The Lucida 3D Scanner:
A Manual

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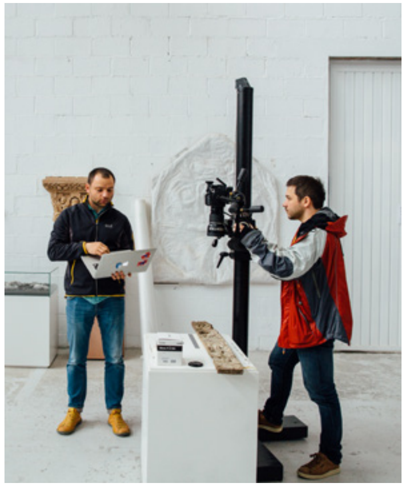
3D Scanning for Cultural Heritage Conservation

The Factum Foundation for Digital Technology in Conservation

Factum Foundation was established in 2009 as the sister organisation to Factum Arte, a multi-disciplinary workshop mediating the complex boundary between technology and contemporary art. In a world in which mass tourism, iconoclasm, or neglect, amongst other factors, pose a serious threat to works of art and culture, the Foundation was formed as a not-for-profit organisation dedicated to the digital recording and rematerialisation of cultural heritage for the purpose of conservation, study and dissemination.



Training in 3D recording from Lucida to photogrammetry at Factum Foundation in summer 2016 – two photographers from Dagestan

Through its work on endangered cultural heritage sites, in museums or cultural institutions, and its research into the newest scanning and rematerialisation technology, Factum Foundation is committed to establishing the importance of high-resolution 3D recording with a view to preserving our shared cultural heritage for future generations.

To this end, a large part of its work is dedicated to empowering local organisations and individuals with the education and technology required to actively participate in he digitisation of archaeological sites, monuments or artefacts, thereby engaging their interest and involvement in culture on a local level. In line with the Foundation's ideals, ownership and copyright of the data recorded always remain with the institution tasked with looking after the object or site on all current and future commercial applications. In return for this commercial control, the data is made freely available for academic, conservation and research applications.

A quick introduction to 3D scanning

In recent years, high-resolution 3D recording has become part of a coherent non-contact approach to the documentation of cultural heritage and to strategies for its long-term preservation. This not only creates new opportunities for presenting culture in both virtual and physical ways, but it also transfers skills and technologies to create a new economy benefitting local communities.

The methodology advocated by Factum Foundation involves 3D recording both the general shape and the surface texture and colour of artefacts and sites. The processing of the data depends on its intended use, but it is essential that the recording takes place at the highest resolution. The data can be archived in various forms; raw data offers the possibility of reprocessing in the future at higher resolution. Various visualisation techniques make it possible to stream data safely so it can be accessed, studied and shared without specialist software. 3D printing and CNC milling can re-

Facsimile of The Wedding at Cana by Paolo Veronese (1563. The original is in the Musée du Louvre; the facsimile was installed by Factum Arte and the Fondazione Giorgio Cini in the original location – the refectory of the Basilica di San Giorgio Maggiore, Venice sult in accurate re-materialisations only if the data is correctly recorded. The conservation community, restoration specialists, exhibition designers, visitor centres, academic institutions, schools, and interested parties can all benefit from this approach.

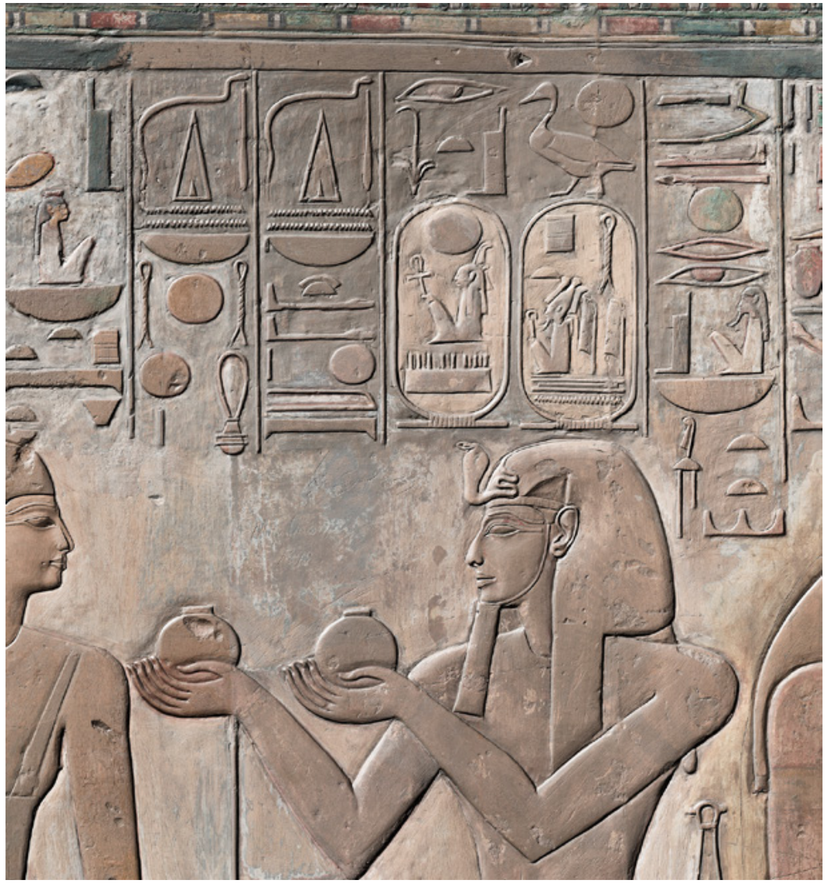
Exact facsimiles, made possible through advances in 3D recording and output technologies, are integral to the work carried out by Factum. Nevertheless, a great deal of misunderstanding still exists about the role they can play in cultural heritage preservation. In the 21st century, however, a realisation of the threat posed to cultural heritage is resulting in the re-evaluation of the significance of facsimiles. This is a multidisciplinary approach that is helping visitors understand the complexity involved in preservation and leading to a renegotiation of the relationship between the original and the authentic. If people become more conscious of the fact that visiting monuments such as the tombs in the Valley of the Kings, Luxor significantly contributes to their degradation, then it is likely that a new sense of public awareness will emerge. Through the careful employment of facsimiles, we can develop a form of preservation of the original object that doesn't deny the public a close and intellectually stimulating interaction with art and culture.

Close-range 3D scanning

It is important that the right type of 3D recording is undertaken for each heritage site or object and that the application is considered prior to the recording phase of a project. In general, the more complete the dataset – a complete dataset would comprise high-resolution colour, high-resolution surface texture as well as an accurate rendition of shape – the more uses it will have for academic, conservation and research purposes.

For a facsimile, the acquisition of high-resolution surface data for an object is essential – this requires close-range 3D scanning.

Close-range 3D scanners (working distance greater than 8cm and less than 100cm) are used to record the shape and surface of objects in detail. Triangulation based 3D laser scanners use a laser light and one



A coloured render of 3D data from the Hall of Beauties in the Tomb of Seti I, Valley of the Kings, West Bank, Luxor

or two cameras to record a subject. The distance of the object to the scanner is calculated through trigonometry to create a precise map of the surface. Structured light scanners use projected patterns of light instead of a laser for triangulation – the camera(s) records these patterns and calculates the position of every point in the field of view. (See Appendix A for more information on the types of 3D scanners used by Factum Foundation). The Lucida 3D Scanner is an example of a close-range 3D laser system

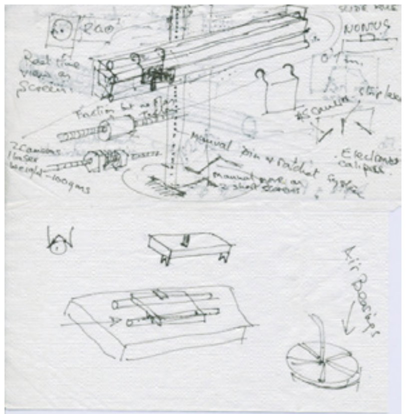
The Lucida 3D Scanner

Lucida is a 3D laser scanner custom-built by Factum Arte with financial and logistical support from Factum Foundation. Conceived and developed by artist and engineer Manuel Franquelo, this system is the result of fourteen years of investigation into the high-resolution recording of the surface of paintings and relief objects

The development of the Lucida 3D Scanner

Factum Arte and Factum Foundation have extensive experience in employing commercially available digital technology to record cultural heritage sites and objects for rematerialisation in diverse locations around the world – from the Valley of the Kings in Egypt to the Musée du Louvre in Paris. From the early 2000s, due to the complex requirements of each project, Factum has also been adapting and improving commercial closerange 3D recording systems in order to achieve higher conservation standards and better data.

Factum Arte started working with 3D Scanners UK in 2000, using and adapting their Reversa scanner for work in the tomb of Seti I. The SETI Scanner, mounted onto CNC controlled X, Y, and Z axes, was the first variation. The Yabba Scanner was the second variation, a crucifix scanner specially prepared for work in the British Museum. The Reversa head mounted onto the SETI frame was used in the tomb of Tutankhamun in 2009, but by this time, the system was becoming obsolete. In order to improve control of both the hardware and software it was decided that a new scanner would be developed in house.



First sketches of the Lucida system on a napkin

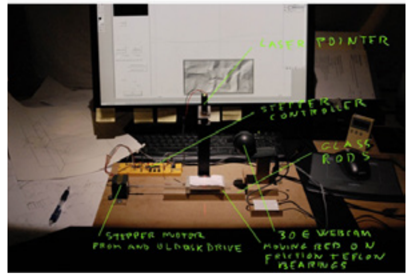
The idea was to create a laser scanner for conservation that would record high-resolution texture of any 2.5D surface.

The first iteration of the scanner, a two-camera laser system employing linear guides for vertical and horizontal movement in 48 x 48 cm 'tiles', was first used in 2011 to record the preparatory panels for The Triumph of the Eucharist by Rubens at the Prado Museum in Madrid. Between 2011 and 2013 new prototypes were created with a stable and modular frame to support the linear guides and to allow the user to scan a number of tiles in succession.

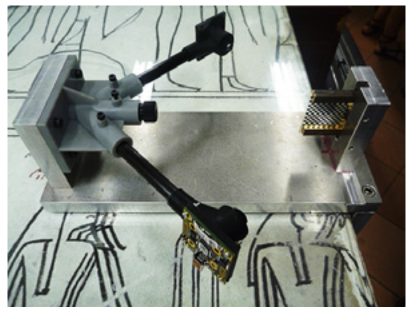
Other changes were made including the introduction of z-axis movement – to/from the object – which permits re-scanning at various depths within a single tile; or the development of a simple user interface and the creation of the editing, merging and blending applications, enabling full control of the data processing.

Although research into this technology is ongoing, the Lucida currently in use at Factum was finished in 2015.

Prototype of the scanning head in wood



First setup to test system basics



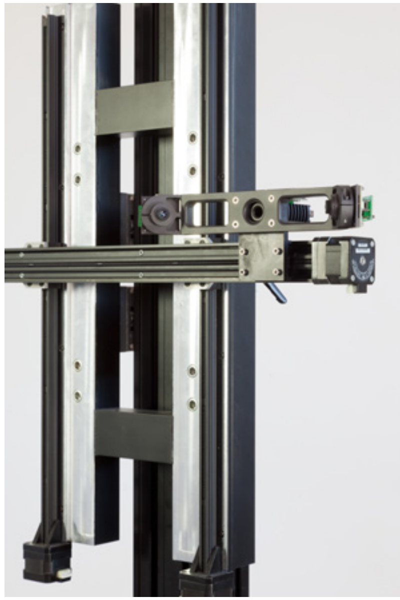
Static working scanning head prototype

A 3D laser scanner for conservation

The Lucida 3D Scanner is a non-contact laser system designed to record the texture and surface of paintings or low-reliefs at high-resolution (up to 100 microns), creating datasets for study or rematerialisation. The scanner is portable, easy to use, and requires only mains electricity and a low-light environment to function.

Fitted with two cameras and one laser, it records depth information that can be handled as both an image and a 3D file. A thin vertical strip of red light is projected onto the surface of the artwork. As the strip moves over the surface, it is recorded as raw black & white video by two cameras positioned at an angle of 45 degrees on either side of the laser. The distortions of the line produced by the relief can be rendered to produce an image or converted into 3D information. The scanning head moves parallel to the surface plane of the object, controlled by linear guides, and is always at a distance from the surface.

The Lucida 3D Scanner has a number of advantages over commercially available systems:



Close-up of the Lucida two-camera, one laser scanning head

1. The Lucida is able to record surfaces that are generally considered problematic - including shiny, glossy or varnished, as well as dark or black surfaces - by overcoming the problem of contrast and reflection through innovative hardware, and algorithms designed to reduce noise without altering surface characteristics. For recording technology to be meaningful for cultural applications, it is essential that the correspondence between the surface and recorded data is as close as possible. Understanding the relationship between noise and information is critical.

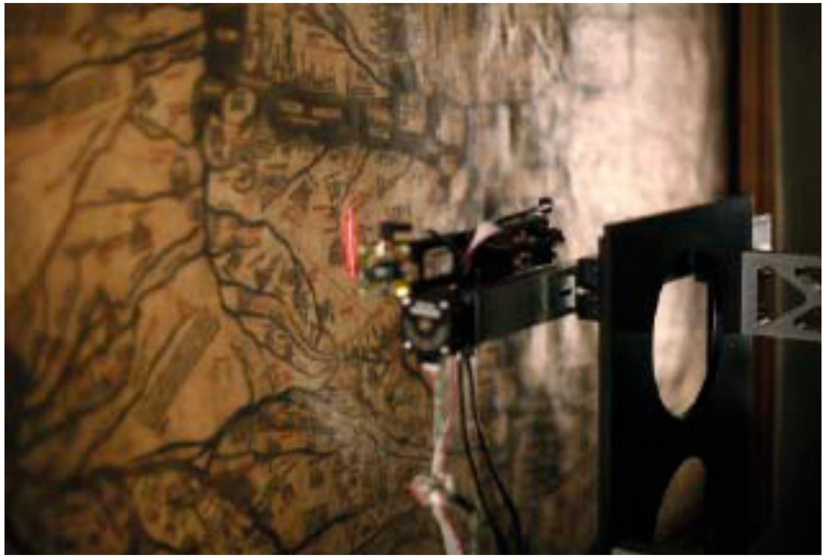
Colour image of the standard board – which contains problematic surfaces including shiny and very dark surfaces – photographed with raking light to highlight relief

Render of the 3D data of the standard board obtained with Lucida

2. The Lucida is unique in storing 3D information in the form of raw tonal video, making it possible to re-process the data in the future at higher resolutions or with new technology. This is a radical innovation that reflects a deep understanding of the needs of the conservation community. Other scanning systems automatically process the recorded data into a three-dimensional point cloud or mesh, which results in an irreversible abstraction and a permanent loss of information. Lucida also generates a series of files for use: AVI (Video), RIS (3D), TIFF 32 bit and 16 bit (greyscale depthmap) and TIFF 8 bit (shaded rendering).

3. Another innovation is the use of increasingly powerful image stitching software as an integral part of the process (Adobe Photoshop and/or PTGui). After the RIS files have been edited to fill holes and remove noise, the shaded renders are corrected using projective geometry and stitched together. They can then be ‘switched’ for the 32bit greyscale data that contains the depth information. This ‘edited’, ‘merged’ and ‘aligned’ file can be exported into software like Artcam as an STL or OBJ (standard 3D formats) and used to rematerialise the 3D data in physical form with the surface character of the original.

It is by virtue of these steps that the recorded data can be processed and accessed without specialised 3D software that tend to be expensive and require regular, often costly, updates.



Recording the Hereford Mappa Mundi at Hereford Cathedral with the Lucida 3D Scanner

4. The render of the 3D data (a shaded 8-bit TIFF file) can be integrated with other image files to produce multilayered browsers that can accurately integrate infra-red, X-ray, colour and other types of information in conservation reports, historical images and various forms of forensically accurate analysis. Multi-layered files are helpful to researchers and conservators because they provide an information-rich, accurate, objective and meaningful method for monitoring the condition of the artwork.

The Lucida 3D Scanner has been used in major cultural institutions to provide data that will become integral for conservation, including the Musée du Louvre (Paris), the National Gallery (London) and the Prado Museum (Madrid).

Credits

Manuel Franquelo: Concept and design of electronics, mechanics, optics, and software.

Fabricated and tested in Factum Arte by Carlos Bayod, Jorge Cano, Dwight Perry, Carlos Alonso, Nicolás Díez, Manuel Franquelo Jr, Guendalina Damone, Enrique Esteban and Aliaa Ismail under the supervision of Manuel Franquelo.

The Lucida 3D Scanner

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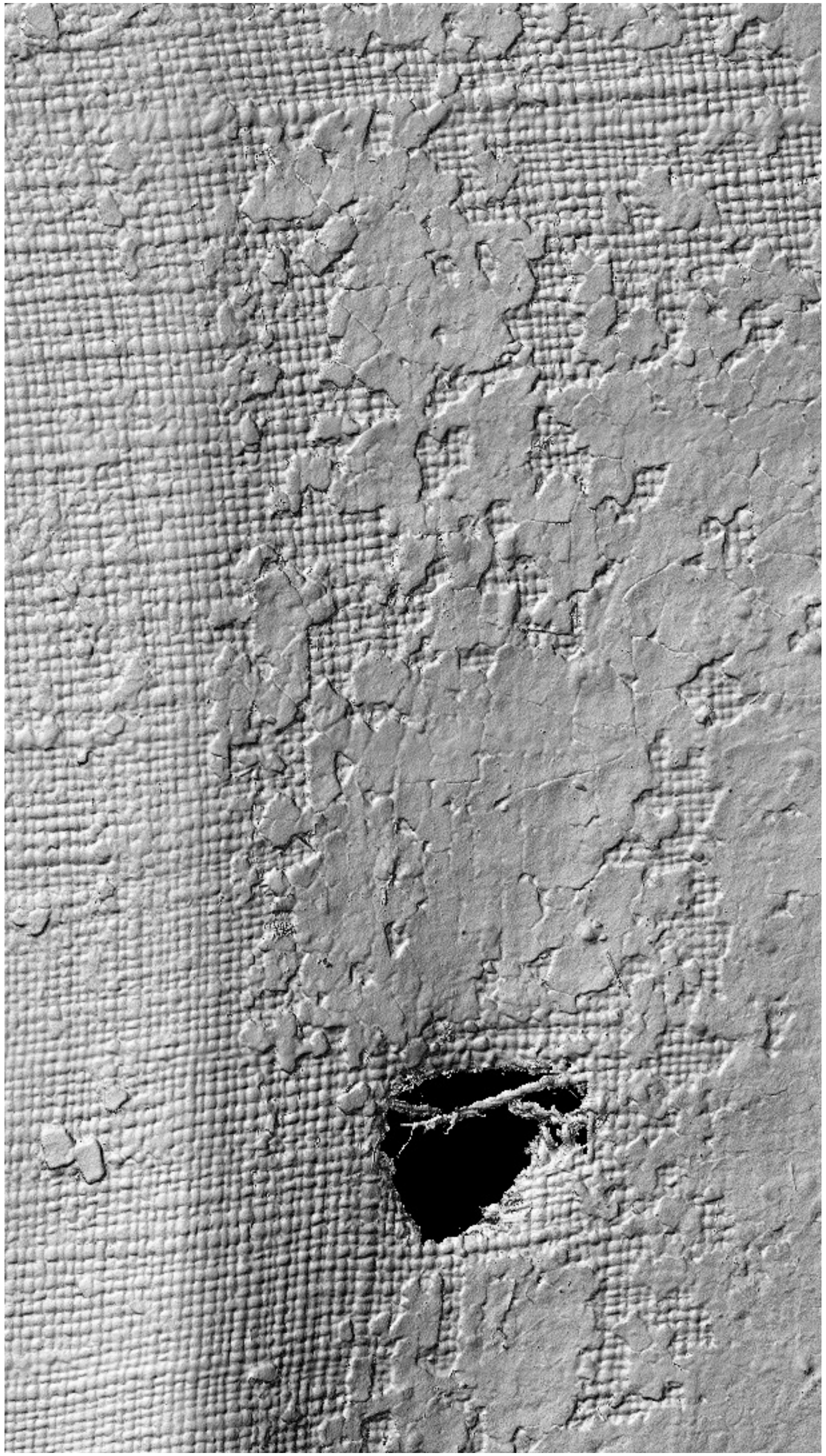

1

Welcome.
Let’s get started

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Damaged canvas, detail
3D scanned in 2011 in Factum Arte, Madrid

1 Let's get started

Specifications

Laser diode
Manufacturer and model: Laser Components ADL-65075TA2
Type: Auto Power Controlled Laser Diode. Stable light power output, compact size, high brightness laser light source
Wavelength: 650 nm
Power: 5 mW

Cameras
Manufacturer and model: IDS UI-1221LE-M-GL
Type of cameras: Monochrome
Sensor: CMOS Mono by Aptina Imaging
Lens: Sunex DSL-300 EFL=17.1 f/4.2
Data transmission speed: max 25 Mbytes/s per camera
Interface: USB 2.0
Resolution: 752 x 480 pixels

Microcontroller
Chip: 8-bit Atmel AVR Atmega 328
Clock speed: 16MHz
Operating Voltage: 5V

Linear motion
Manufacturer and model: Haydon Kerk RGS06 Motorized hybrid linear rails & actuators

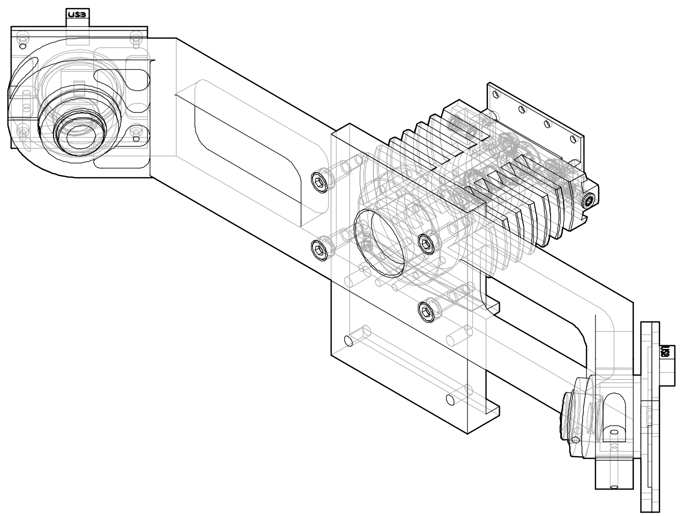
Data features
File formats: 3D (RIS), 3D (32 bit-TIFF), 3D (16 bit-TIFF), 2D render (8-bit TIFF), raw video (AVI)
Point resolution: 10,000 points per cm2
Megabytes per m2: RIS (420 MB), 3D depthmap 32bit-TIFF (420 MB), 2D render 8bit-TIFF (88 MB), AVI (272 GB)

1 Let's get started

How does it work?

Designed and developed by the artist Manuel Franquelo, Lucida has been created to obtain contact-free, high-resolution 3D data out of the surface of paintings and low-relief objects.
The system projects a thin beam of red light onto the surface of the painting. As the beam moves across the object the distortions caused by the surface fluctuation are recorded by two video cameras positioned adjacent on the assembly either side of the laser. The video footage is archived as raw data as well as processed as a tonal depthmap.

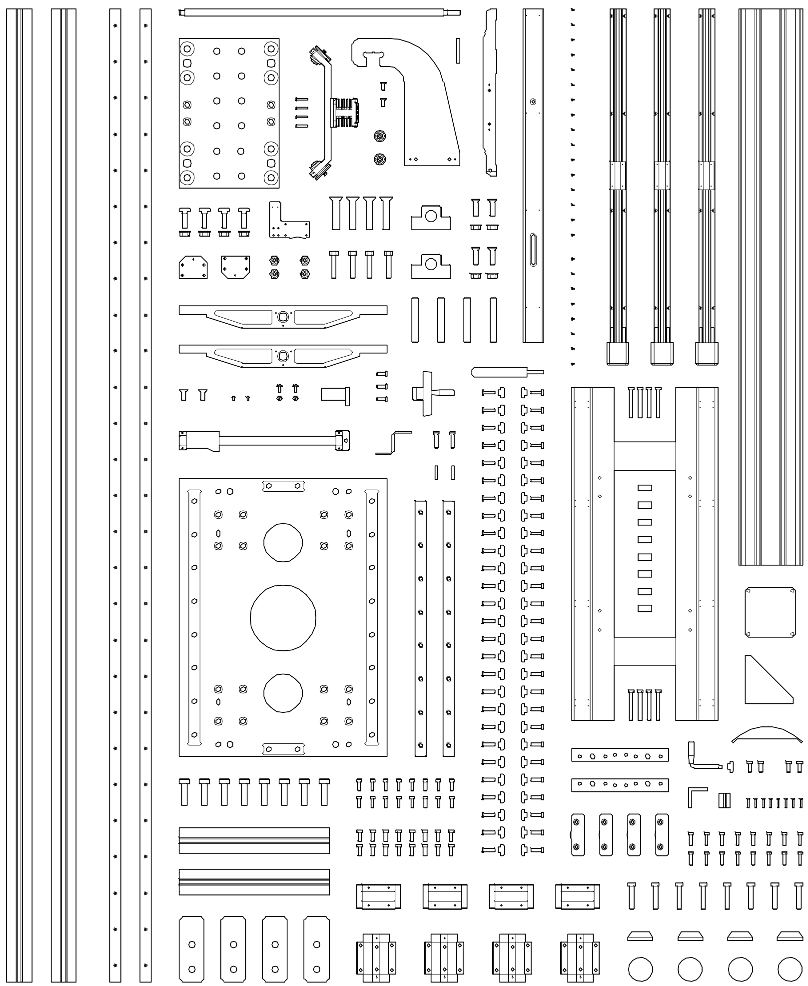
Scanning features
Depth of field: 25 mm
Maximum scanning depth using Z axis: 200 mm
Distance to the target: 65-90 mm
Maximum scanning area (m2):
Only limited by storage capacity and structural frame
Scanning speed (m2/h): ca. 0.25



1 Let's get started

Components

What's in the case?



