1.3.4, or automatic ones (ref. Sect. 1.1.3.7).
- optimized alignment through the global alignment (ref. Sect. 2.2.3.3).

2.4 Model Generation

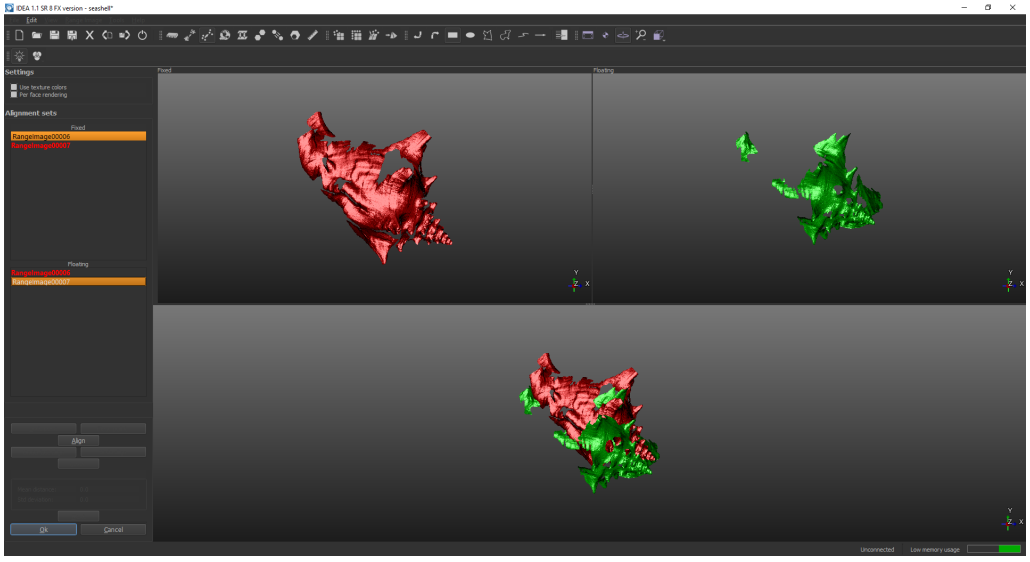
IDEA adds to the procedures for managing the range images the features to generate and manage the triangle mesh. The meshes can be generated from the scans, imported by files and exported in some standard exchange formats.

2.4.1 Mesh generation

The mesh generation can be carried out starting from the data of one or more range images. Once selected the data to convert in mesh, by clicking the button will appear a panel (Figure 2.28) in which it is possible to set the generation parameters.
Based on the type of the object of interest, it is possible to chose one of the standard profiles shown in Figure 2.28, that automatically set the parameters of generation appropriate to that type of object, otherwise it is also possible to customize such parameters acceding to the advanced settings section with button ▶.

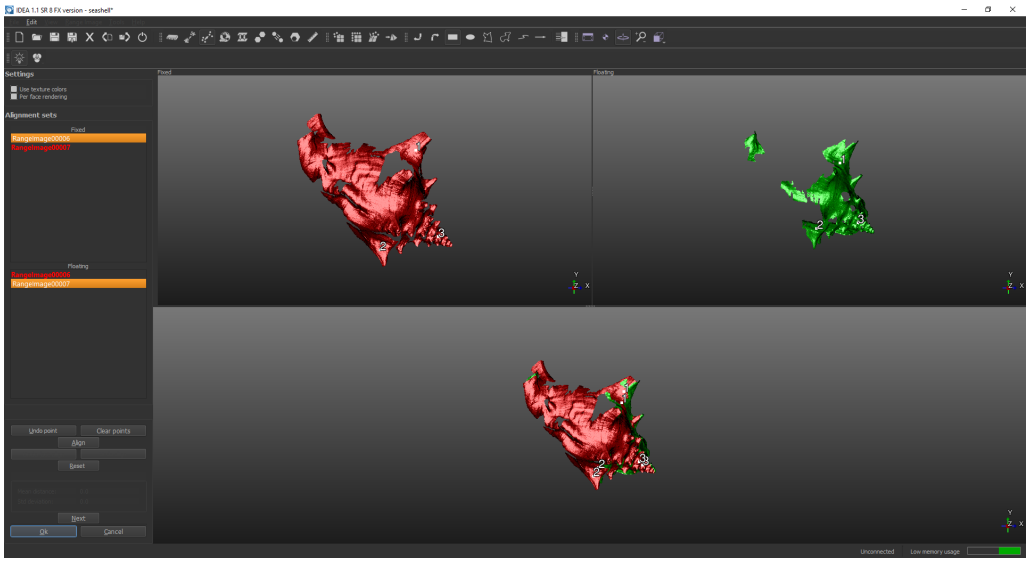


(a)