For product updates, new components and accessories please visit:
www.factum-arte.com

1 Let's get started

Components

Ref.	Units	Component
01	1	Calibration arm
02	1	Calibration stand
03	1	Calibration dowel pin
04	1	Calibration threaded handle
05	1	Scanner head
06	1	Shim plate
07	1	Horizontal linear guide
08	1	Horizontal channel
09	2	Carriage connection plate
10	2	Vertical linear guide
11	1	Backing frame
12	8	Stand-off
13	4	Carriage
14	2	Carriage plate
15	1	Brake connecting profile
16	1	Brake connecting plate
17	1	Brake handle
18	1	Tower profile 1000 mm + Profiles + Guide rods
19	1	Tower cap
20	1	Square
21	1	Square cap
22	1	Tower plate
23	2	Beam
24	1	Threaded plastic piece
25	1	Lead screw
26	2	Bearing
27	2	Bearing mount
28	1	Hand wheel
29	4	Carriage
30	2	Guide

1 Let's get started

Components

Ref.	Units	Component
31	1	Digital caliper
32	1	Digital caliper connecting plate
33	1	Base plate
34	4	Carriage
35	2	Guide 1750 mm
36	4	Profile 1750 mm
37	4	Profile 270 mm
38	4	End plate
39	4	Adjustable oot
40	4	Foot cap

Components. Accesories

Ref.	Units	Component
41	1	Controllers box and wires
42	1	Controllers AC adaptor
43	1	Power cable
44	1	USB cables set
45	1	USB extensions set
46	1	Allen keys set
47	1	Spanners set
48	1	Micro-screwdrivers set
49	1	Laptop
50	1	Laptop AC adaptor
51	1	Laptop mouse
52	1	Laptop bag
53	1	Long rectangular case
54	1	Large square case

1 Let's get started

Components. Screws and nuts

Ref.	Units	Component
A	2	M6 x 24 Socket head cap screw
B	2	4.5 x 24 mm Cylindrical dowel pin
C	4	No 6-32 x 1/2 Socket head cap screw
D	8	M3 x 0.5 Socket head cap screw
E	2	M6 x 5 Socket countersunk head screw + nuts
F	8	No 6-32 x 1/2 Socket head cap screw
G	16	M3 x 5 Socket head cap screw
H	8	M6 x 45 Socket head cap screw
I	2	M6 x 15 Socket head cap screw
J	2	M6 x 15 Socket head cap screw
K	4	M12 x 50 Socket countersunk head screw
L	8	M8 x 25 Bosch FS7 + Nuts
M	4	M8 x 25 Bosch FS7 + Nuts
N	4	M12 x 22 Socket countersunk head screw
O	3	M5 x 14 Socket head cap screw
P	4	M8 x 40 Hexagonal head
Q	16	M5 x 20 Socket head cap screw
R	2	M5 x 10 Pan cross head + Nuts
S	2	M5 + Nuts
T	2	M3 + Nuts
U	16	M5 x 20 Socket head cap screw
V	16	M6 x 15 Socket countersunk head screw
W	58	M6 x 20 Socket countersunk head screw
X	8	M8 x 40 Socket head cap screw
Y	4	B12 x 40 Socket head cap screw
Z	4	M12 x 90 Threaded rod + Nuts

For product updates, new components and accessories please visit:
www.factum-arte.com

2

Setting up

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Hereford Mappa Mundi, c. 1300, ink on vellum, detail
3D scanned in 2012 in Hereford Cathedral, England

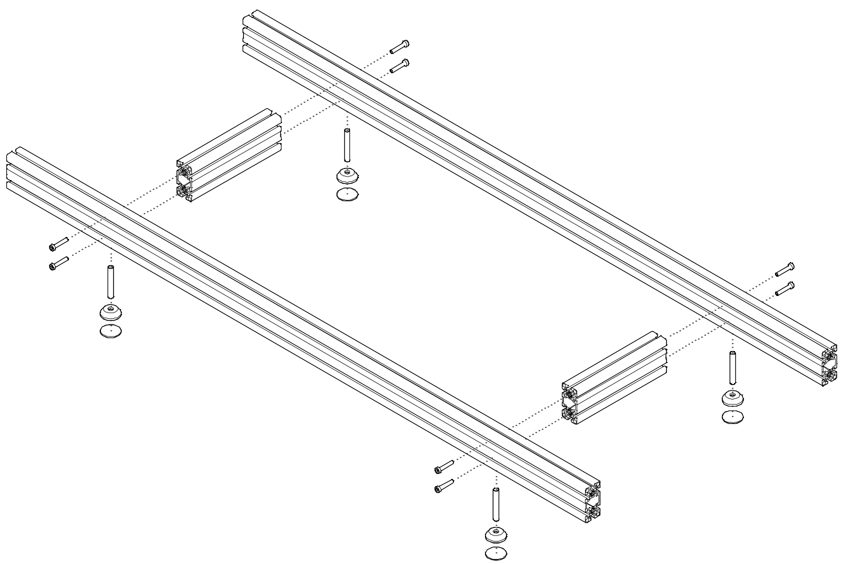
2 Setting up

Step 01/16

Components:
40 (4x) Foot cap
39 (4x) Adjustable foot
37 (2x) Profile 270 mm
36 (2x) Profile 1750 mm

	X
	8 units M8 x 40

	Z
	4 units M12 x 80

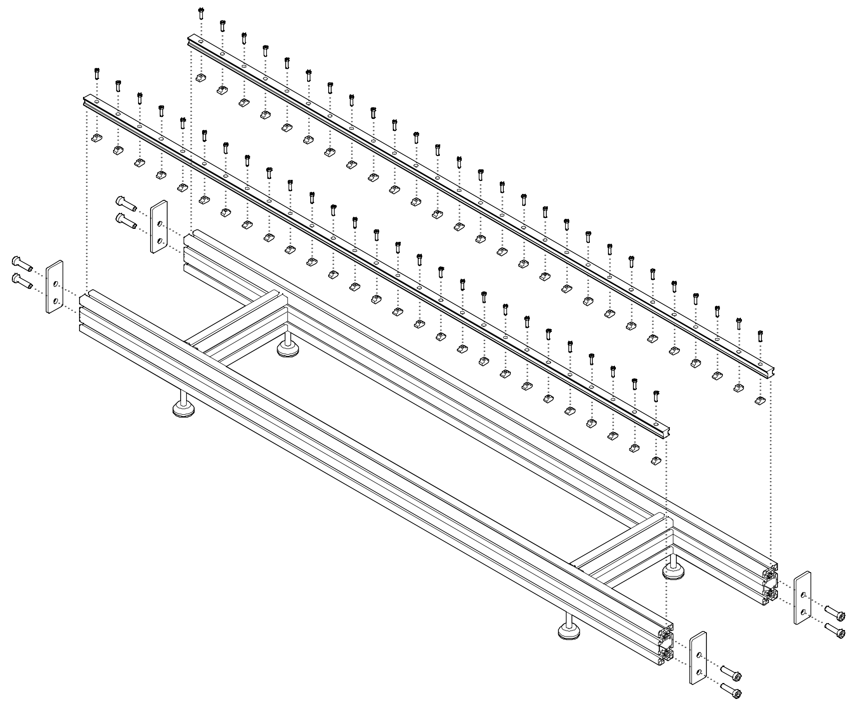


2 Setting up

Step 02/16

Components:
38 (4x) End plate
35 (2x) Guide 1750 mm
34 (4x) Carriage

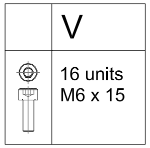
	W
	58 units M6 x 20

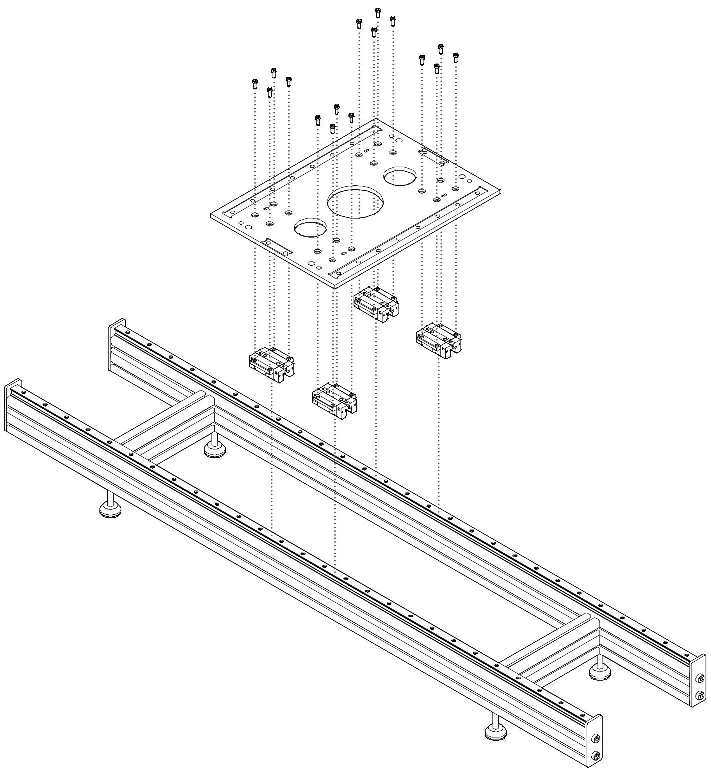


2 Setting up

Step 03/16

Components.
33 (1x) Base plate

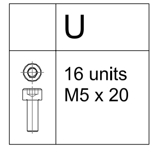


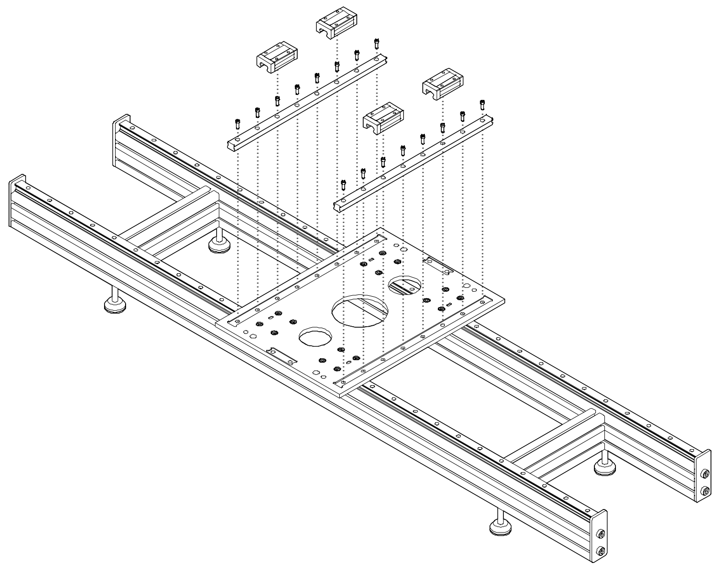


2 Setting up

Step 04/16

Components:
30 (2x) Guide
29 (4x) Carriage

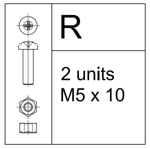


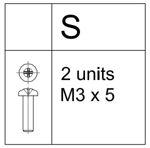


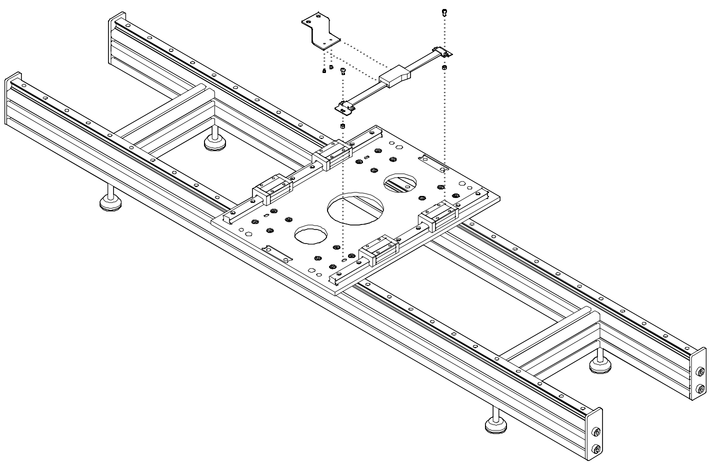
2 Setting up

Step 05/16

Components:
32 (1x) Digital caliper connecting plate
33 (1x) Digital caliper



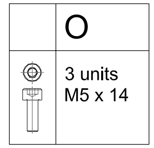


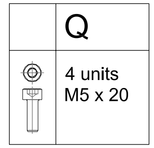


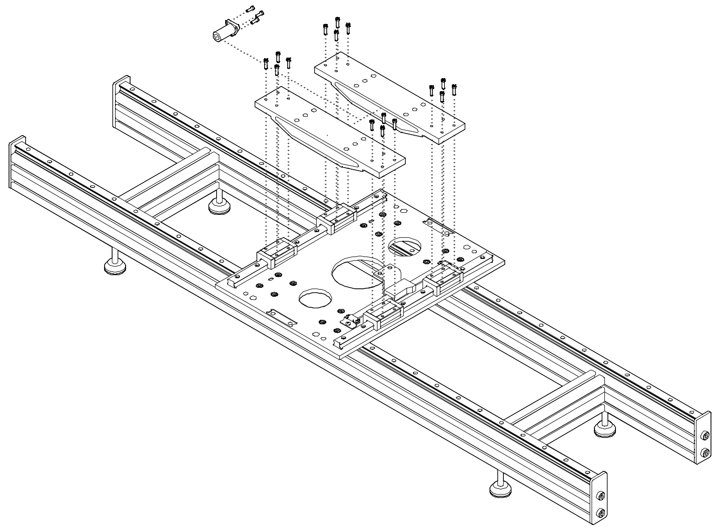
2 Setting up

Step 06/16

Components:
24 (1x) Threaded plastic piece
23 (2x) Beam





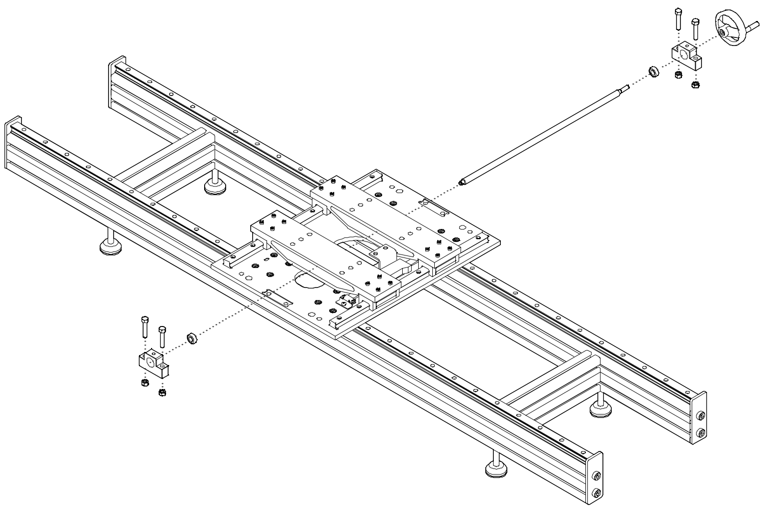


2 Setting up

Step 07/16

Components:
28 (1x) Handwheel
27 (2x) Bearing mount
26 (2x) Bearing
25 (1x) Leadscrew

P
4 units
M8 x 40



2 Setting up

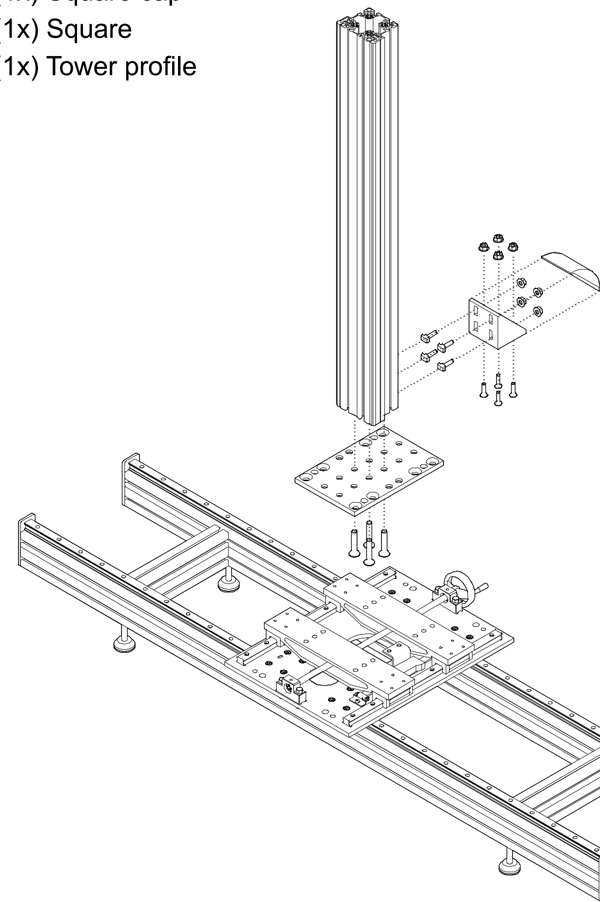
Step 08/16

Components:
22 (1x) Tower plate
21 (1x) Square cap
20 (1x) Square
18 (1x) Tower profile

K
4 units
M12 x 50

L
4 units
M8 x 25

M
4 units
M8 x 25



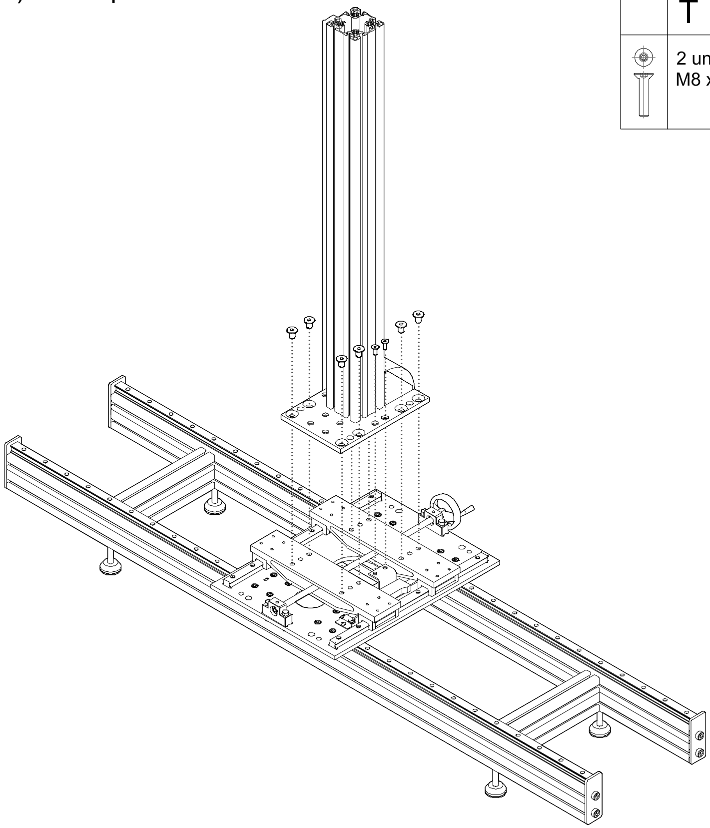
2 Setting up

Step 09/16

Components:
22 (1x) Tower plate
21 (1x) Square cap
20 (1x) Square
18 (1x) Tower profile

	N
	8 units M12 x 12

	T
	2 units M8 x 20

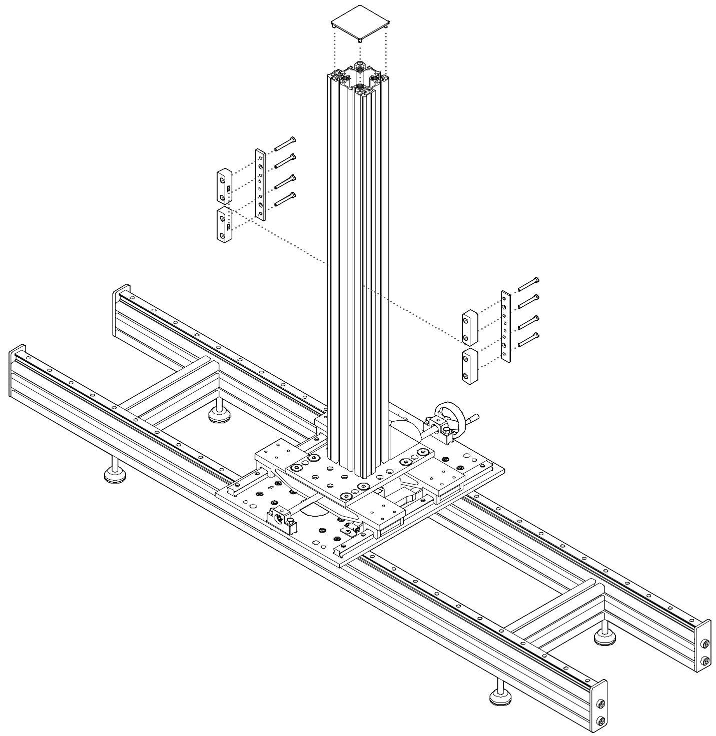


2 Setting up

Step 10/16

Components:
19 (1x) Tower cap
14 (2x) Carriage plate
13 (4x) Carriage

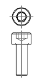
	H
	8 units M6 x 50

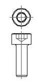


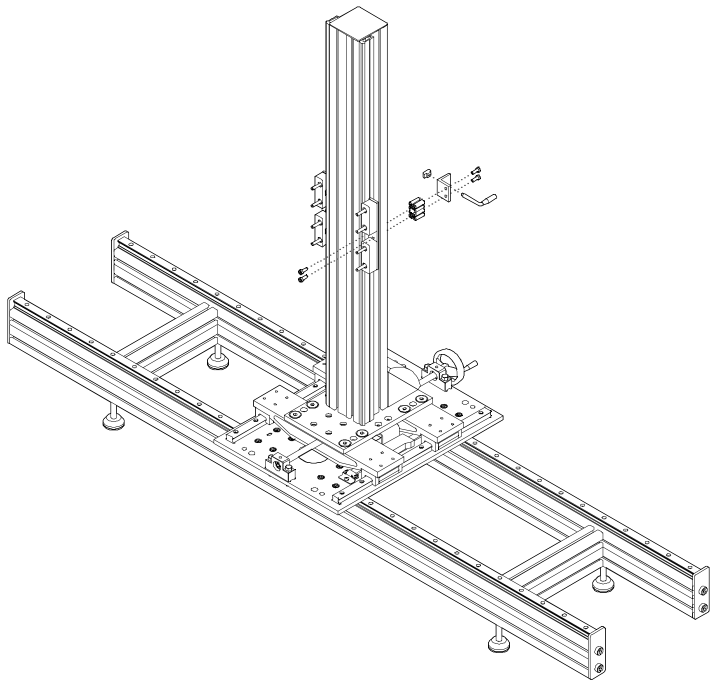
2 Setting up

Step 11/16

Components:
17 (1x) Break handle
16 (1x) Break connecting plate
15 (1x) Break connecting profile

	J
	2 units M6 x 15

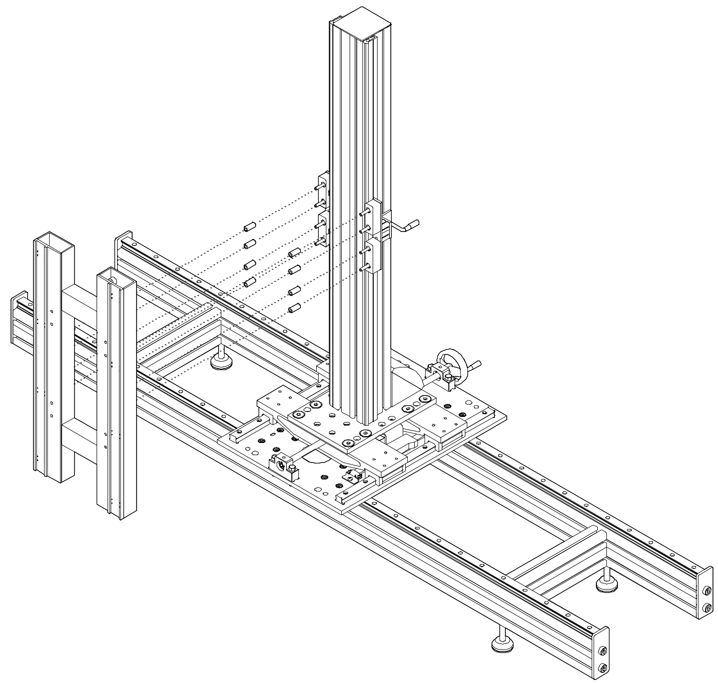
	I
	2 units M6 x 15



2 Setting up

Step 12/16

Components:
12 (8x) Stand-off
11 (1x) Backing frame



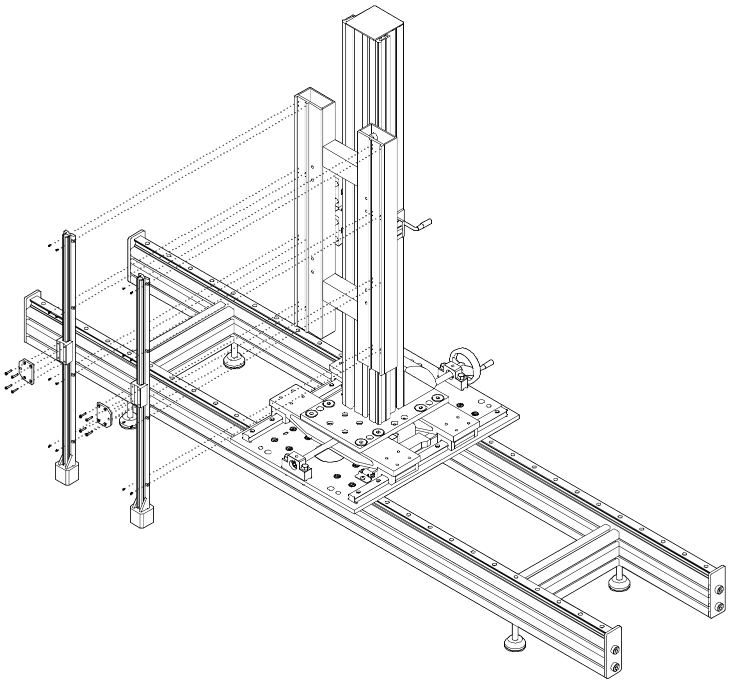
2 Setting up

Step 13/16

Copmponents:
10 (2x) Vertical linear guide
09 (2x) Carriage connection plate

	F
	8 units No 6-32

	G
	16 units M3 x 5



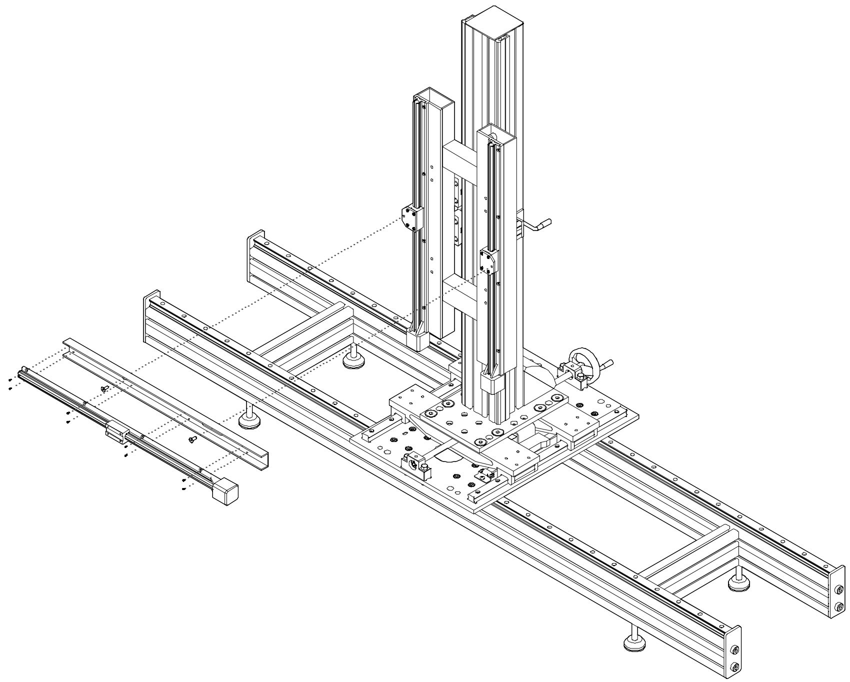
2 Setting up

Step 14/16

Components:
08 (1x) Horizontal channel
07 (1x) Horizontal linear guide

	D
	8 units M3 x 5

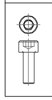
	E
	2 units M6 x 5

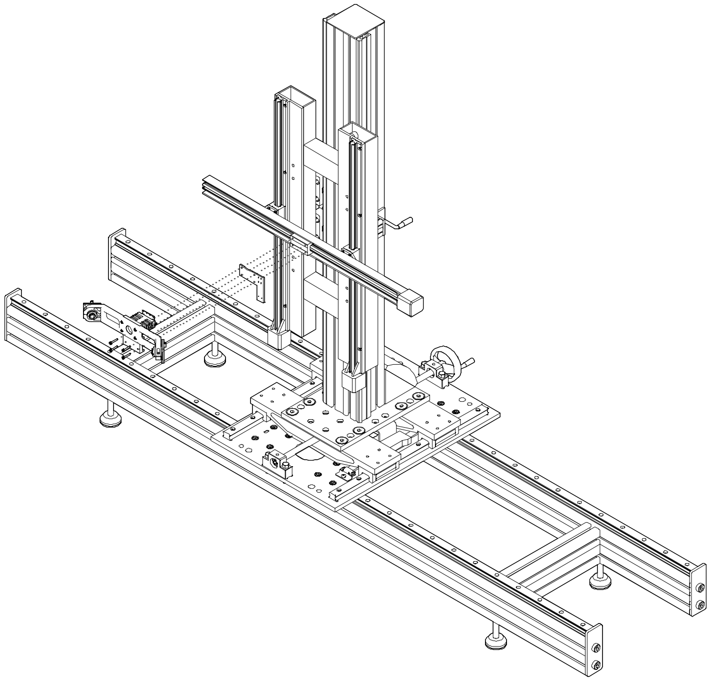


2 Setting up

Step 15/16

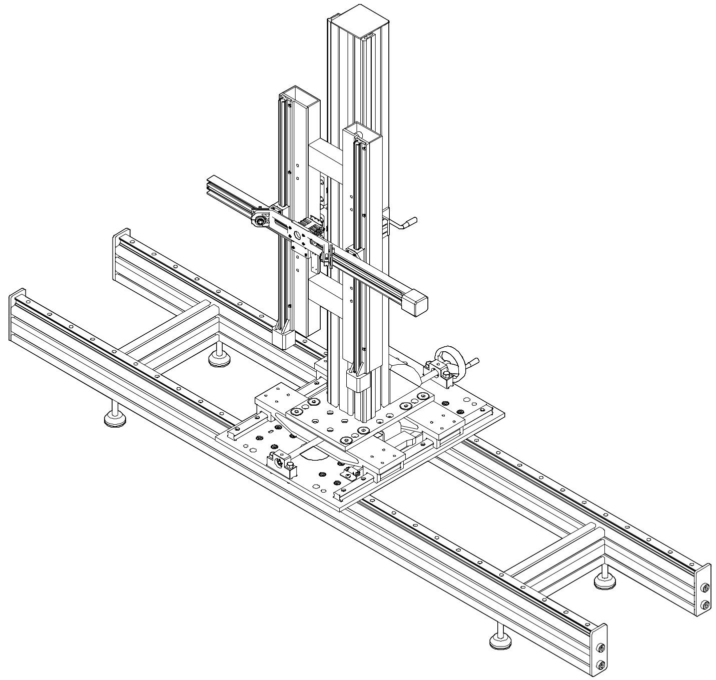
Components:
06 (1x) Shim plate
05 (1x) Scanner head

	C
	4 units No 6-32



2 Setting up

Step 16/16



2 Setting up

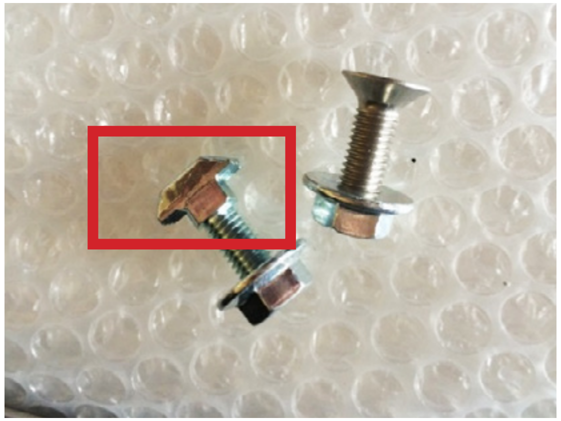
Photo guide

You can also approach the setup of the Lucida using the following steps accompanied with images. Some users may prefer this option.

Step 1: Prepare the legs for the rails

1.1 Match the black triangle brackets to the aluminium legs. Make sure the edges perfectly line up. The legs support the entire structure - it is important to assemble them correctly.

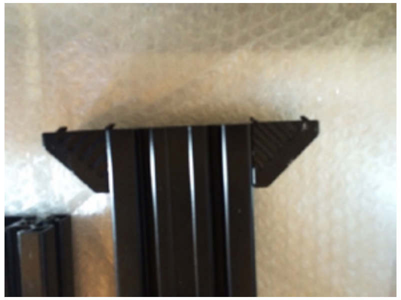
1.2 Use the silver screw heads to attach the triangle brackets to the legs.



The highlighted section goes inside the grooves of the rails and locks when tightened.

2 Setting up

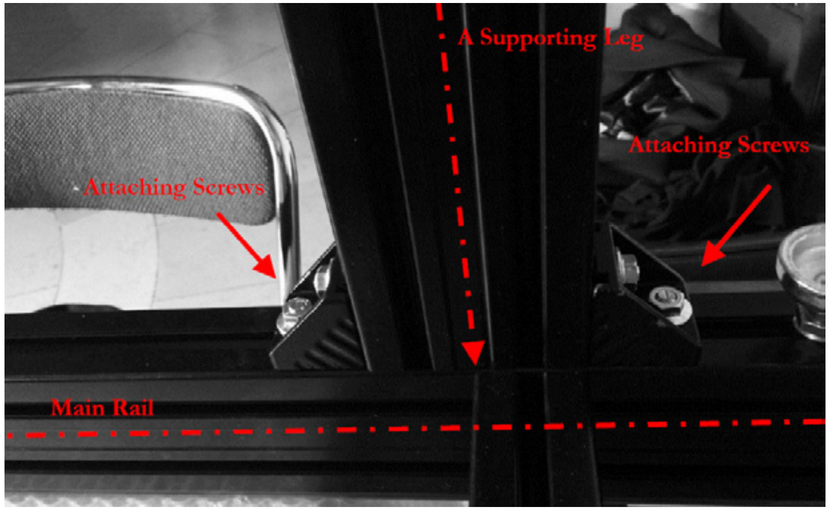
Photo guide



1.3 Repeat the procedure for the other side of the leg and for the other three legs.

Step 2: Attach the legs to the rail and the feet to the legs

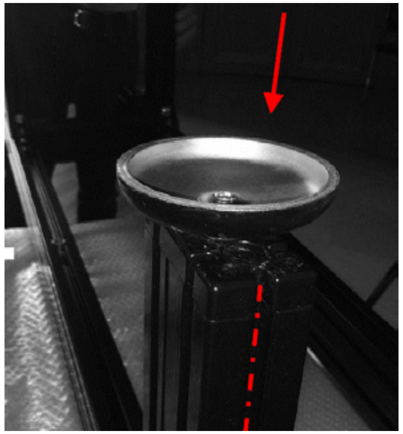
2.1 Line up the legs so the two screws connect with the groove on the rail. The four legs must be equidistant from the centre to balance the weight distribution.



Push the screws towards the outer edge of the slots to make for easier access and facilitate the fixing and removing process.

2 Setting up

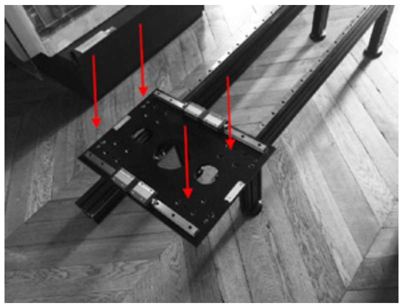
Photo guide



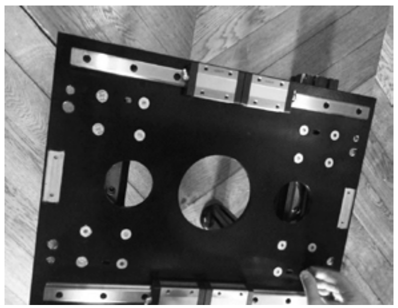
2.2 Secure the feet: simply screw the feet into the threaded hole on bottom of supporting legs.

Step 3: Secure the plate onto the rails

The base structure consists of two connected rails; each of the rails contains two carriages. The carriages are mobile and can be adjusted to the perforated screw holes on the aluminium plate.



3.1 Align the plate to the carriages. Each carriage has four points of attachment.



3.2 Attach using the designated **M4 x 16mm** screws. Gently screw all four screws to make sure the plate is well aligned. Then tighten using the allen key.

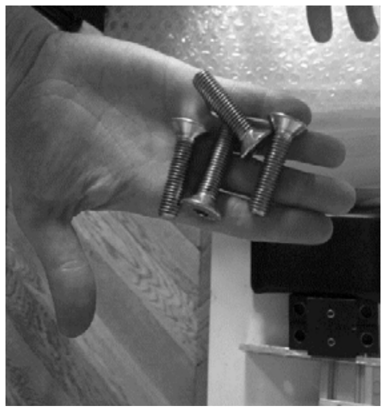
2 Setting up

Photo guide

Step 4: Secure base plate to mast

The base plate has 12 holes. To attach it to the base of the mast requires only four of these holes. This allows for three possible positions for the mast: one at the front, a second in the middle and a final one at the back. The position that is most frequently adopted is with the mast located at the front as will be shown in Step 4.

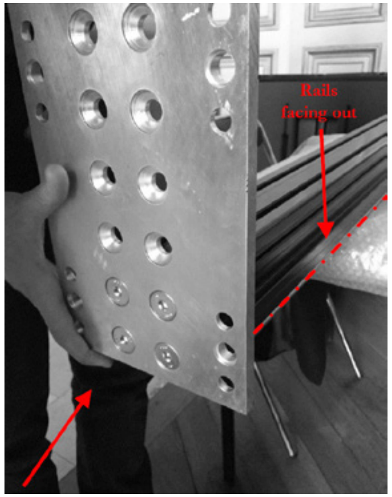
4.1 Place the mast on a table. Use the top four holes and make sure before attaching any of the screws that the rails on the mast are facing upwards and away from the base plate.



4.2 Once the composition is well aligned, screw the plate onto the base of the mast using four **M8** screws.

2 Setting up

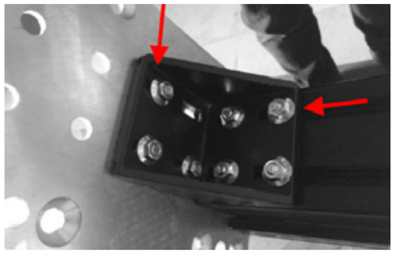
Photo guide



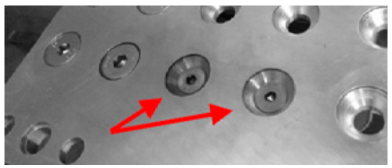
It is important to make sure that the plate is 100 % perpendicular to the mast and the screws well tightened. This ensures the mast is parallel to the wall during recording – the data recorded will be accurate. Any tilt in the verticality of the mast will reduce the range of the scanner and produce data at an angle (more detail in Scanner operation).

Step 5: Secure stabilising pyramid to mast and plate

The stabilising pyramid is an aluminium triangular bracket similar to that used for the preparation of the supporting legs in Step 1 The stabilising pyramid helps fix the position of the mast in relation to the base plate and maintains the verticality of the mast during the recording.



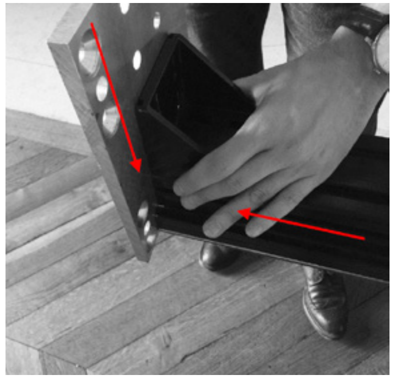
5.1 Use the same screws shown in Step 1 to attach the bracket to the mast.



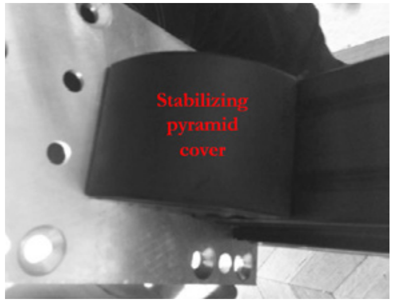
5.2 Use socket-head screws to attach the bracket and mast to base plate.

2 Setting up

Photo guide

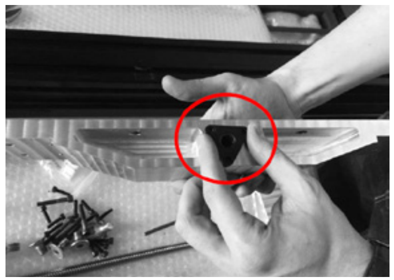


Again, it is important to make sure the base plate and mast are 100% perpendicular. The silver metal tracks on the mast (highlighted) face forwards.



5.3 Place the protective cover on the triangular bracket.

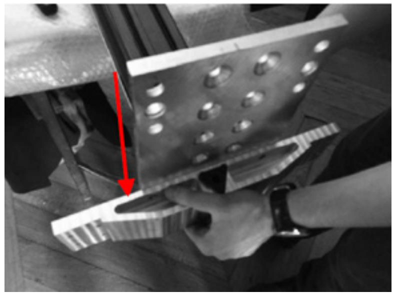
Step 6: Attach beams to the silver base plate



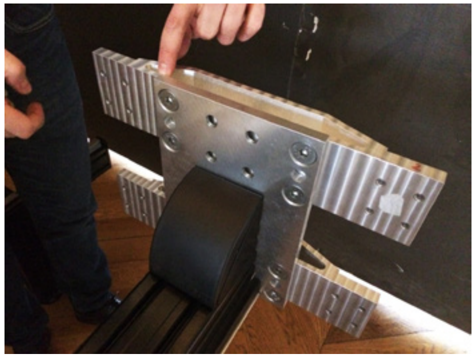
6.1 One of the beams has three small holes around a larger one. Insert the black, plastic threaded tube into the hole of this beam. Make sure that the triangular face is aligned with the three holes on the beam; attach the two pieces together using flat head **M3 x 16mm** screws.

2 Setting up

Photo guide



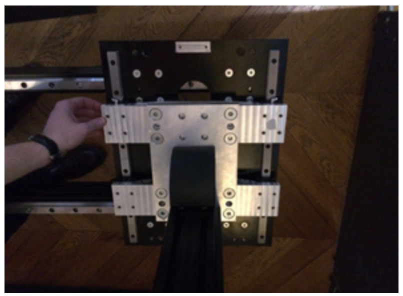
6.2 The beam comprising the threaded tube is attached to front of the scanner, the plastic piece facing inward.



6.3 The beams are attached to the plate using socket head cap screws. Attach both beams at the back of the base plate and make sure that they are properly fixed by attempting to move them.

Step 7: Attach mast to base structure plate

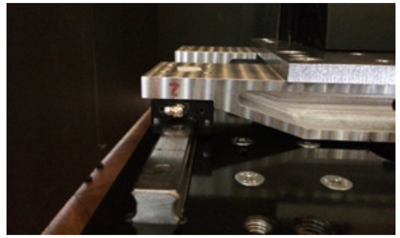
7.1 Evenly space the four carriages so that the structure comprising mast, beams, and silver plate can be attached to the base plate by means of the two beams.



7.2 Carefully lift the vertical structure to a standing position and place onto the base structure.

2 Setting up

Photo guide

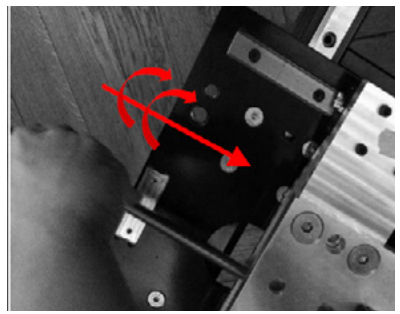


7.3 Carefully align the holes on the carriages to the holes on the beams and make sure there is flat contact. Screw in using **M4 x 16mm**.

Step 8: The z-axis component

The components required in Step 8 are: the threaded rod, the bearings, the bearings fixture and the nut and bolt screws.

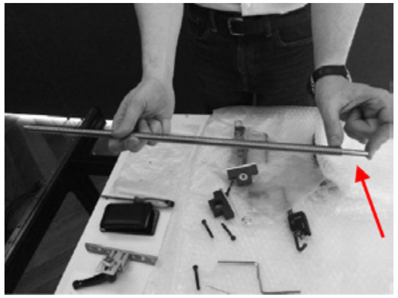
8.1 First, place the two bearing fixtures onto front and back of the base plate; attach them with to it using nut and bolt screws.



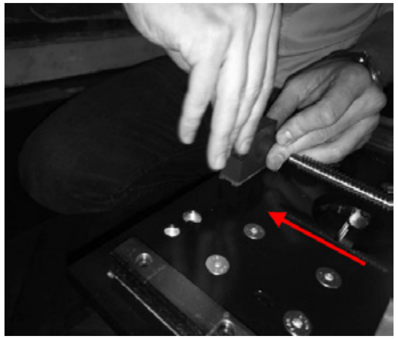
8.2 Now place one of the bearings into the fixture at the front of the scanner.

2 Setting up

Photo guide



8.3 Bring the threaded rod and pass it through the bearing fixture on the back of the plate, and through the first beam. Then, thread it into the second beam until it is close to the front bearing fixture.



8.4 Get the other bearing and insert it on to the rod, now slip the rod with the bearing on it into the bearing fixture. Tighten the screw at the top of the bearing fixture to secure the bearing in place and fix the handle on to the protruding section of the rod.

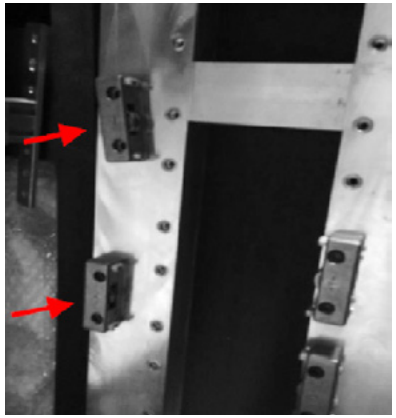
8.5 Rotate the handle to test the sensitivity of the motion. The final result should allow for motion sensitive to a couple of millimetres. If you are not achieving this, loosen or tighten the screw at the top of the bearing fixture and try rotating the handle until the required level of precision is acquired.

Step 9: Attaching the brakes to the backing frame

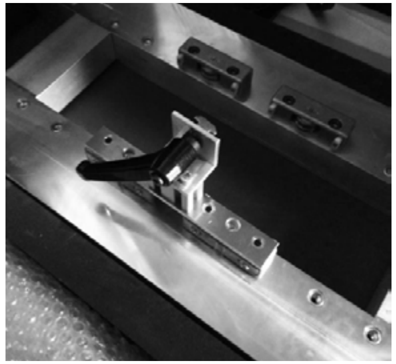
The backing frame goes onto the rails of the mast and its position can be manually adjusted. However, to secure it into position, brakes are needed. A simple mechanical brake system is used to facilitate the process of moving and securing the backing frame. The brake system consists of a handle, an aluminium section, an aluminium angle, a flat bar with perforated holes and a set of accompanying screws.

2 Setting up

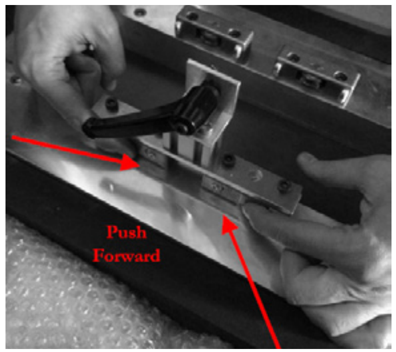
Photo guide



9.1 Start by setting up the brake system: place the flat bar on top of the two carriages on the back of the backing frame.



9.2 Then place the aluminium section attached to the aluminium angle and handle as shown in the image.



9.3 Now pass the screws through the bar and the carriages; screw them into the backing frame using four long screws (two on each carriage) while pushing both the carriages inwards at the same time to make sure that both of them are equidistant from the carriages facing them.

2 Setting up

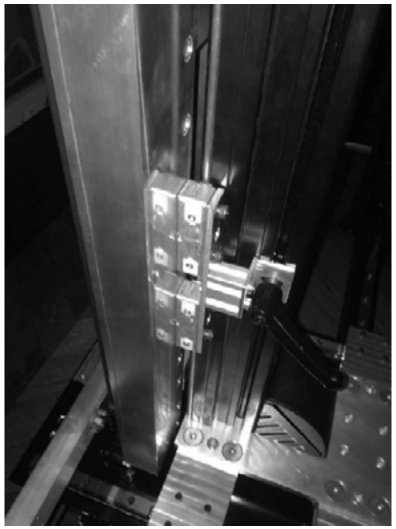
Photo guide

Note that the distance between the carriages must be equal so that the backing frame can move with ease while the rails are connected to all four carriages.

Step 10: Positioning the backing frame

The final step is to slide the backing frame onto the mast. This can be complicated, since most of the time the distance between the carriages is either too tight or too loose to fit on to the rails of the mast.

If the distance between the carriages is too tight then backing frame will not be able to slide on: in this case, loosen the carriages on one side and try to pass it through from the top. If the distance is too great, the backing frame can be placed onto the mast and the distance adjusted while the frame is in position.

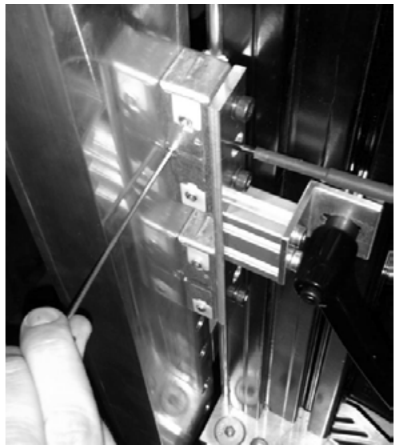


10.1 Slide the frame on to the mast using the guides to position the carriages; make sure the knob from the brakes easily fits inside the grooves on the Lucida mast. Make sure the wheels are touching and rolling on the mast rails.

2 Setting up

Photo guide

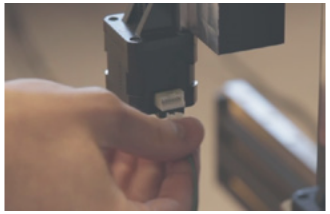
10.2 If the wheels on the carriages need to be tightened or loosened for a better grip to the mast, take the appropriate Allen key and undo the lock in the carriage which allows the wheels to be adjusted.



10.3 Now use a flat head screw driver to adjust the wheels into the desired position and lock structure into place again using the Allen key.