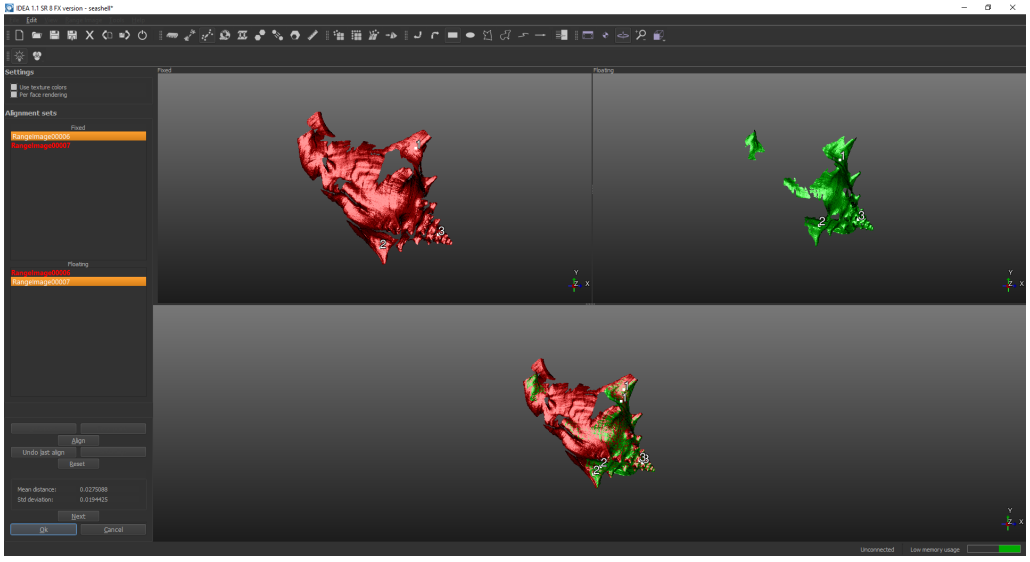


(b)

Figure 2.25: Fixed and moving scans selection.

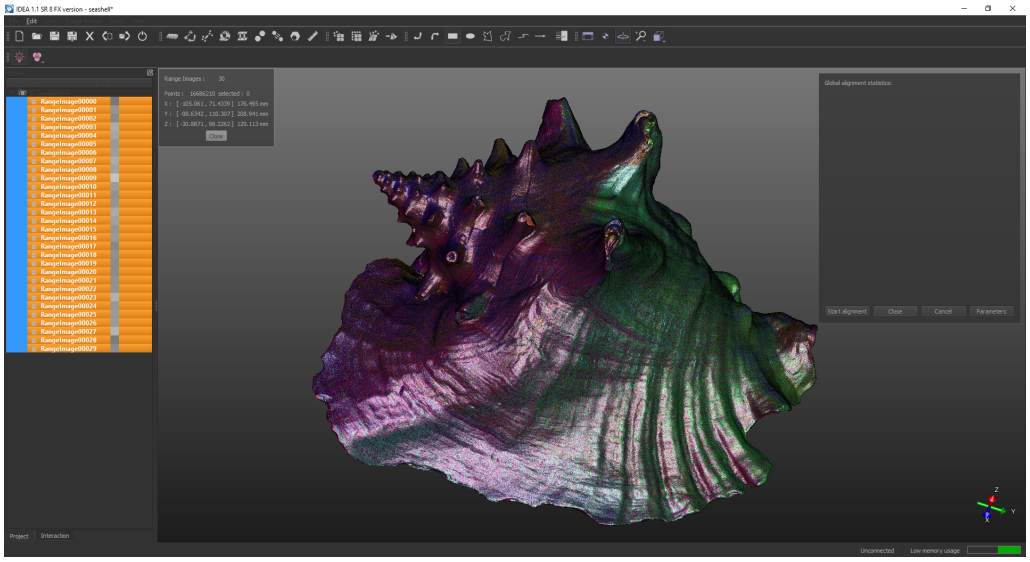


(a)