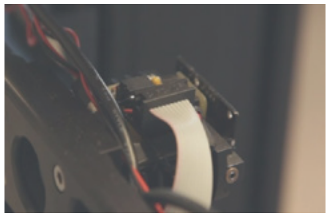
2 Setting up

Wiring

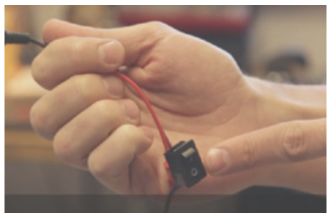
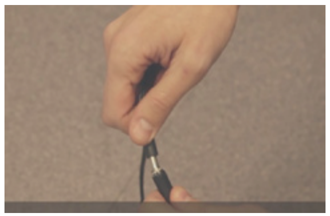



01. Connect the vertical slide motors, connections are interchangeabe
02. Connect the horizontal slide motor


03. Connect the USB cable to Camera 1, note the orientation
04. Connect the USB cable to Camera 2



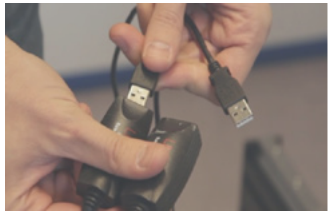
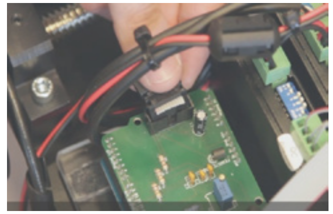

05. Connect the ribbon cable to the PCB on top of the scanner head
06. Plug in the AC transformer, do not connect it to the control box yet

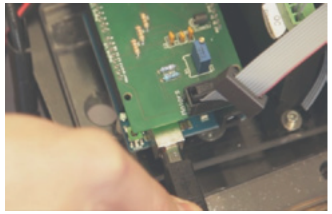
07. Make sure the power switch is turned off
08. Connect the control box to the AC transformer

2 Setting up

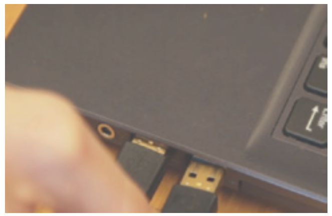
Wiring

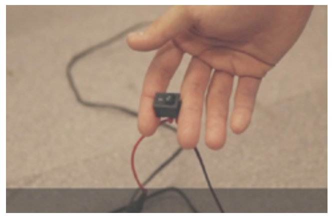
09. Connect the USB cables of the cameras to the extensions
10. Connect the ribbon cable to the PCB of the control box



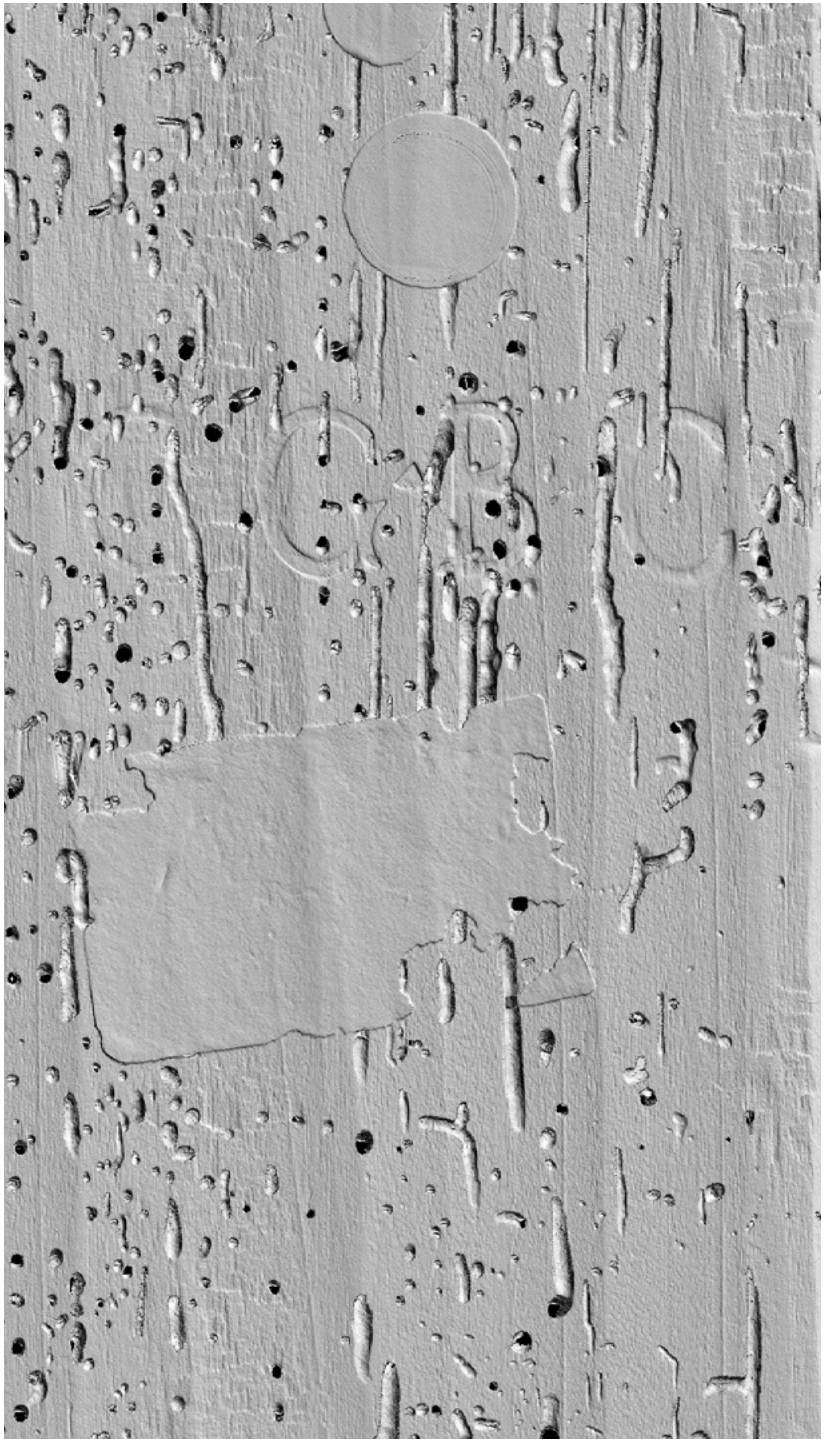

11. Connect the USB cable to the Arduino Proto Shield
12. Connect one camera USB cable to one of the USB 2 ports




13. Connect the other camera USB cable to one of the USB 3 ports
14. Connect the Arduino USB cable to another USB 3 port

15. Connect the mouse to the free USB-SATA port
16. Switch power on, the drivers' status LED will turn green



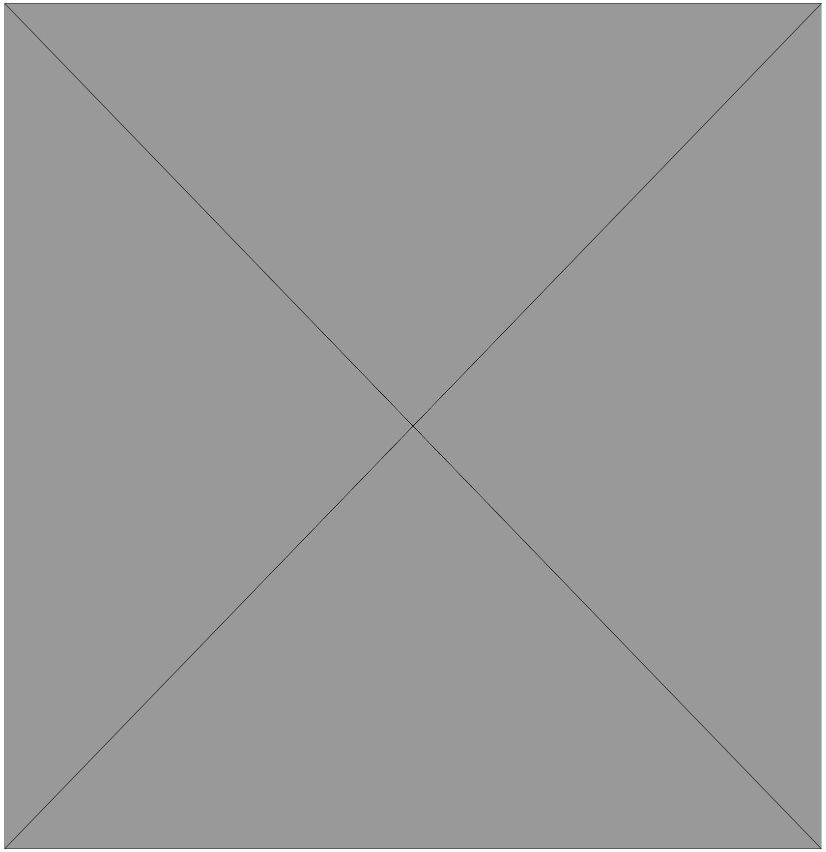
3

Startup process

<<<
San Giorgio (Polittico Griffoni), Ercole de'Roberti, 1472-1473
Tempera on poplar, detail of the back
3D scanned in 2012 in Fondazione Giorgio Cini, Venice

2 Startup

Quick start guide



https://vimeo.com/8261186
password: factum53

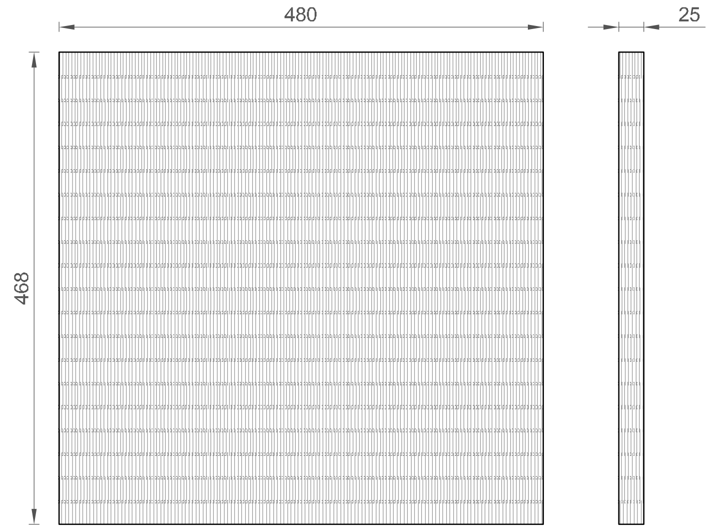
See this video for a a step-by-step tutorial covering these areas:

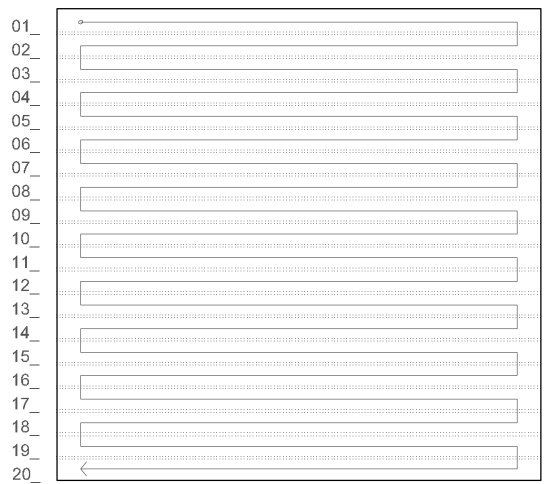
Positioning; Wiring; The Scanning Application; Configuring Arduino's COM Port; How to attach the calibration tool; Calibration; Planning a New Session; New Session.

2 Startup

The scanning tile

The scanning tile consists of a standard area of data composed of 20 horizontal stripes 26 mm wide with a merged overlap of 10%

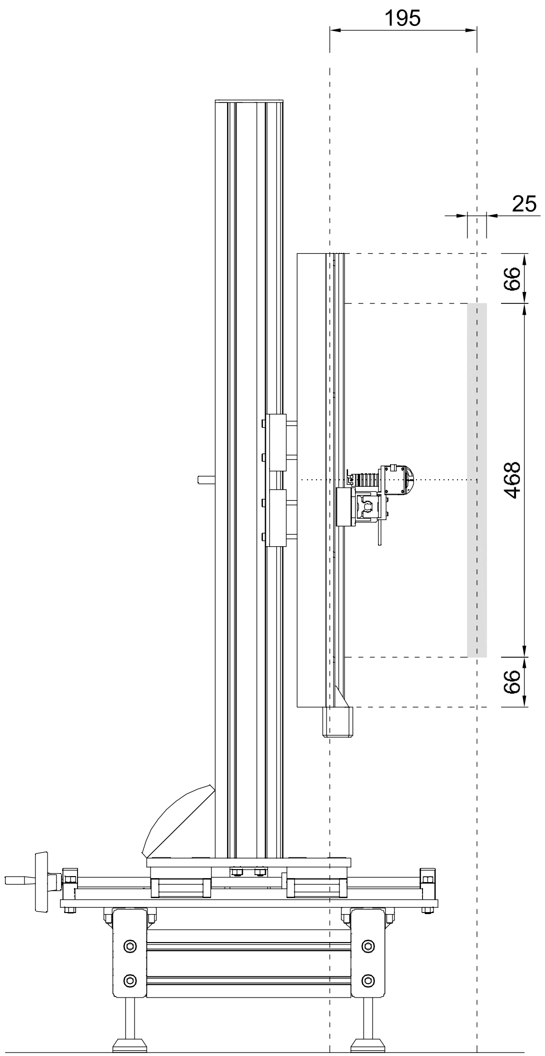




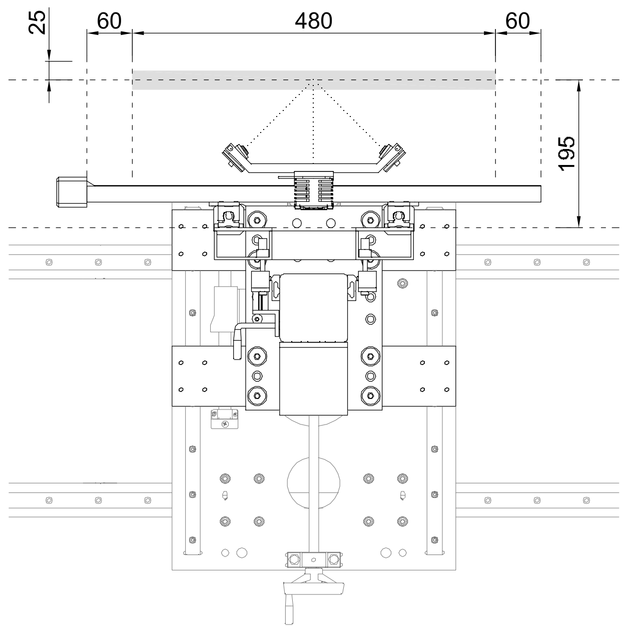
2 Startup

Positioning the scanner

Distance to the target, from the front of the backing frame to the center of the depth of field: 195 mm



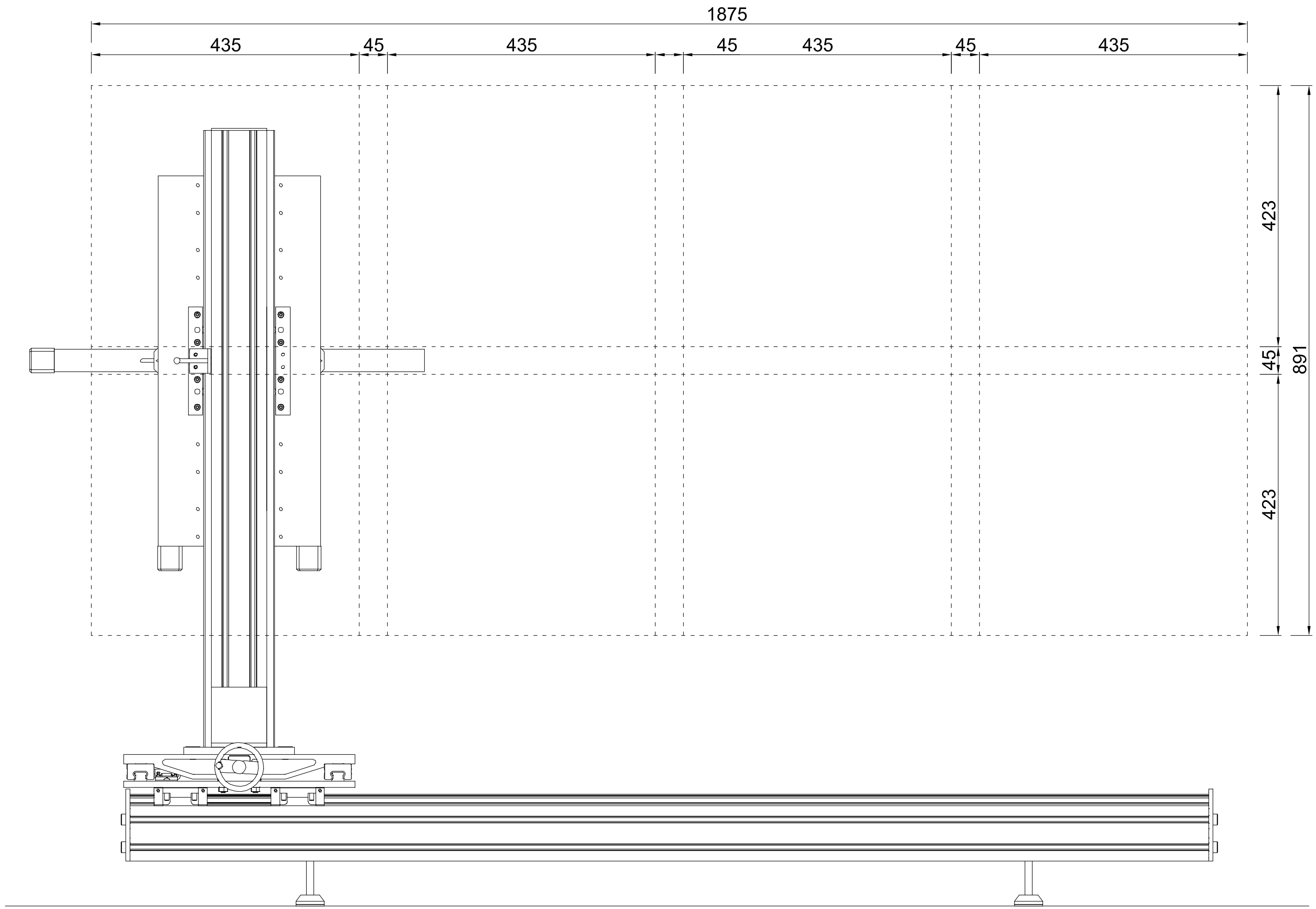
2 Startup



2 Startup

Scanning area

8 full scanning tiles with an approx. 10% overlap: 891 x 1875 mm



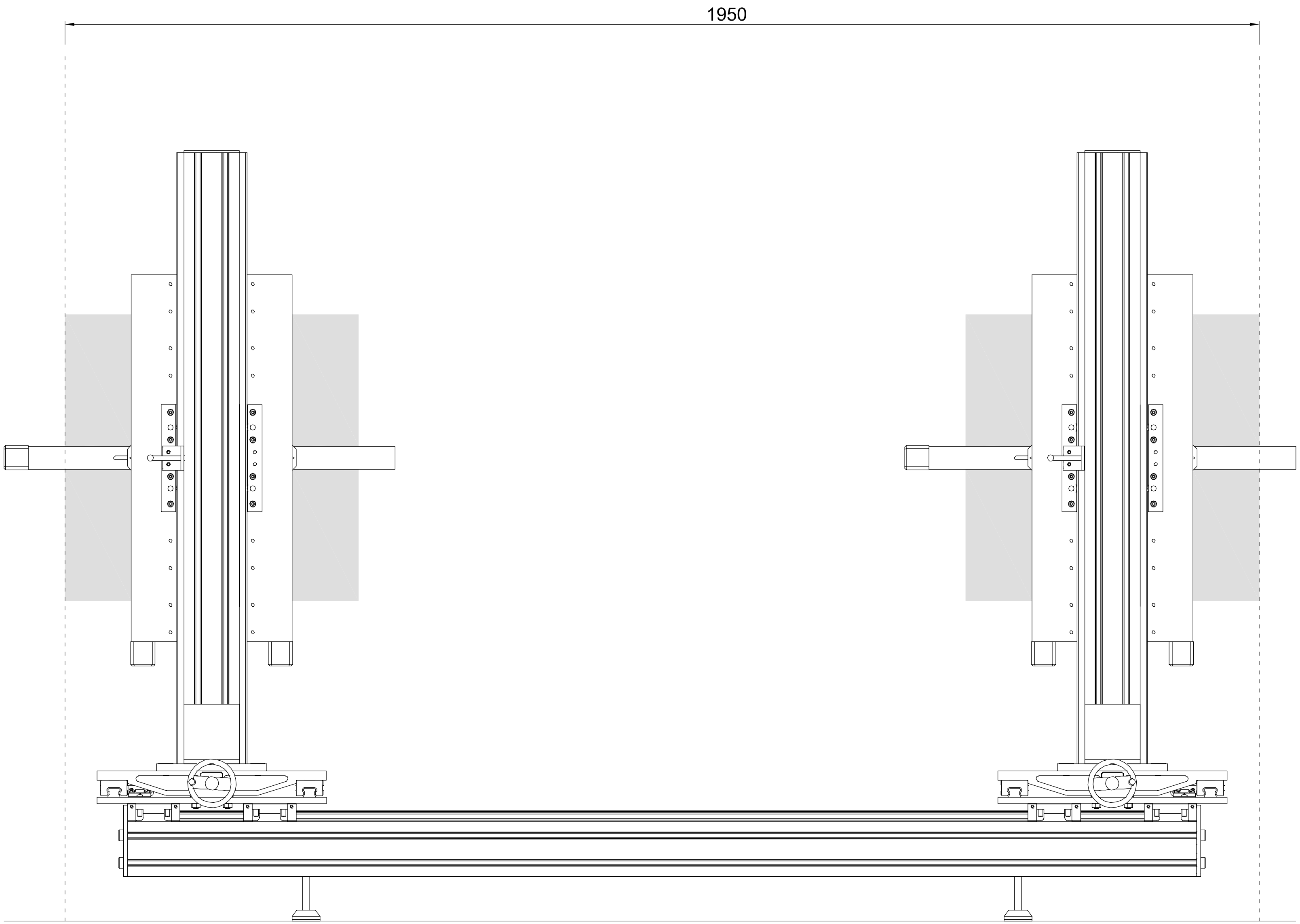
2 Startup

2 Startup

2 Startup

X axis movement

Maximum extent on the X axis: 1950 mm

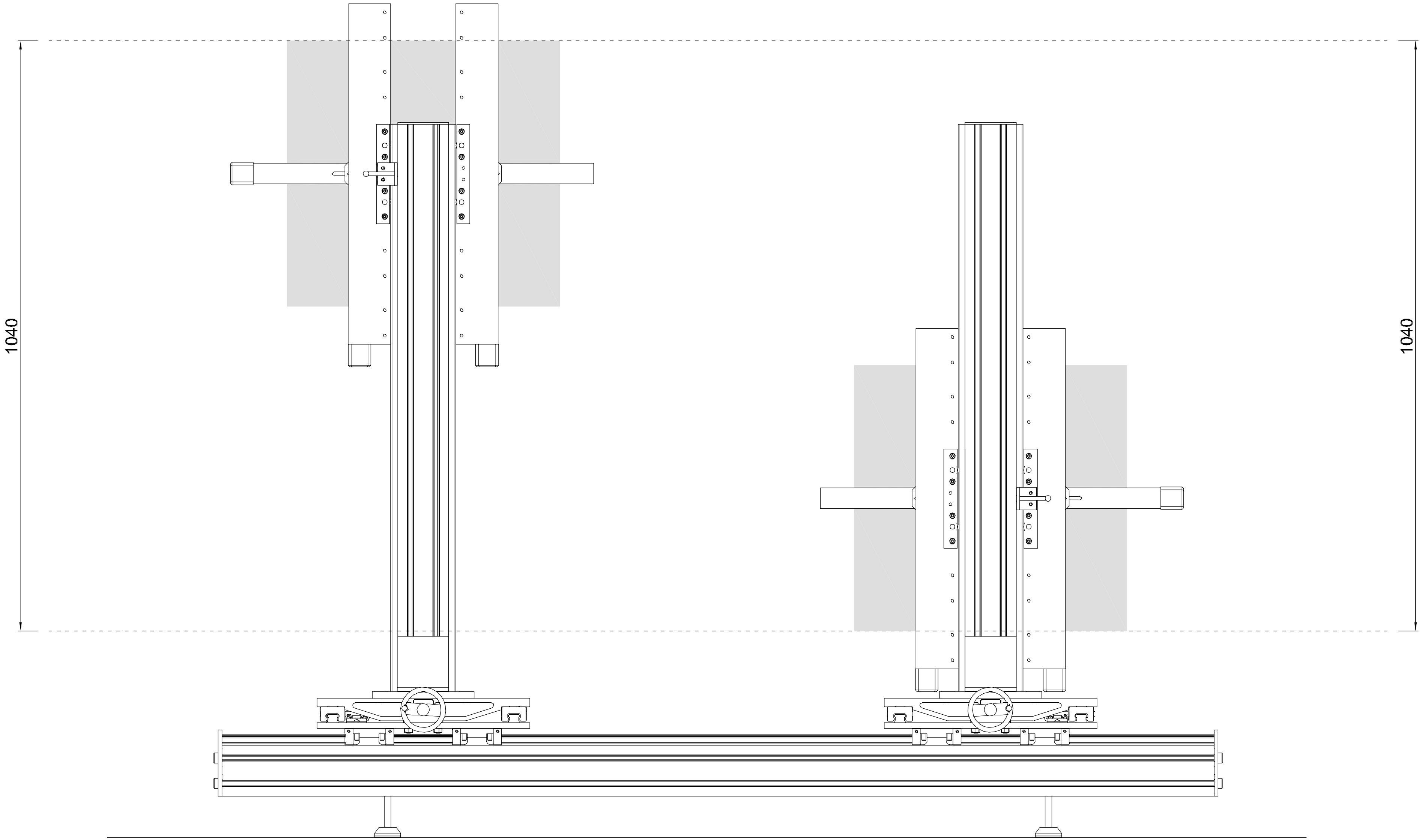


2 Startup

Y axis movement

Maximum extent on the Y axis: 1050 mm

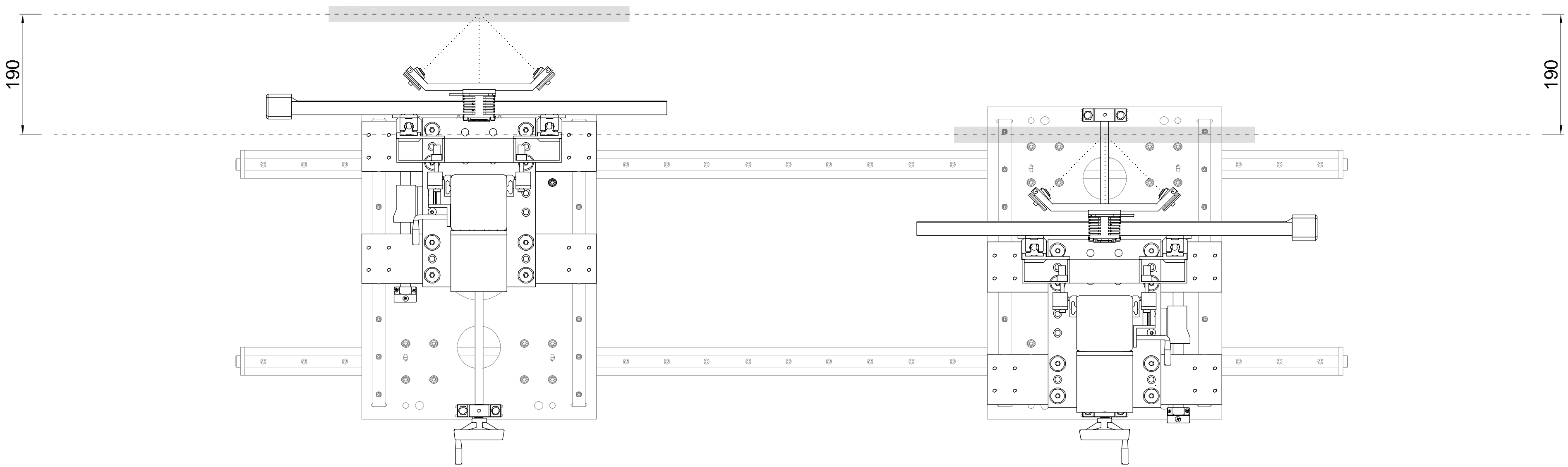
2 Startup



2 Startup

Z axis movemenrt

Maximum extent on the Z axis: 200 mm



2 Startup

2 Startup

Table of Contents: *Operator's Manual*

4

The Scanning Application

<<<

San Vincenzo (Polittico Griffoni), Francesco del Cossa, 1472-1473
Tempera on poplar, detail of the back
3D scanned in 2013 in The National Gallery, London

4 Scanning application

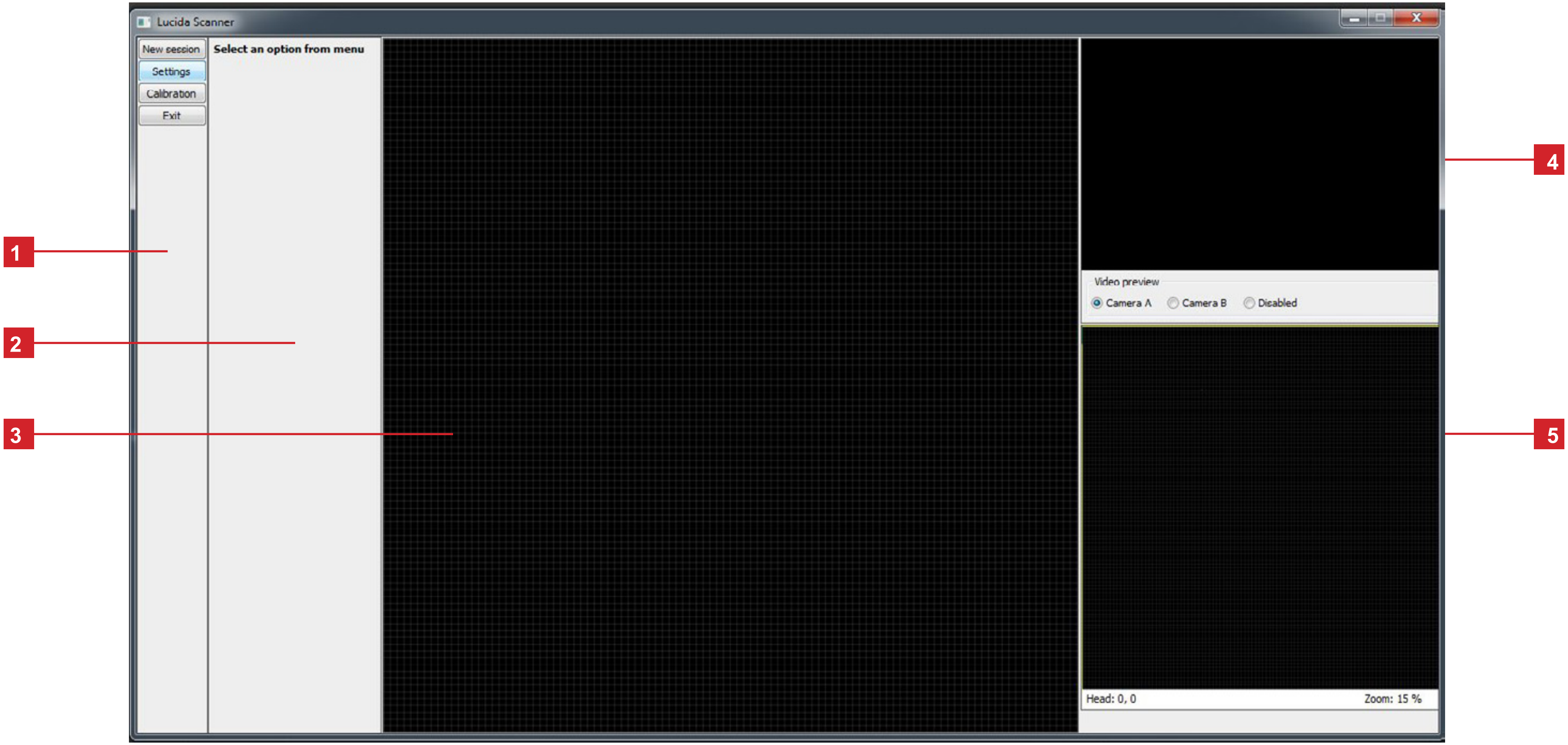
The user interface

Home menu

The graphic user interface of the Scanning Application has been designed to guide the operator step by step throughout the process.

4 Scanning application

1 Menu I: buttons console, first level options (see oposite page)
2 Menu II: buttons console, second level options.
3 Main window: it shows the 3D data as shaded as it is processed.
4 Streaming window: it shows the frames captured by each camera.
5 Navigation window: it shows the progress the scanning session.



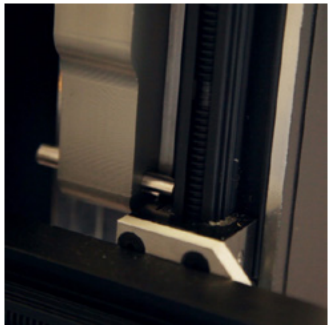
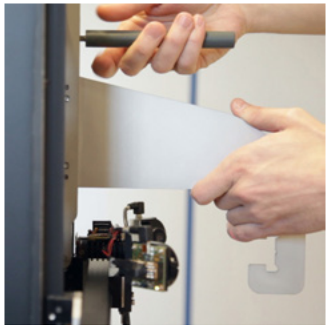
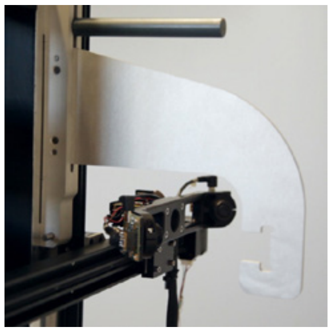
New session: create a new scanning session and movement control.
Settings: adjust settings, movement control and live video streaming.
Calibration: wizard-assisted calibration process.

Reccommended screen resolution: 1920 x 1080 px.

4 Scanning application

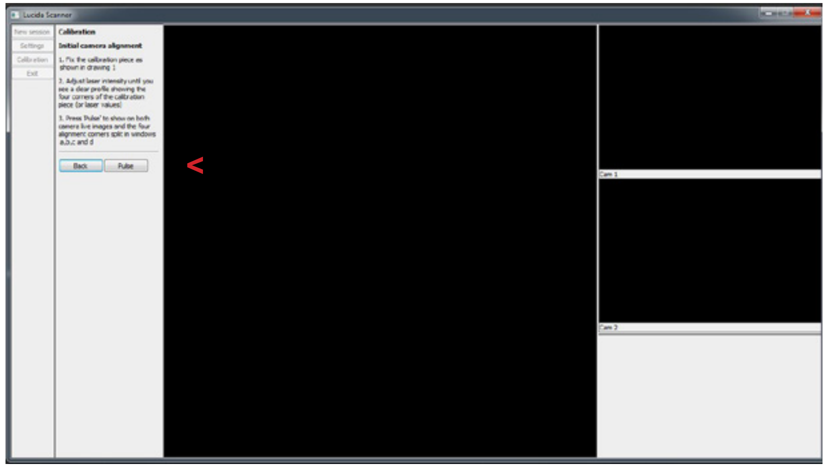
How to attach the calibration tool

1. Align the calibration tool parallel to one of the vertical guides and make sure that both flat sides are fully in contact.
2. Insert the threaded handle and gently tighten the calibration tool to the backing frame through the slot.
3. Move the scanner head upwards (-Y) until the carriage touches the positioning rod of the calibration tool. (See Settings, page 00).
4. IMPORTANT: Once the calibration tool is fixed do not move the scanner head upwards (-Y) as one of the carriages is now locked!
5. Move the scanner head horizontally (-X or +X) until the laser beam hits the centre of the edge of the calibration profile.
6. Adjust the laser intensity until you see a thin, defined line. Keep the tool fixed. Now you are ready to initiate the Calibration process.
7. Once the Calibration process is done simply release the threaded rod and carefully remove the calibration tool from the backing frame.


4 Scanning application

Calibration



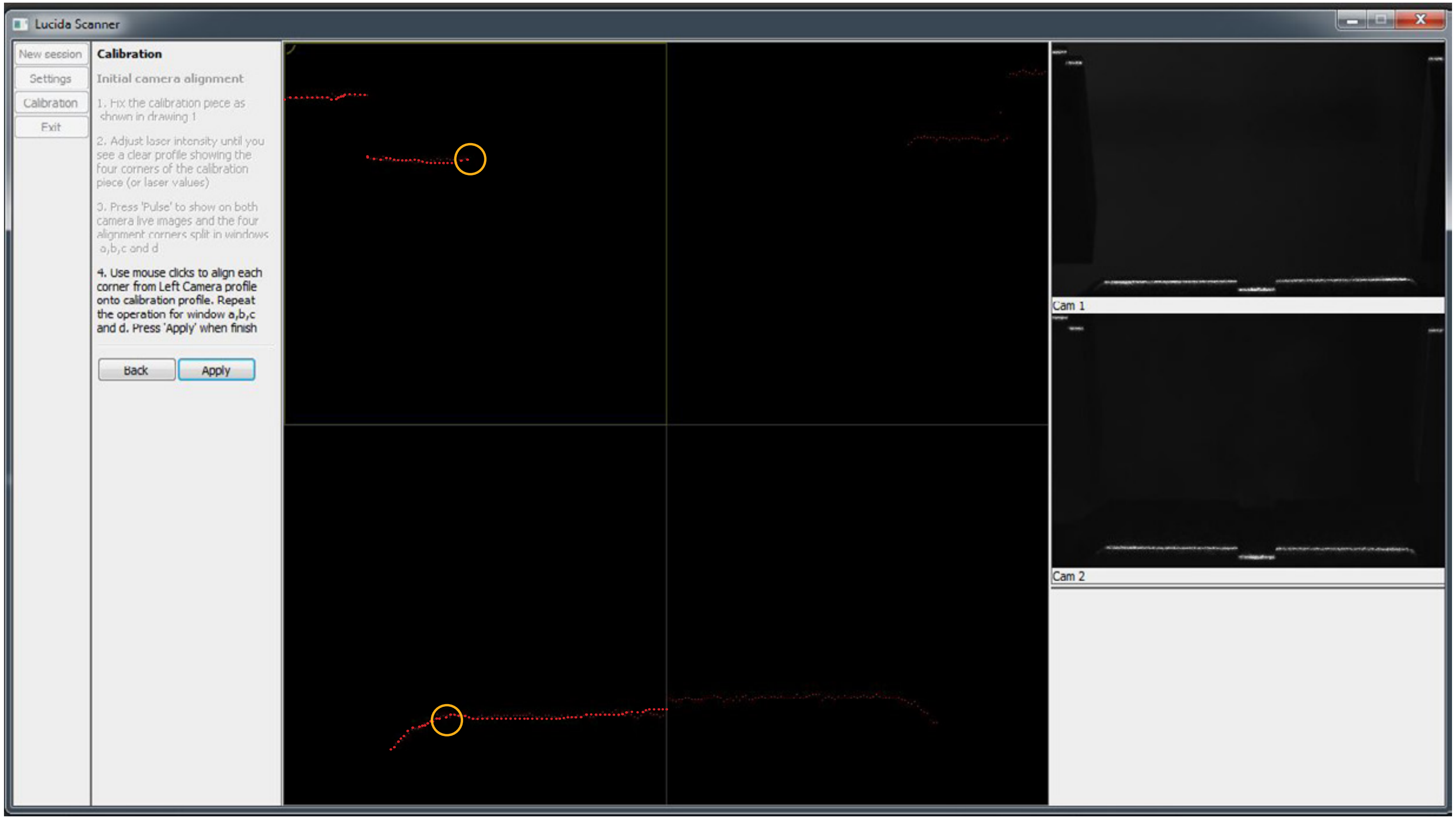
01. Open the Calibration menu and follow the on screen instructions.
02. Press ‘Pulse’ to trigger one shot from each of the two cameras.

03. Check on Cam 1 and Cam 2 that the Calibration profile can be seen completely and the line is clearly defined.
04. If necessary, press ‘Back’ and open the Settings menu to adjust the Laser intensity to a middle level (4-6).
05. Press ‘Back’ and open the Calibration menu again. Press ‘Pulse’.

4 Scanning application

Calibration

06. The four sections in the main window show the four corners of the calibration profile. Red dots represent the view from Camera 1.
07. Mark on the screen the 4 corners for the profile and press 'Apply'



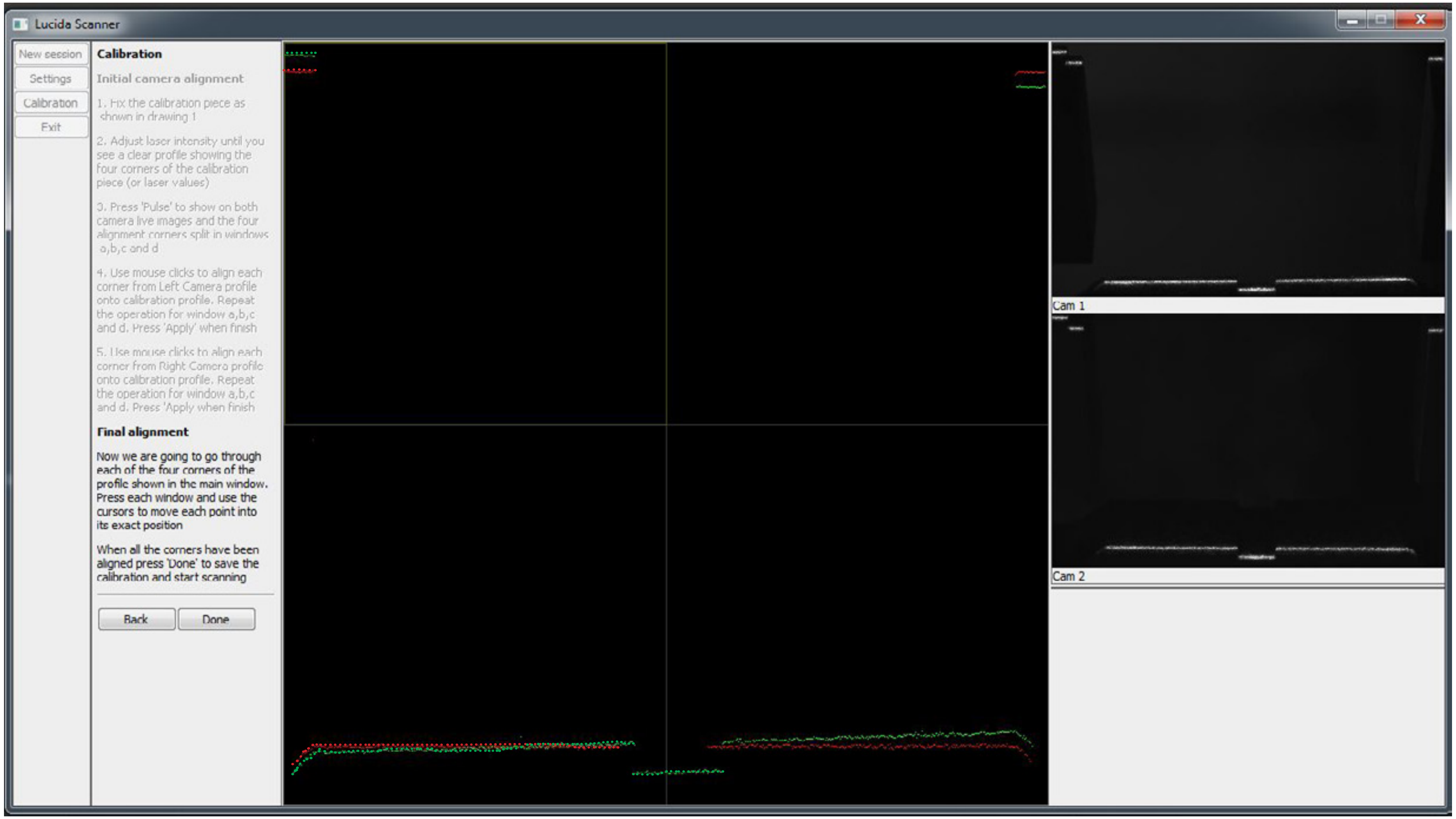
8. Now repeat the operation. Green dots represent the view of the calibration profile as seen from Camera 2.
09. Mark on the screen the 4 corners for the profile and press 'Apply'

4 Scanning application

4 Scanning application

Calibration

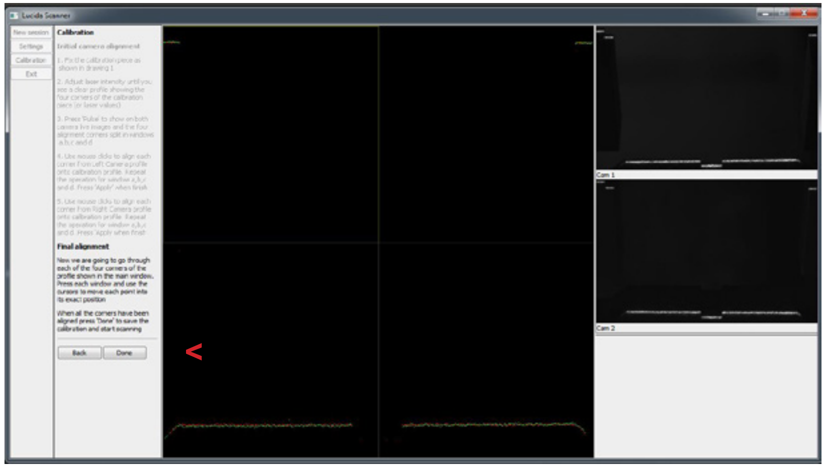
10. The final alignment consists of manually overlapping and aligning the homography (dots) of Cam 2 (green dots) as closely as possible over the homography from Cam 1 (red dots) on each of the 4 corners



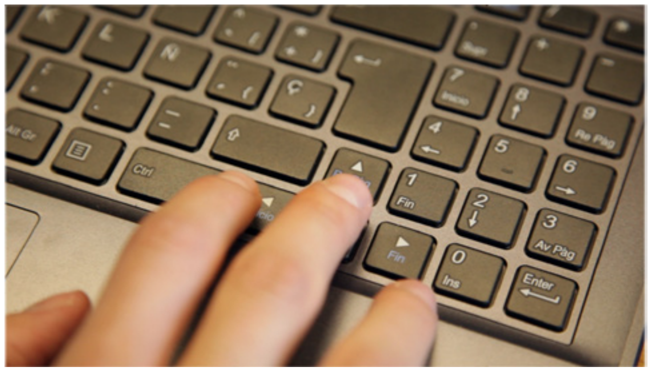
11. Click on one of the 4 corners of the main window and use the arrow keys to place the green dots precisely on top of the red dots.
12. Repeat this operation for each corner as many times as needed..

4 Scanning application

Calibration



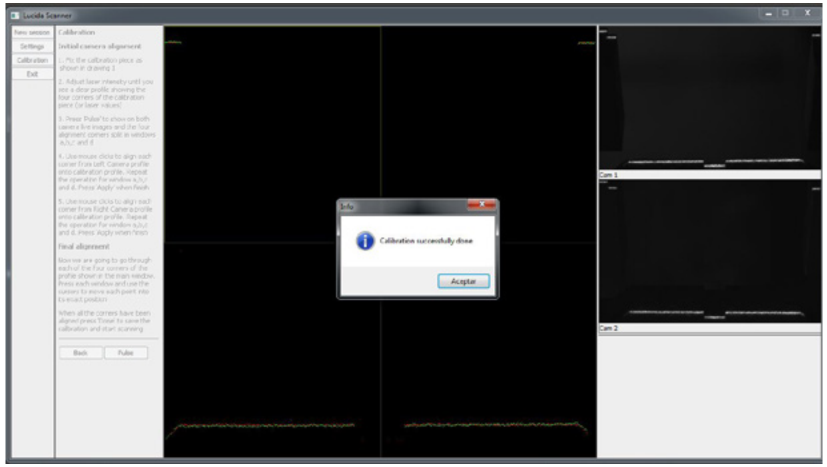
13. The final alignment step should be done carefully and the two homographies must exactly overlap.
14. Take your time to adjust each corner and press then ‘Done’.



If you want to watch videos about the Calibration process please visit:
www.factum-arte.com

4 Scanning application

Calibration



15. ‘Calibration successfully done’ will appear on screen.
16. Press ‘Accept’. The new calibration matrix has been saved.
17. The scanning application will go back to the Home menu.


```
▼<CalibrationFile>
  ▼<Homography_a>
     <h1>0.365121</h1>
     <h2>-0.0398668</h2>
     <h3>-8.71091</h3>
     <h4>0.00298134</h4>
     <h5>0.481645</h5>
     <h6>-8.08913</h6>
     <h7>4.56469e-007</h7>
     <h8>-0.000282602</h8>
     <h9>1</h9>
   </Homography_a>
  ▼<Homography_b>
     <h1>0.368153</h1>
     <h2>-0.0386434</h2>
     <h3>-8.05935</h3>
     <h4>0.00261111</h4>
     <h5>0.484864</h5>
     <h6>-9.88766</h6>
     <h7>4.82451e-006</h7>
     <h8>-0.000283553</h8>
     <h9>1</h9>
   </Homography_b>
 </CalibrationFile>
```


18. The calibration matrix is saved as an XML file in the folder Data.

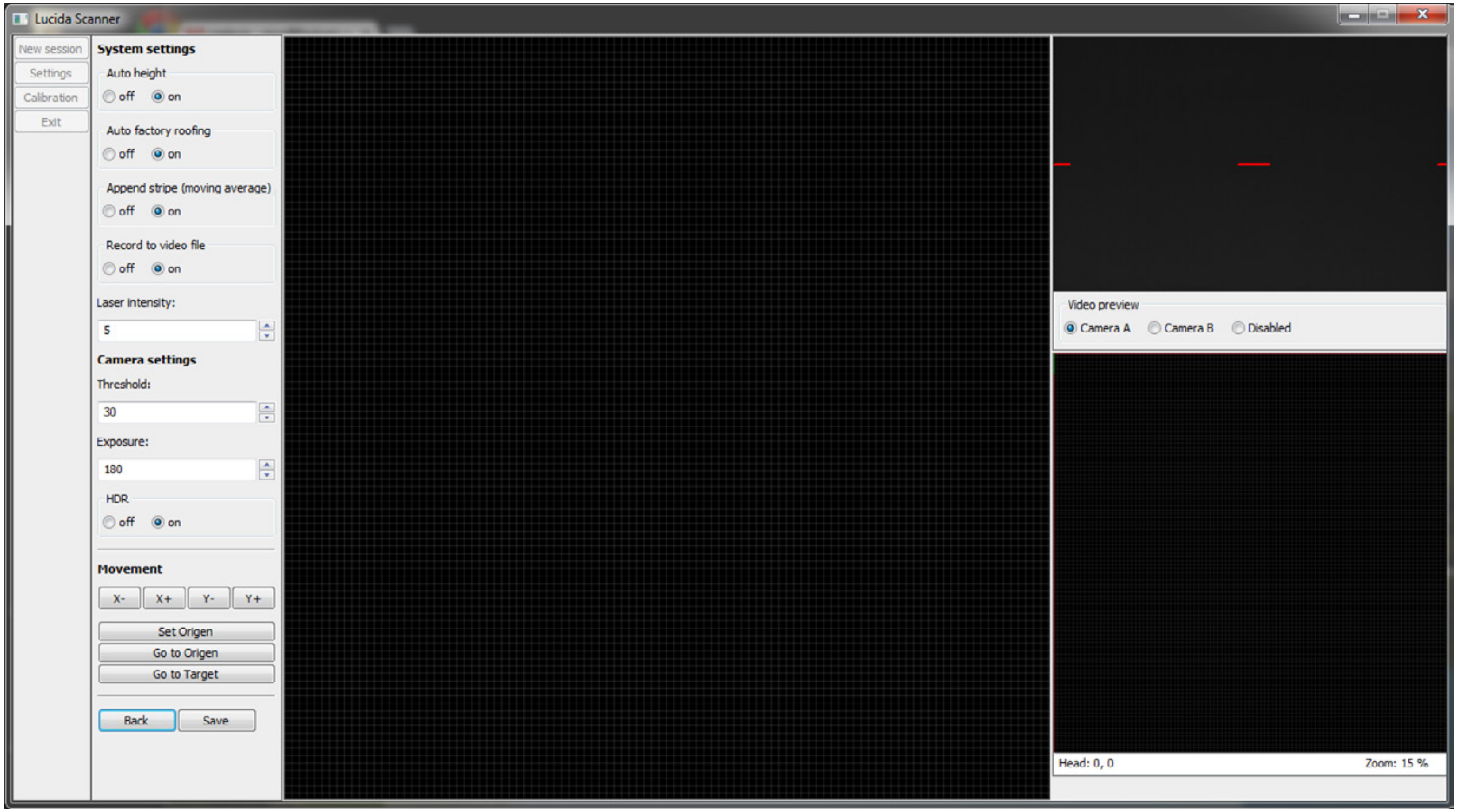
4 Scanning application

Settings

From the Settings menu you can modify certain parameters before starting a New Session. The Settings are set by default as shown in the image below.

4 Scanning application

System settings: to turn Off/On internal processes in the application
Camera settings: to adjust parameters of the video capture.
Movement: to control the displacement of the scanner head.



The Video preview window shows live streaming from each of the two cameras in order to check parameters like the Laser intensity, etc. The red lines help to determine the center of the depth of field.

Press 'Save' or 'Back' to go the Home menu once you have finished..

4 Scanning application

System settings

Auto height
Options: Off / On (default: On).
Auto factory roofing
Options: Off / On (default: On).
Append stripe
Options: Off / On (default: On).
Record to video file
Options: Off / On (default: On).

Laser intensity
Range: 1 to 10.

What is the correct Laser intensity level?
The Laser intensity level should be set according to the surface characteristics of the object to scan and its capacity to absorb light. Lower levels of Laser intensity make the laser beam thinner (Fig. 1), which can result in loss of data. Higher levels make the laser beam thicker and brighter (Fig. 2) but increase the amount of so called speckle-noise, which can reduce the quality of the scan. Therefore, the correct Laser intensity level for a particular object is the minimum possible to record all data without loss.

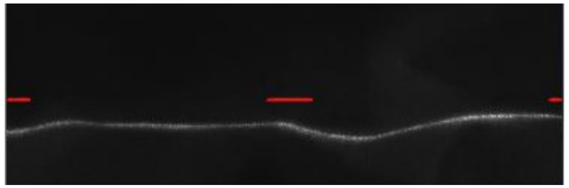


Fig. 1

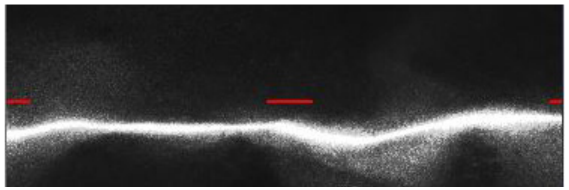


Fig. 2

4 Scanning application

Camera settings

Threshold
Sets the segmentation from the grayscale image.
Range: 1 to 000 (default: 030).
Exposure
Sets the quantity of light reaching the camera sensor.
Range: 1 to 000 (default: 180).
HDR
Captures two frames at different exposure levels and combines them to produce an image representative of a broader tonal range.
Options: Off / On (default: On).