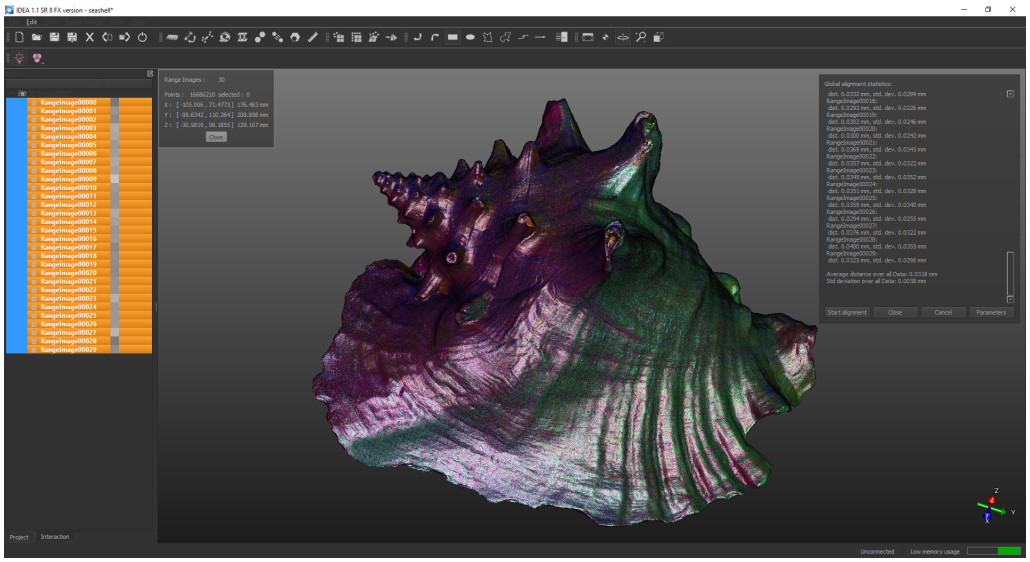


(b)

Figure 2.26: three-point based alignment of fixed and moving scans.



(a)



(b)

Figure 2.27: Example of global alignment procedure.

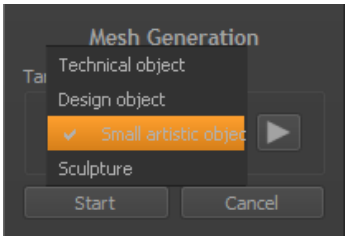


Figure 2.28: Mesh generation panel.

2.4.2 Datum alignment

Zeroing the position of the 3D model in the global reference system can be done with the "*Datum Alignment* tool. This tool is often used to make the base of an object coincide with the plane XY of the system. In the flat area of the mesh that corresponds to the base if the object, the user creates a plane with the tool *Approximate selection with a plane* (ref. Sect. 1.1.3.8); the datum alignment moves the object so that the plane created on it base coincides on the plane XY of the system.

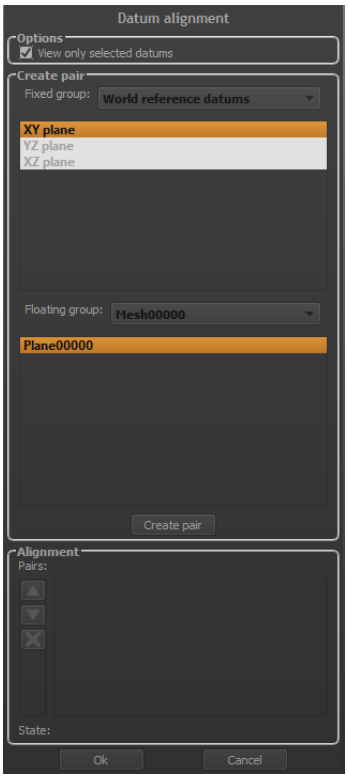


Figure 2.29: Datum alignment panel.

Usually this kind of alignment allows to move a mesh so that 3 of its planes coincide with the same number of planes calculated and saved in the project (that always has at least the system planes). The planes are divided in 2 groups, one of the fixed planes, containing the system planes and one for the planes built on the mesh one has to align. The alignment is defined with the button *create pair* which associates a fixed plan with a moving one: a list containing one to three pairs of planes, each one with a reference plane (fixed) and a moving plane of the mesh, is created; such list orders with decreasing priorities the alignment bindings. The section *Alignment* displays the list of the pairs, ordered with decreasing priority: once selected a pair, the buttons on the left allow to erase it or to modify its priority. Each variation of the alignment given by modifications to the pairs or the list is instantly applied.

Part Two

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3. Glossary

USB bus the Universal Serial Bus is an interface that allows to easily connect different devices to a computer. Theoretically, the USB bus 2.0 could transfer up to 50 MB/s but practically a high-performance desktop computer can only reach approximately 40 MB/s; most of the notebook and embedded devices do not even reach 40 MB/s;

Range image it is the three-dimensional equivalent of a photo: it stores the 3D coordinates, arranged within an acquisition grid, of the captured data.

Mesh three-dimensional surface composed by a list of polygons; in case the polygons employed are triangles, then it is called triangle mesh.