Movement

X- / X+ / Y- / Y+
Moves the scanner head in the four directions of the scanning plane
Set origin
Sets the current position of the scanner as the new 0,0 position
Go to origin
Moves the scanner head to the current 0,0 position
Go to target
Moves the scanner head to an X,Y position marked on the window

The position of the scanner head is shown in the Navigation window.

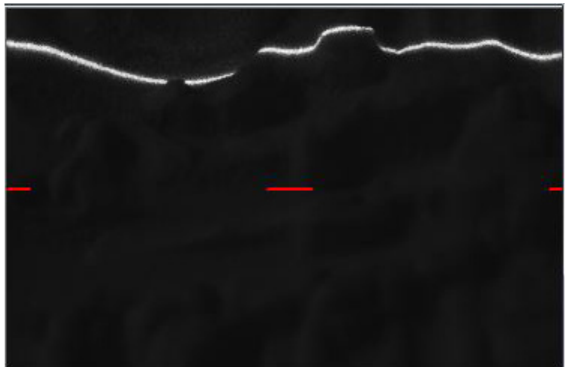
IMPORTANT:
The Scanning Application remembers the origin (0,0 position) if you start a New Session and even if you Exit the Application. The original position will only be *forgotten* if the Arduino cable is disconnected.

Therefore, do not disconnect the Arduino cable if you intend to do successive recording sessions and keeping the scanner head at the same 0,0 position.

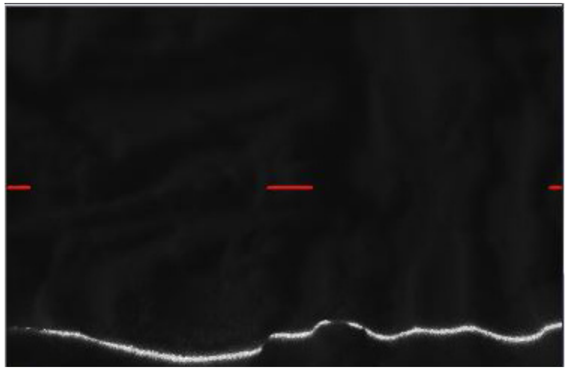
4 Scanning application

Planning a New session

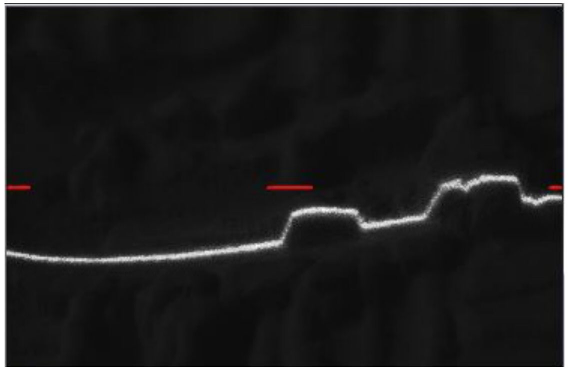
01. Set the scanner at the right distance to the object, so the laser beam is always visible within the Preview window:



Too close...



Too far...

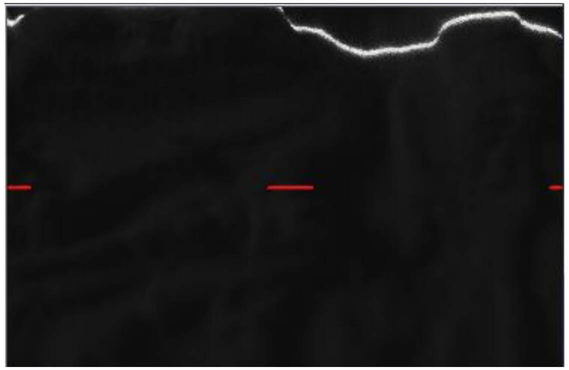


Correct distance!

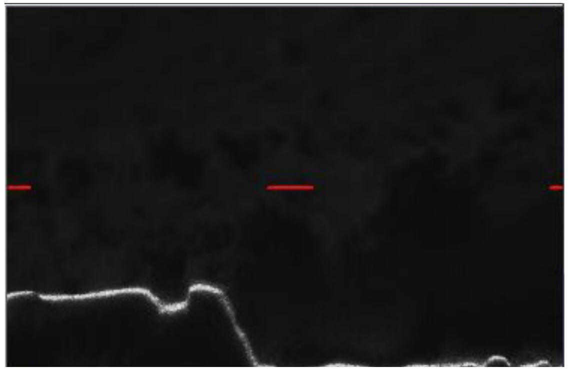
4 Scanning application

Planning a New session

02. If the laser beam disappears from the Preview window this means the recording is out of the 25 mm (depth of field) range:



Out of range.
Too close.



Out of range.
Too far.

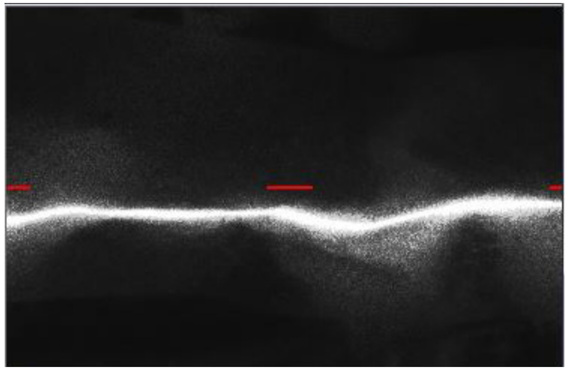
IMPORTANT: Before starting a New Session check the distance to the painting on the whole area you wish to scan. Use the Preview window in the Settings menu to make sure that the laser beam is always within the cameras' depth of field.

03. Confirm that the backing frame of the scanner is parallel to the object and then rotate the hand-wheel to move the scanner forward or backwards along the Z axis, until you get to the right distance.

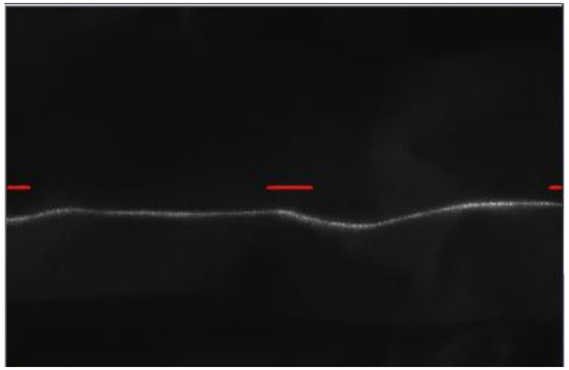
4 Scanning application

Planning a New session

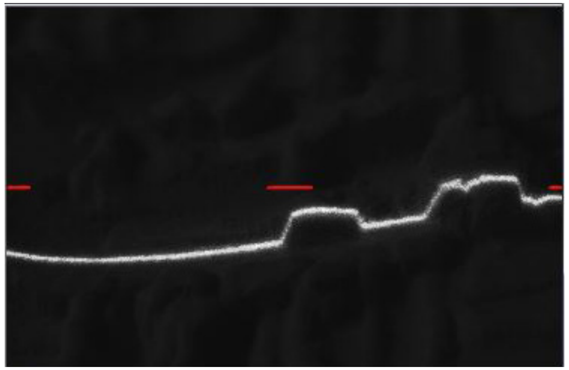
04. Now set the Laser intensity at the correct level for the object that you wish to scan - it changes with each material -, for example:



Laser intensity: 10
Too high...



Laser intensity: 1
Too low...

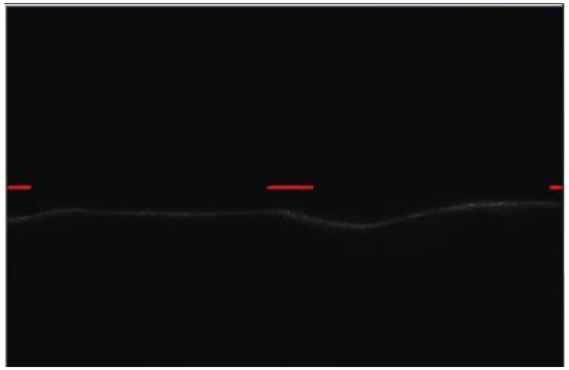


Laser intensity: 3
Good!

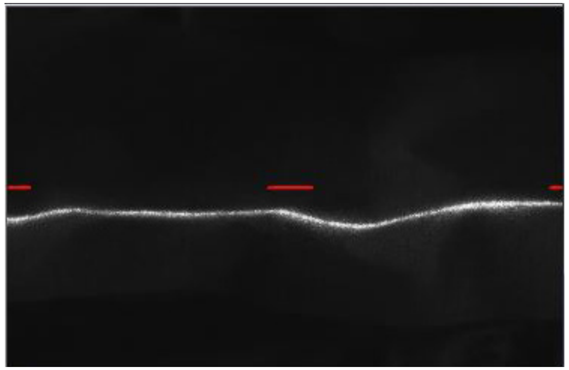
4 Scanning application

Planning a New session

05. You can also adjust the Camera settings (default values are Threshold: 30, Exposure: 180) for different results, for example:



Laser intensity: 3
Threshold: 30
Exposure: 20



Laser intensity: 3
Threshold: 255
Exposure: 180

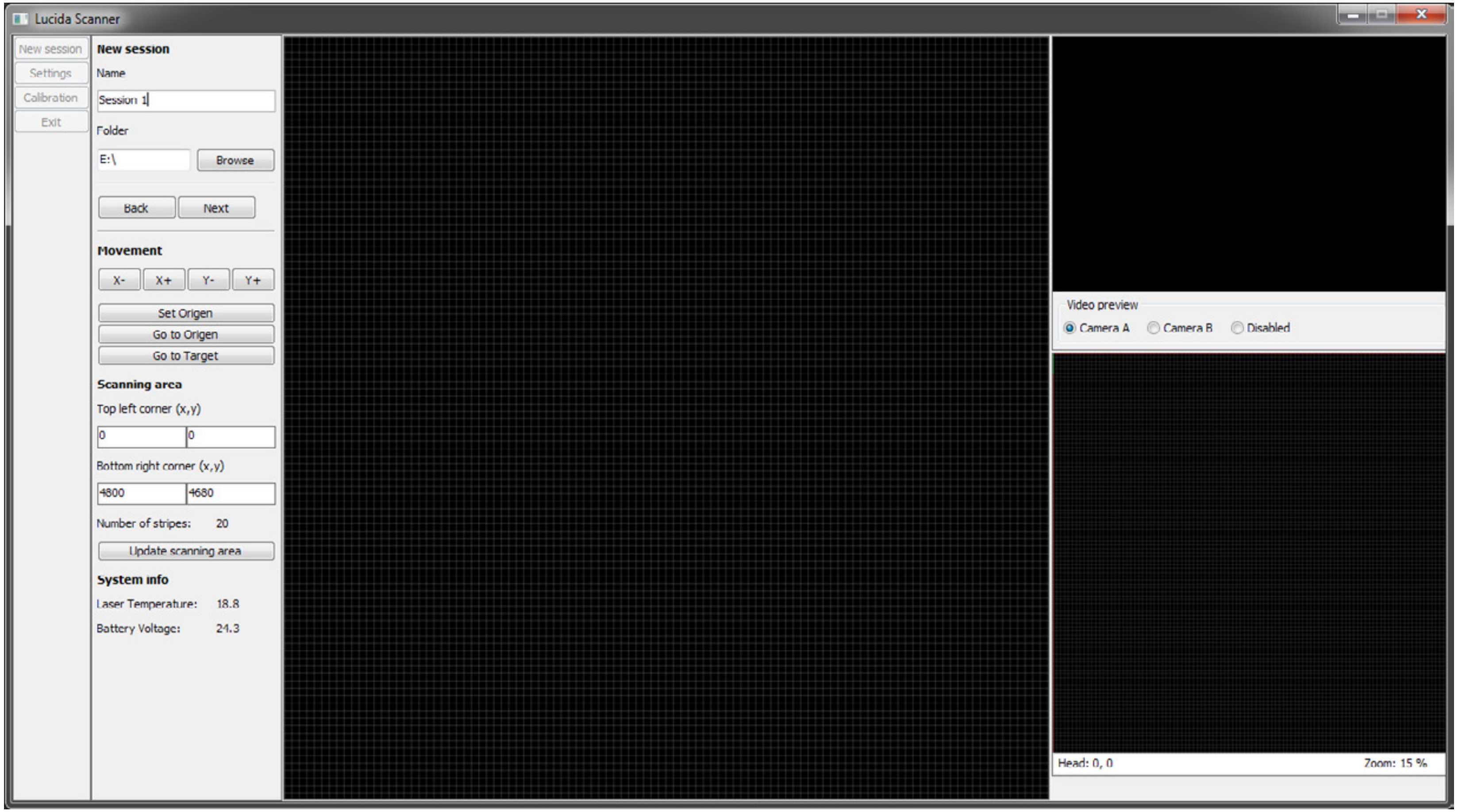
IMPORTANT: Before starting a New Session check the Laser intensity and the Camera settings on the whole area you wish to scan. Slight variations in the material, color, tone, shine, etc. may result in loss of data or excess speckle noise. If there is large variation in the different areas, choose values that will allow you to scan more area.

If you want to watch videos about Planning a New session please visit: www.factum-arte.com

4 Scanning application

New session

Before starting a New Session make sure that the Calibration and the Settings are properly saved. Press ‘New session’ to record a new scan. The Scanning Application will guide you through the process.



IMPORTANT: Make sure that the laptop and the scanner are properly connected to mains and/or the batteries are fully charged before starting a New Session.

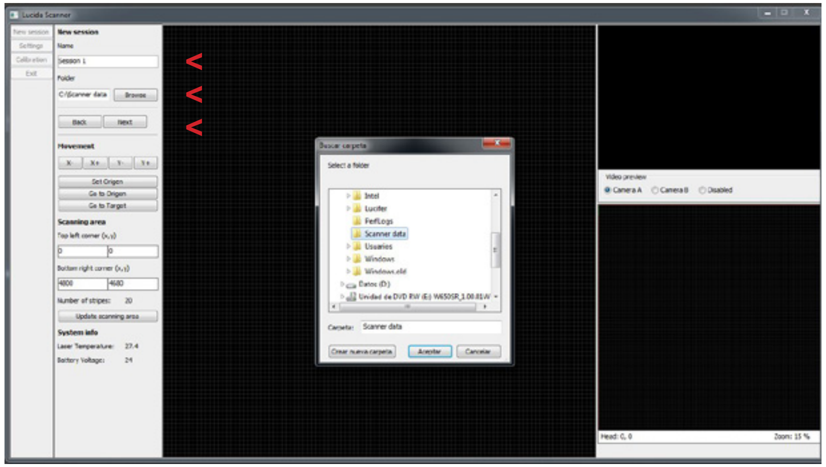
4 Scanning application

New session: inserts Name and path in the session Folder.
Movement: controls the Movement of the scanning head.
Scanning area: controls the Scanning area and Number of stripes.
System info: indicates Laser temperature and Battery voltage.

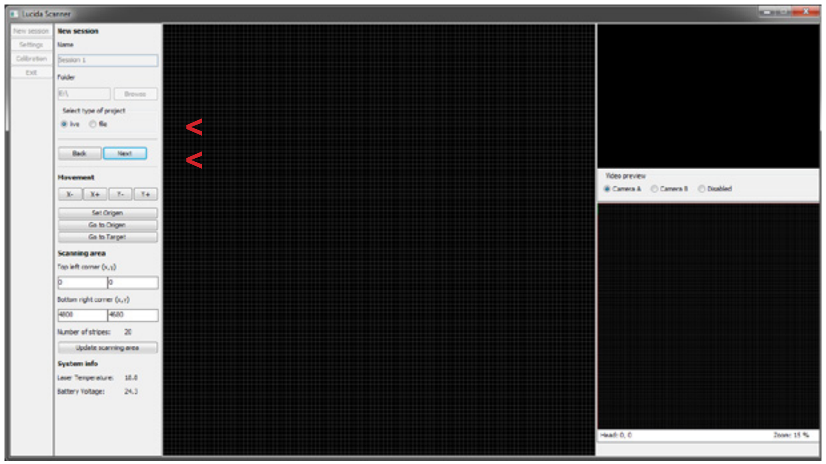
Press ‘Back’ to go to the Home menu if you wish to modify Settings.

4 Scanning application

Scanning a tile



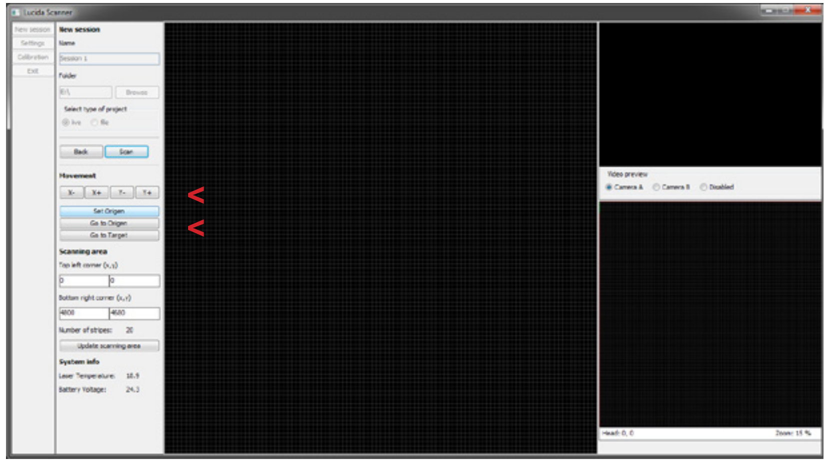
01. Type the name of the new scanning session
02. Press ‘Browse’ to select a folder where the session will be saved
03. Press ‘Next’.



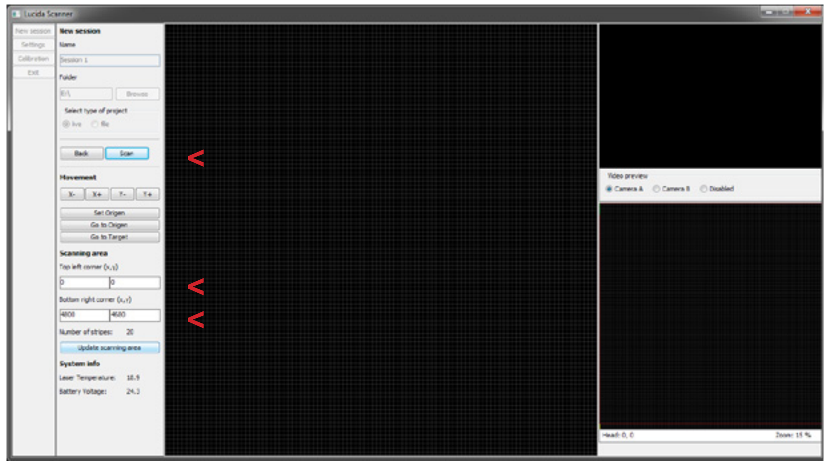
04. ‘Select type of project’. Click ‘Live’ if you want to create a session with live video. Click ‘File‘ if you want to create a session using a pre-recorded video file (default: Live). Press ‘Next’.

4 Scanning application

Scanning a tile



05. Use the arrow keys to position the scanner head at the beginning (top-left corner from the user’s point of view) of the scanning area.
06. Press ‘Set origin’. The position of the head is now set to 0,0.

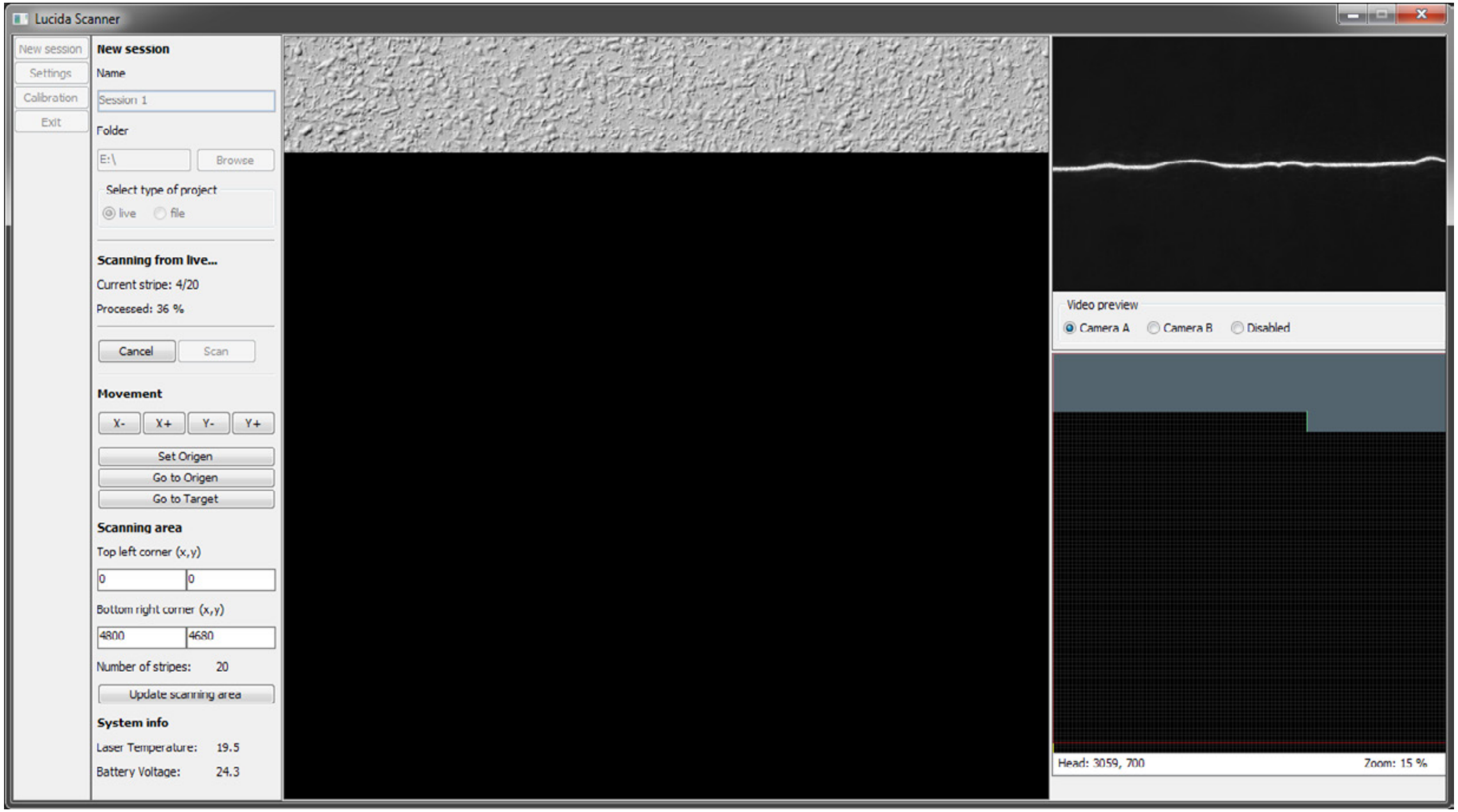


07. Scanning area. The default scanning area is set to one tile:
Top left corner (x, y): 0,0; Bottom right corner (x, y): 4800, 4680.
08. For scanning a tile don’t modify the Scanning area. Press ‘Scan’.

4 Scanning application

Scanning a tile

Once you press Scan the message ‘Scanning from live...’ will appear on screen and a full tile of 20 stripes will be recorded automatically. This process will take approximately 1 hour to complete.



The Application will indicate the progress of the session as follows:
‘Current stripe’: from 1 to 20 and
‘Processed’: percentage of stripe recorded.

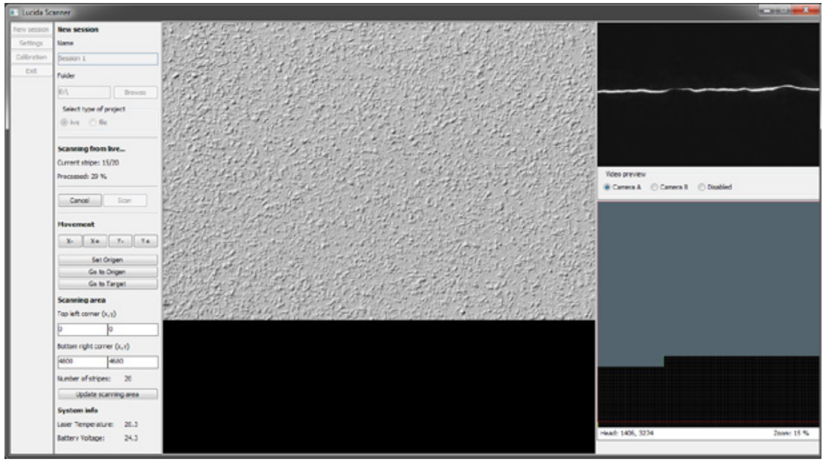
4 Scanning application

Live information of the progress of the session:
Streaming window: shows the frames captured by each camera.
Navigation window: shows the progress the scanning session.
Main window: shows a rendering of the 3D data as it is processed

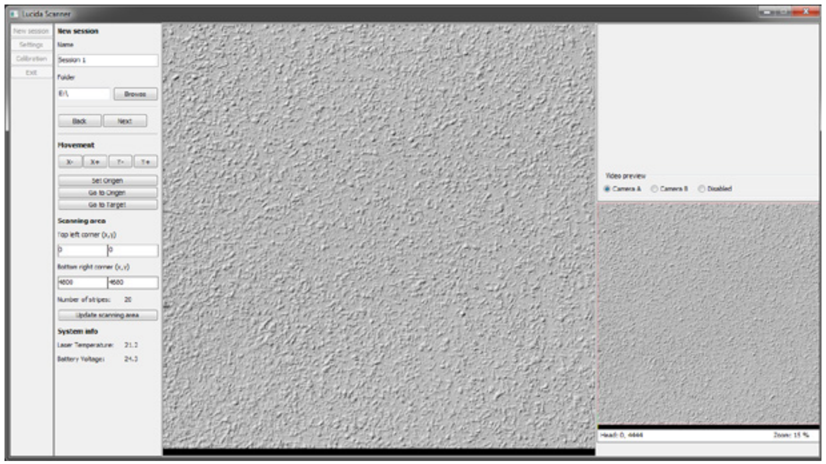
IMPORTANT: Do not press any button in the Application while scanning. If you wish to stop the process at any time press ‘Cancel’. You will need to start a New session if you wish to continue scanning.

4 Scanning application

Scanning a tile



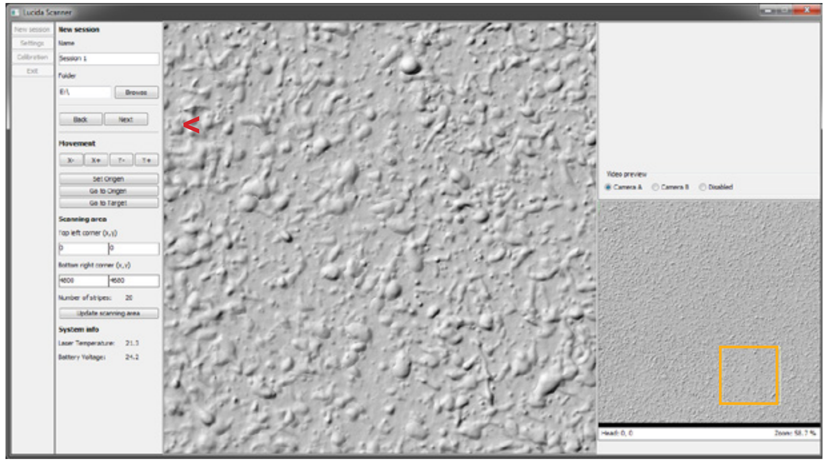
09. The rendering of the processed 3D data is shown in the Main window at the end of each stripe. If you Cancel a session you will lose the data of the current stripe, but the previous stripes are saved.



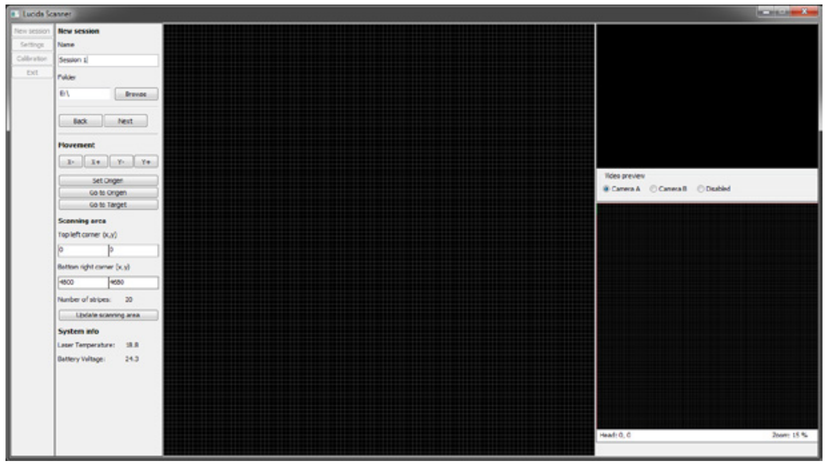
10. When the tile is finished the full rendering of the scanned tile will also appear in the Navigation window, as well as in the Main window. At this point he data is already saved, no further action is needed.

4 Scanning application

Scanning a tile



11. Click in the Navigation window to zoom on the scanned data and use the mouse wheel to zoom in and out the rendered image.
12. Drag in the Navigation widow to pan through the rendered image.



13. Press ‘Back’ to go to the Home menu. The rendered images in the Navigation window will remain and the Main image will disappear.
14. If you press ‘New Session’ all the windows will reset.

4 Scanning application

What’s in the session folder

The session folder after scanning a tile contains the following files:

Session 1.ris
3D data of the tile in RIS format.

Session 1.xml
Text information about the session.

Session 1_00.avi
(...)
Session 1_19.avi
Raw video files of each of the 20 stripes recorded by the 2 cameras.

Session 1_depthMap_16b.tiff
3D data of the tile in a depth map format in 16 bits.

Session 1_depthMap_32b.tiff
3D data of the tile in a depth map format in 32 bits.

Session 1_shaded.tiff
3D data of the tile as a render with simulation of relief.

homography_calibration.xml
Homography matrix of this session’s calibration.

system.txt
Text information about the session.

4 Scanning application

Re-scanning a specific area

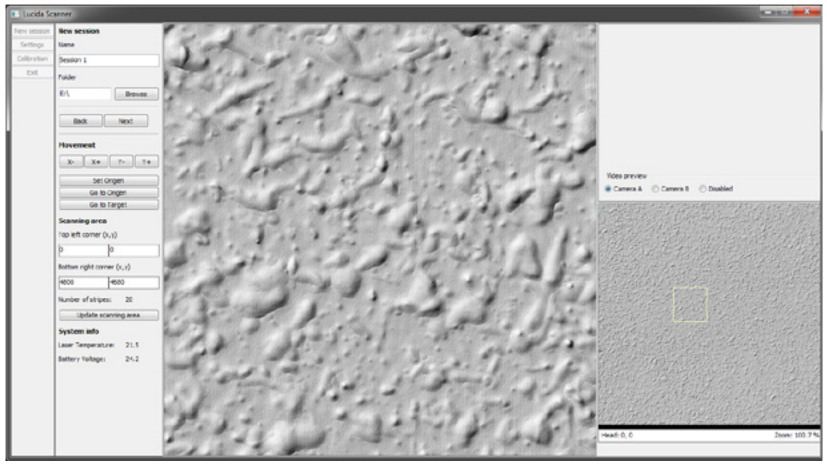
When is it necessary to re-scan a specific area?
A good scan captures as much information as possible. Captured data is represented on the screen with a grey tone whereas absence of data is shown as black.

If you see a black area in your data it is necessary to re-scan. The most common reasons for data loss that are:

- The area is out of the depth-of-field (too close or too far from the scanner). Solution: move the Z axis accordingly and re-scan it.
- The laser intensity is too low to capture the particular color or material (usually dark tones). Solution: increase the Laser intensity level and re-scan.

Other common reasons for re-scanning a specific area could be:

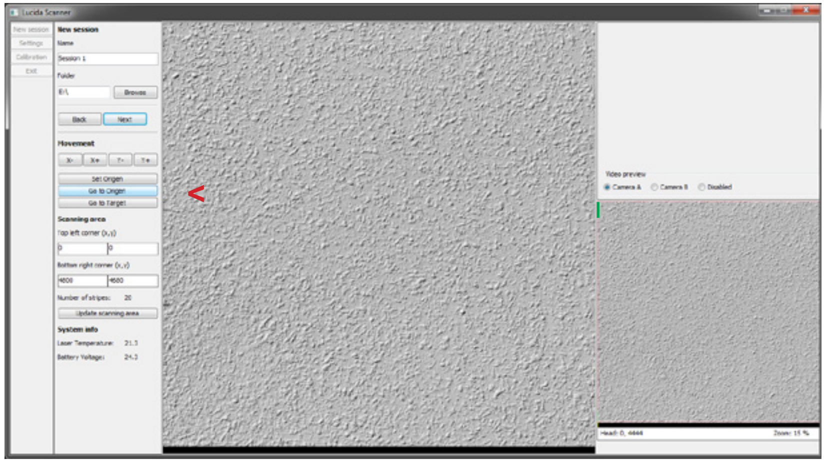
- Strong vibrations caused local distortion of data (vertical lines).
- Area presents too much speckle noise and needs to be re-scanned with a lower laser intensity.



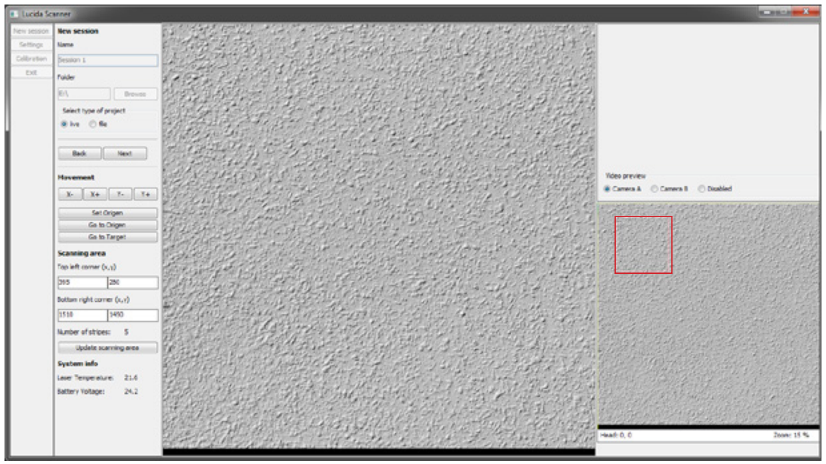
15. Do not press ‘Back’. This will take you to the Home menu and the renders will disappear. You will need them for referencing.
16. Repeat steps 01 to 04. Do not repeat an existing Folder name.

4 Scanning application

Re-scanning a specific area



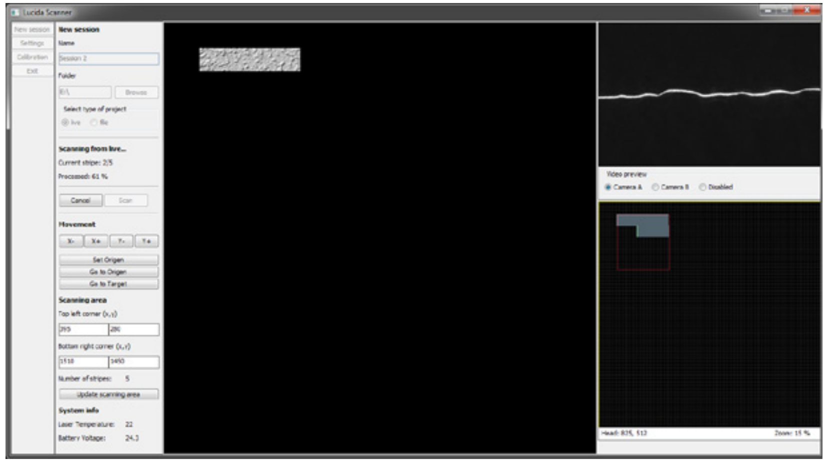
17. Click ‘Go to origin’. The head will go to the last session’s origin. Do not disconnect the Arduino or you will lose the origin 0,0.
18. Click on the Navigation window and zoom out completely



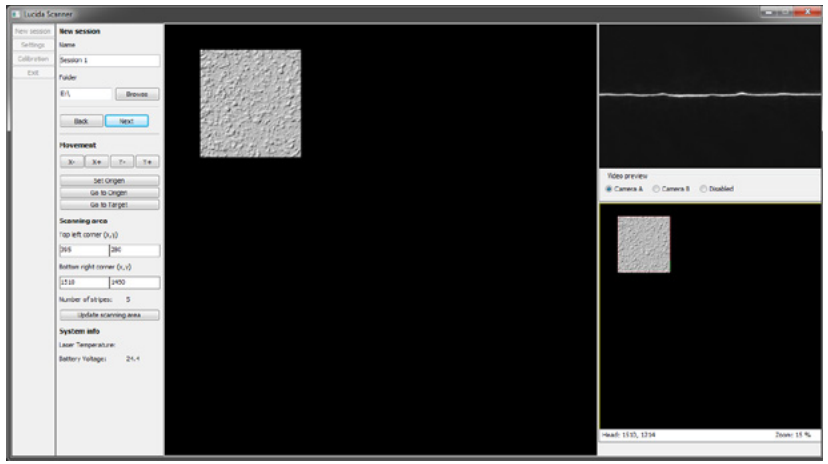
19. Select a specific area to scan: you can do this by clicking in the Navigation window and dragging to draw a rectangle or by typing the (x, y) coordinates of the ‘Top left corner’ and ‘Bottom right corner’.

4 Scanning application

Re-scanning a specific area



20. Note that the (y) coordinate of the ‘Bottom right corner’ will be automatically increased to match a certain ‘Number of stripes’.
21. Press ‘Update scanning area’. Press ‘Scan’.



22. The specific area being recorded will appear in both the Main and the Navigation window at its relative location within the tile.
23. When the scanning process is finished, repeat steps 11 to 14.

5

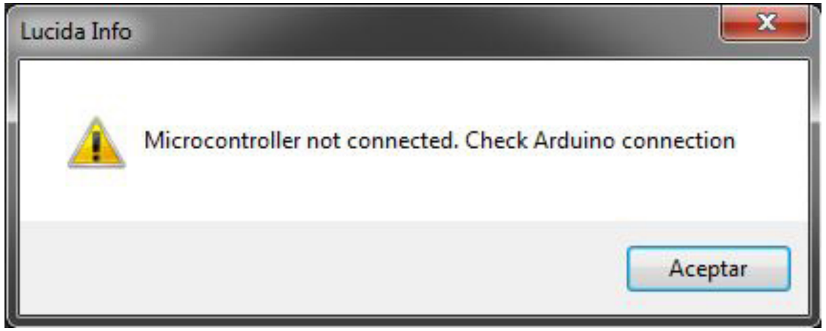
Troubleshooting

<<<
World Map, Anonymous, Silk, Detail
3D scanned in 2011 in Factum Arte, Madrid

5 Troubleshooting

Arduino not connected

If the Arduino board is assigned to a COM port in the laptop different to the one which is configured in the **system_settings** file an error message (below) will pop up when opening the Scanning Application: **'Microcontroller not connected. Check Arduino connection'.**



01. Press 'Accept'. The Scanning Application will open. Press 'Exit'.
02. Check in the 'Devices and printers' menu in the laptop which port has been assigned to the Arduino (in the example: COM3) (Fig. 1).
03. Open the system_settings file as a text file.
04. Look for the line '<SerialPortName>COM3</SerialPortName>' and match the port number to that assigned by the laptop (Fig. 2).
05. You may have to do this again if you change the laptop.

```
<!-- Serial port name (for the arduino).
<!-- Type: string -->
<SerialPortName>COM3</SerialPortName>
```

Fig. 2

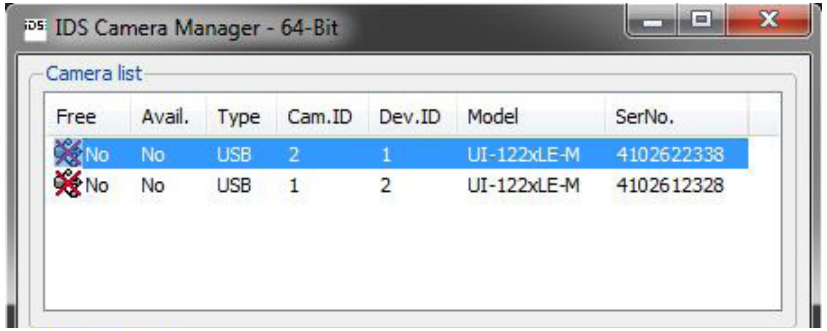
Fig. 1

5 Troubleshooting

Cameras not connected

If the Scanning Application is closed without pressing 'Exit' button, the access to the USB cameras may remain open. If that is the case, when you open the Scanning Application again the cameras may not be detected.

01. Open the IDS Camera Manager application that is installed with the camera drivers to check the status of the cameras.



02. In order to solve this problem, unplug the cameras from their USB ports and plug them again after a few seconds. This should make the laptop reset the status of the cameras to this:

Free	Avail.	Type	Cam. ID	Dev. ID	Model	SerNo.
Yes	**Yes**	**USB**	**1**	**1**	**UI-122xLE-M**	**...**
Yes	**Yes**	**USB**	**2**	**2**	**UI-122xLE-M**	**...**

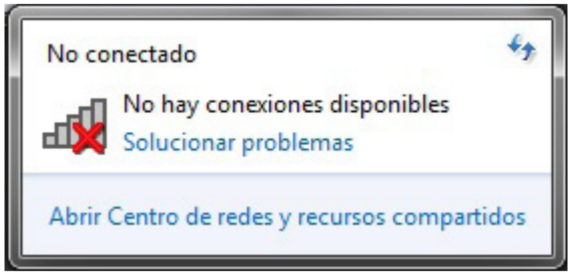
03. If the problem is not solved, unplug cameras again, restart the computer and plug cameras back in.

5 Troubleshooting

Trigger not responding

01. If after pressing the ‘Pulse’ button in the Calibration process nothing appears on the Preview windows it may be because no signal has been sent to the trigger of the cameras.
02. This could be caused by a failure in the wiring connections.
03. In order to solve this, check whether the trigger cables, which connect the PCB on top of the scanner head to the cameras, are properly connected and/or damaged.
04. Open the Calibration menu and press ‘Pulse’ again.
05. If the problem is not solved check if the ribbon cable which connect the Arduino board with the PCB on top of the scanner head is properly connected and/or damaged.
06. Open the Calibration menu and press ‘Pulse’ again.

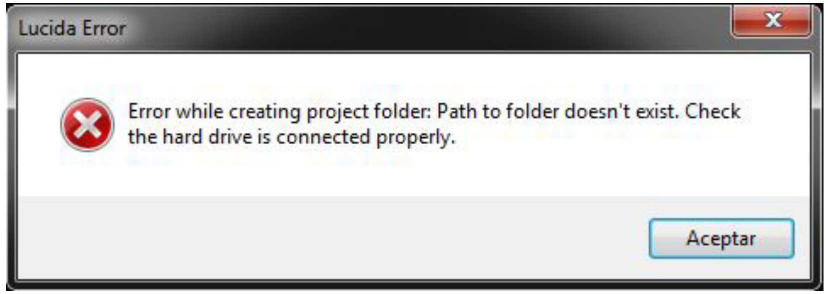
Wifi not available



01. Lucida Scanning Application automatically turns off the Wifi connectivity of the laptop when you open it and turns it on when you exit.
02. If the Scanning Application is closed without pressing ‘Exit’ button the Wifi adaptor will remain disconnected.
03. In order to solve this open the Scanning Application again and press ‘Exit’. This will re-enable the laptop Wifi adaptor.

5 Troubleshooting

Incorrect folder path



01. When the name of a session folder already exists, an error will pop up: ‘Error while creating project folder. Path to the folder doesn’t exist. Check the hard drive is connected properly’.
02. To solve the problem just give a new name to the session folder.
03. Also, when the Folder path does not exist in the computer drive the same pop up error window will appear. To solve the problem just change the path to an existing one.

Calibration tool incorrectly placed

01. If after pressing the ‘Pulse’ button in the Calibration process the laser stripes in the two Preview windows don’t look as they should this could be due a badly fixed calibration tool.
02. In order to solve the problem, make sure the positioning dowel pin of the calibration assembly is resting straight/true on the top side of the vertical carriage. Check also that the back surface of the calibration assembly is in flat contact with the milled surface of the backing board, without touching any bolts from the board (see section Calibration).

Support: factum@factum-arte.com / +34 915 500 978

If you want to watch videos about Troubleshooting please visit:

www.factum-arte.com

Glossary

Alignment. Last step of the Calibration process that consists of overlapping the homographies (dots) from both cameras by hand.

Backing frame. Structural support made from aluminum profiles to which three motorized guides and the scanning head are attached. As a mechanical set, it defines a scanning area of 480 x 468 mm.

Beam. Laser beam. The strip of vertical light projected by the red laser diode. It has a total length of about 50 mm although the effective length captured by the cameras is 26 mm (width of a stripe).

Calibration. Comparison between measurements - one of known magnitude made with one device (Lucida's calibration profile) and another measurement made in as similar way as possible with a second device (homography of each camera's view).

Depth of field. Distance between the nearest and the farthest objects in a frame that appear acceptably sharp in image. In the case of Lucida, the depth of field often refers to the maximum relief that can be recorded in a particular scanning session: 25 mm. For deeper relief surfaces it is possible to move the scanner along the Z axis.

Depthmap. One of the output files created automatically in a session, consisting on a render of the 3D data which has been captured and processed. The format of the Shaded file is a TIFF.

Exposure. Parameter in the Camera settings that sets the quantity of light reaching the camera sensor (default: 180).

File. Session created out of pre-recorded video files, as opposed to 'Live', a session created from live video from the cameras (default).

Glossary

Frames. Each of the 4800 shots captured by each of the 2 video cameras in one stripe. The resolution of each frame is 752 x 480 px.

Guides. Each of the linear motion slides that allow the movement of the scanner. The scanning head is moved by a system of motorized linear guides. The other guides correspond to the X, Y, Z movement.

HDR. High Dynamic Range. Function that captures two frames at different exposure levels and combines them to produce an image representative of a broader tonal range.

Head. Scanning head. Assembly of parts that form the main core of the Lucida scanner. It includes the laser diode and the two cameras.

Homography. In the field of computer vision, any two images of the same planar surface in space are related by a homography. This is used in our Calibration process to correct the camera perspectives.

Laser. Laser diode. Device that emits light coherently. In Lucida, spatial coherency allows the laser to be focused in a tight spot which, thanks to a system of lenses, is projected as a linear beam.

Live. Session created out of live video from the cameras (default), as opposed to 'File', a session created from pre-recorded video files.

Micron. Micrometer or µm. 1/1000 of a millimeter. Lucida 3D scanner records at a resolution of 100 microns, that is, 1/10 of a millimeter.

Noise. When an image is formed by a rough surface which is illuminated by a coherent light such as a laser beam, a speckle pattern is observed in the image plane.

Glossary

Processed data. Digital information that has been transformed from one format to another one. The Scanning Application processes the raw video footage from the cameras to convert it into 3D information.

Profile. Calibration profile. Square of 23 x 23 mm formed by the four corners defined in the calibration tool, necessary for the Calibration.

Raw data. Data collected from a source that has not been subjected to processing or any other manipulation. Lucida stores raw video as one of the most valuable tools for the digital preservation of objects.

Resolution. Resolution is used here to mean the number of points per surface unit present in the processed 3D data. In Lucida, depthmap files contain 100 dots per cm² - 254 dpi. This is equivalent to saying that the resolution of the Lucida scanner is 100 μm.

Scanner. Lucida. System developed to obtain contact-free high-resolution 3D data from the surface of paintings and low-reliefs objects. Lucida projects a thin beam of red light onto the surface of the painting. As the beam moves across the object the distortions caused by the surface fluctuation are recorded by two video cameras positioned adjacent on the assembly either side of the laser. The video footage is archived as raw data as well as processed as a 3D depthmap file.

Settings. In the Scanning Application, the Settings menu permits the control of certain parameters to optimise the scanning session. They are divided into System settings and Camera settings.

Shaded. One of the output files created automatically in a session made up of a render of the 3D data which has been captured and processed. The format of the Shaded file is a TIFF.

Glossary

Stripe. Set of 3D data composed by 2x 4800 video frames along a distance of 480 mm. The width of a stripe is 26 mm. A tile of data is composed by 20 horizontal stripes with an overlap of 10%.

Threshold. Parameter of the Camera settings that sets the segmentation from the grayscale image (default: 030).

TIFF. Tagged Image File Format. File format for handling and storing images and data within a single file by including the header tags defining the image’s geometry.

Tile. Set of 3D data composed by 20 stripes of 2x 4800 frames each. A tile determines Lucida’s standard scanning area: 480 x 468 mm.

XML. Extensive Markup Language. Markup language that defines a set of rules for encoding documents (text) in a format that is both human-readable and machine-readable.

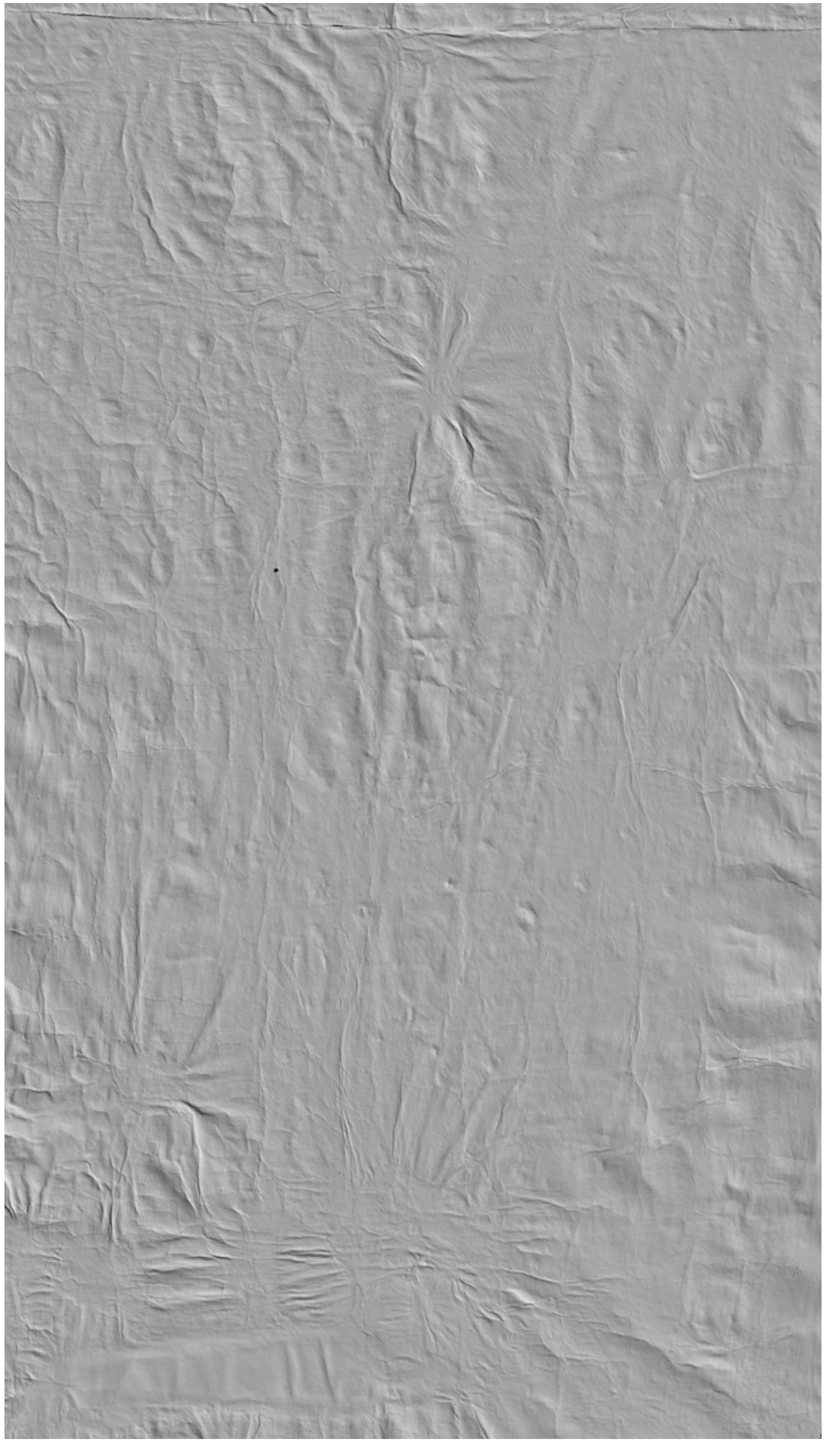
(x, y) coordinates. Position of a point within the tile. The coordinates help to determine the position of the scanning head in a session, as well as the four corners of a selected area for scanning.

X axis movement. Placement of the scanner (left-right) along the horizontal guides that run parallel to the scanning plane.

Y axis movement. Placement of the scanner (up-down) along the vertical guides that run parallel to the scanning plane.

Z axis movement. Placement of the scanner (forward-backwards) along the horizontal guides that run perpendicular to the surface of the scanning plane.

Table of Contents: *Operator's Manual*



6

Merging App

Lucida Merging Application

The Merging Application (Merging App) works with RIS files and is used to merge a rescanned section with its corresponding tile. It is usually recommended that all rescans are merged with their tiles before editing them (Section 2).

Reasons for having rescans of one or more sections in a tile include:

a) *Local vibrations*: these appear as regular patterns of vertical lines in specific areas. In such a case, it would not have been necessary to modify the settings of the scanner before rescanning the necessary area.

b) *Areas with black data*: these result from too low a laser intensity. In this case the settings (laser intensity, exposure or threshold) would have been changed prior to rescanning.

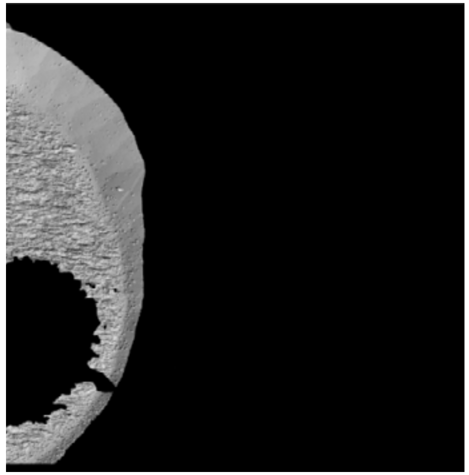
c) *Areas that are out of range*: these occur when the laser is either too close or too far from the object. In this case it would have been necessary to use the hand wheel to modify the distance (z-axis) between the scanner and the object. The use of a caliper or a ruler to know the exact distance moved is essential, as we will see in the merging tutorial.

For the Merging App to work properly it is important that the rescans were done with the same origin as the base tile. This will ensure that the rescan is in the correct position in relation to the original tile. It is recommended that all rescans comprise some extra area to allow for a margin of error when merging (see Lucida Operator manual, p.p. 31-33).

Merging Tutorial Example

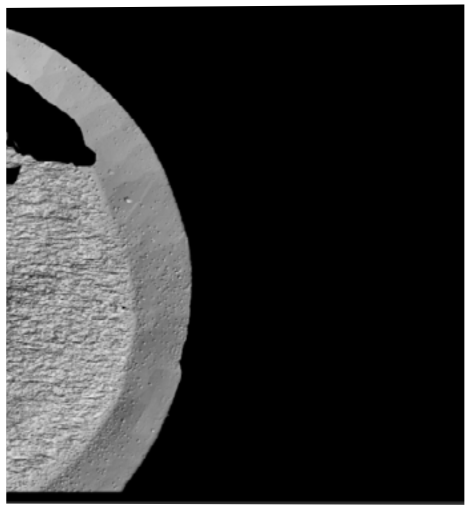
The following example demonstrates the merging of tile 01B with tile 01B_RS1 (RS = rescan). 01B is the main tile and 01B_RS1 is the rescanned section.

This object has a complex topography. The area in black was out of range of the laser.



01B

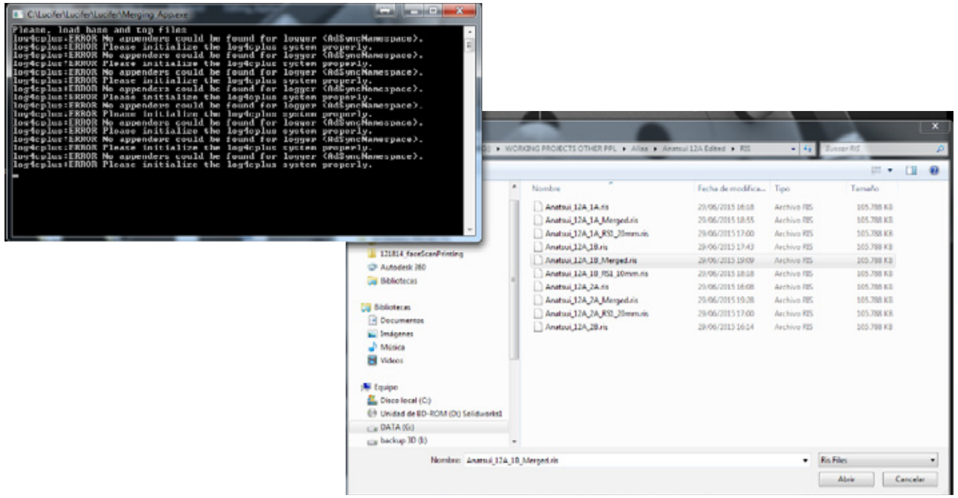
The rescanned area.



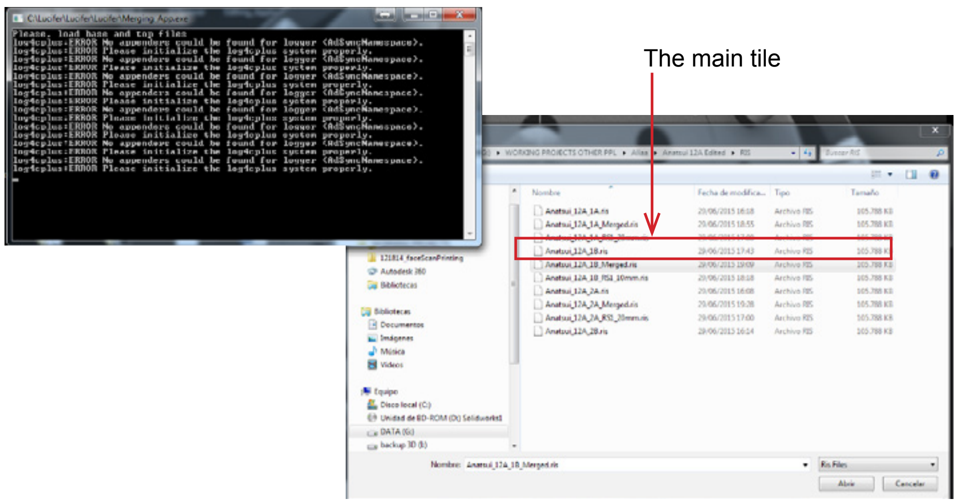
01B_RS1

6 Merge

1. Open the Merging Application

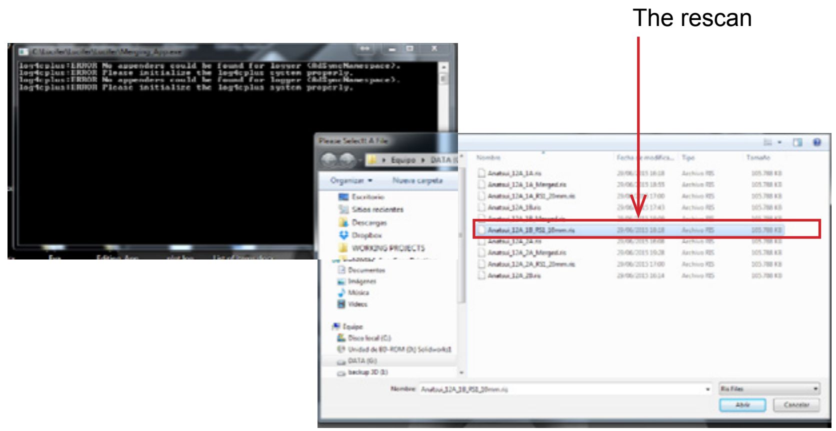


2. Load the main tile RIS file (e.g. 01B.ris)

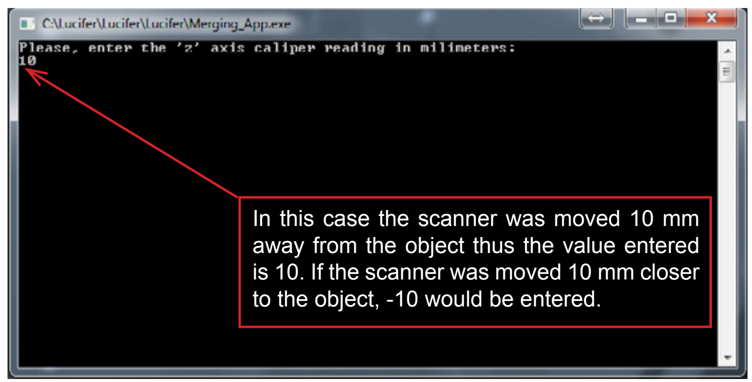


6 Merge

3. Load the rescan (e.g. 01B_RS1.ris)

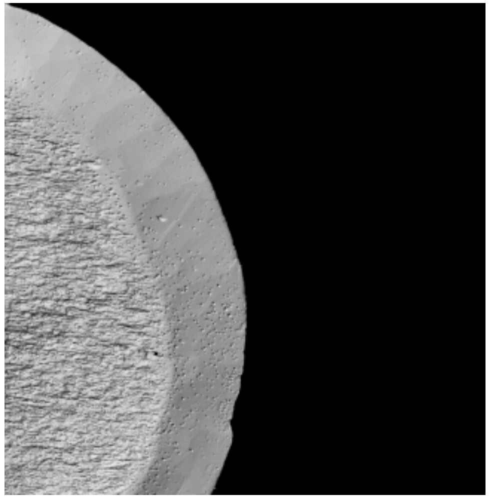


4. A message will appear saying: '*Please enter the "z" axis caliper reading in millimetres*' (the displacement value). If the distance of the scanner to the object was not modified, enter 0. If the scanner was moved, enter the distance in millimetres. Movement away from the object is recognised by the software as a positive value and movement closer to the object as a negative value.

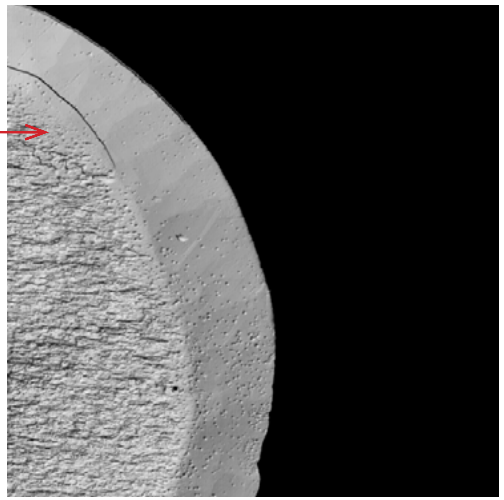


7 Merge

4.1 The result of the merge will appear along with the window shown in step 5. The images below illustrate an example of a succesful merge using the correct displacement value and an unsuccesful merge using an incorrect displacement value.



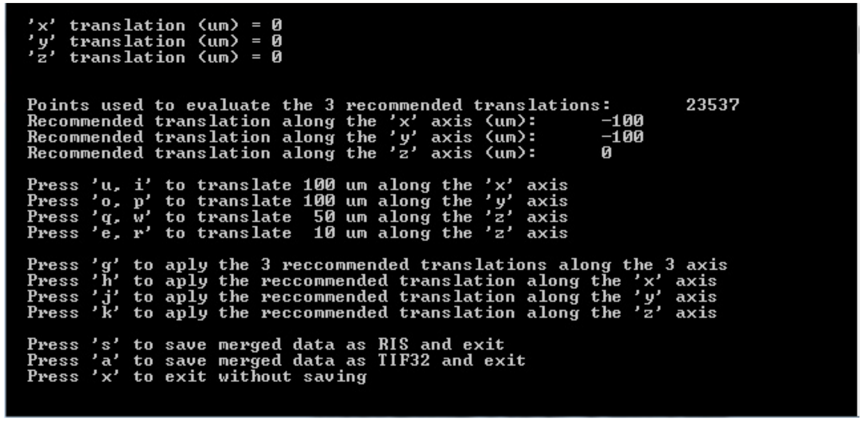
01B and 01B_RS1 succesfully merged with the correct displacement value.



01B and 01B_RS1 were not succesfully merged in this case because of an **incorrect displacement value**. Note the thick black line.

7 Merge

5. The window below will appear alongside the final merge following the input of the displacement value.



```
'x' translation (um) = 0
'y' translation (um) = 0
'z' translation (um) = 0

Points used to evaluate the 3 recommended translations:        23537
Recommended translation along the 'x' axis (um):      -100
Recommended translation along the 'y' axis (um):      -100
Recommended translation along the 'z' axis (um):      0

Press 'u, i' to translate 100 um along the 'x' axis
Press 'o, p' to translate 100 um along the 'y' axis
Press 'q, w' to translate  50 um along the 'z' axis
Press 'e, r' to translate  10 um along the 'z' axis

Press 'g' to aply the 3 reccommended translations along the 3 axis
Press 'h' to aply the reccommended translation along the 'x' axis
Press 'j' to aply the reccommended translation along the 'y' axis
Press 'k' to aply the reccommended translation along the 'z' axis

Press 's' to save merged data as RIS and exit
Press 'a' to save merged data as TIF32 and exit
Press 'x' to exit without saving
```

If the merge was unsuccesful, press '**x**' and restart the merging process with a different displacement value. Pay attention to the number and whether it is positive or negative.

If the merge was succesful, press '**a**' to save the outcome as a TIFF 32 bit and press '**s**' to save it as a RIS file. It is recommended that the user do both.

If a mistake was made during the recording, the re-scanned tile can be displaced from the original tile along the x,y-axes. The user will notice artifacts and misalignment after trying to merge along the z-axis. In this case, the merging is not as straightforward as shown above. Follow the directions on the next page to solve the problem.

6 Merge

To automatically adjust the position of the original tile and the rescan use the following commands:

g: adjusts position in the x,y,z-axes
h: adjusts position in the x-axis
k: adjusts position in the z-axis
j: adjusts position in the y-axis

To manually adjust the position of the original tile and rescan use the following commands:

q: moves second tile down along z-axis by 50 microns
w: moves second tile up along z-axis by 50 microns
e: moves second tile down along z-axis by 10 microns
r: moves second tile up along z-axis by 10 microns
u: moves second tile left along the x-axis (-x) by 50 microns
i: moves second tile right along x-axis (+x) by 50 microns
o: moves second tile down along y-axis (-y) by 50 microns
p: moves second tile up along the y-axis (+y) by 50 microns

If the two tiles have been correctly merged, it will be impossible to tell where the join is i.e. there will be no artifacts. Once you are happy with the result, press '**a**' to save the outcome as a TIFF 32 bit and press '**s**' to save it as a RIS file.

Note: do not save the file until the merging is complete. Once the file has been saved, it cannot be modified.

7

Editing App

7 Edit

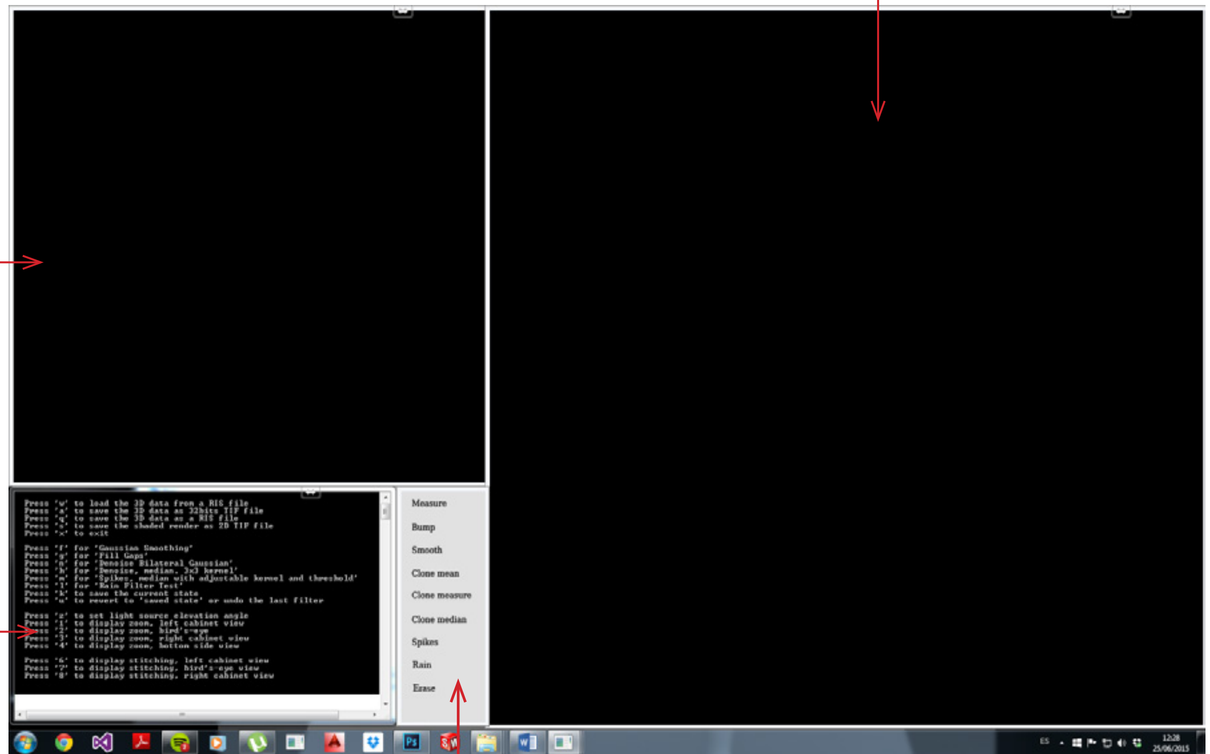
Lucida Editing Application

The aim of editing is to clean the scan by removing noise, spikes, holes, rain and other artefacts using a number of commands and tools. Lucida produces four different files (RIS, TIFF 32bit, TIFF 8bit, AVI). The editing application works only with the RIS files.

1. Editing Application Interface

Render View Window:
Displays the full scan. Move the cursor to navigate to or select the areas that you want to zoom into.

The Command Window:
Contains the list of possible commands and is where the values must be inserted for the different filters. If you ´lose´ the Command Window, press Esc to reactivate it.



The Tool Window: Contains the tools used to modify the specific area in the Zoom View Window.

7 Edit

Zoom View Window:
Displays a zoomed in view of the selected area in the Render View Window. This window shows the area in detail and is a useful tool when considering what filters are necessary and/or what tools should be applied.

7 Edit

2. List of Commands

The following commands apply filters to the whole file:

Press “w” to load the 3D data from a RIS file.

Press “q” to save the 3D data as a RIS file.
The RIS file is important as it can be opened by the Lucida Editing Application, and therefore it can be used to obtain the other two TIF files.

Press “a” to save the 3D data as 32 bit TIF file.
The edited file should be saved in three formats: 32bit TIFF file, 8bit TIFF file, and RIS.

Press “s” to save the shaded render as 2D TIF file.
The shaded render is used as a way to view the file as an image.

Press “x” to exit without saving.

Press “f” for Gaussian Smoothing.
This is used to smooth extremely rough surfaces. The possible values here range from: sigma: 0.5, kernel: 3x3 to sigma:1.5, kernel:7x7. 0.5 is the lowest smoothing value and 1.5 is the highest.

Press “g” for Fill Gaps.
The possible values here range from 1 mm to 10 mm in diameter. The value should be chosen according to the size of the holes or 'gaps'. For small holes choose a minimum value, but always base your decision on the largest hole possible to fill.

Press “n” for Denoise Bilateral Gaussian.
This is mainly used for flat and less textured surfaces (like paintings on wood panel). It removes the noise from the surface by slightly smoothing it.

7 Edit

Press “h” for Denoise, median. 3x3 kernel and threshold (?)
This command is a more general tool to remove noise. It can be used for more textured high relief surfaces as its smoothing effect is much stronger than that of the Denoise Bilateral Gaussian.

Press “m” for Spikes, median with adjustable kernel and threshold.
This is used to flatten surfaces populated with spikes and creates a smoothing effect.

Press “l” for Rain Filter Test
This command removes floating particles that occur due to excess ambient light, particularily found around the edges of a painting.

Press “k” to save the current file in its current state

Press “u” to revert to the saved state or undo the last filter
Right click on a selected area in the Render View Window to view the previous state. In order to compare the previous and current state, alternate between the left and right click on the mouse. Note: you can only do this before saving the current state.

Press “z” to set a light source elevation angle

The following commands change the view in the Render View Window:

- Press “**1**” to display zoom, left cabinet view
- Press “**2**” to display zoom, bird's-eye
- Press “**3**” to display zoom, right cabinet view
- Press “**4**” to display zoom, bottom side view

7 Edit

The following commands change the view in the Zoom View Window:

- Press “**6**” to display stitching, left cabinet view
- Press “**7**” to display stitching, bird's-eye
- Press “**8**” to display stitching, right cabinet view

3. List of Tools

Tools are used to manually modify specific selections in the file. Select the area to be edited in the Render View Window and directly edit it on the Zoom View Window. Tools are secondary to commands and should be used only if the command did not work to fulll effect. Input the necessary values into the window that apearrs when you select the tool.

Measure: shows the coordinates of each point.

Bump: creates curvature to specific areas.

Smooth: smooths out areas with too much noise.

Clone mean; Clone measure; Clone median: these tools are used to replicate an area.

Spikes: smooths the spikes.

Rain: removes floating particles and is particularly used on the edges of the 3D surface.

Erase: can be used to erase unnecessary data - for example data lying outside the area of interest.

7 Edit

4. Planning an editing session

Below is the recommended order of commands when implementing an editing session (these commands apply filters to the whole file):

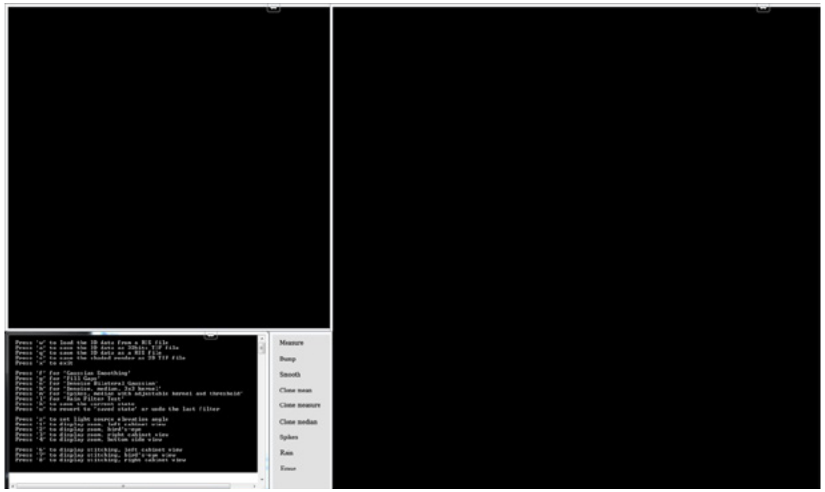
1. Open the file in the Editing Application
2. Check for holes and gaps in the file
3. Use the Fill Gaps command to fill the holes on the surface
4. Use the Rain Filter to remove the floating particles
5. Check for more holes or gaps and if applicable fill them again (sometimes holes that were not visible before appear as a result of removing floating particles).
6. Use the Spikes Median to remove any spikes if necessary
7. Use the applicable Denoise Median
8. Use the Gaussian Smoothing if necessary
9. Save the file in all 3 formats
10. Exit the application

Tools can be used to refine certain areas where the commands did not remove or smooth out the imperfections. It is best to apply the selected tool right after its corresponding command (ie. 'Rain' tool after 'Rain filter', 'Spikes' tool after 'Spikes Median', etc.).

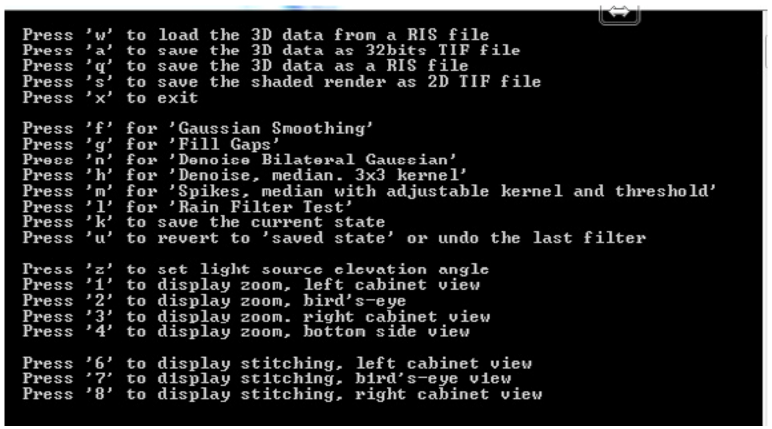
7 Edit

5. Example Editing Session

5.1 Open the Editing Application



The Editing Application

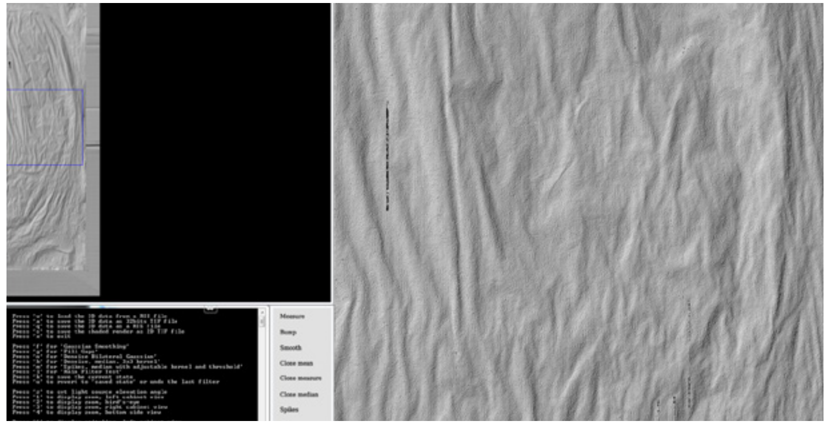


```
Press 'w' to load the 3D data from a RIS file
Press 'a' to save the 3D data as 32bits TIF file
Press 'q' to save the 3D data as a RIS file
Press 's' to save the shaded render as 2D TIF file
Press 'x' to exit

Press 'f' for 'Gaussian Smoothing'
Press 'g' for 'Fill Gaps'
Press 'n' for 'Denoise Bilateral Gaussian'
Press 'h' for 'Denoise, median. 3x3 kernel'
Press 'm' for 'Spikes, median with adjustable kernel and threshold'
Press 'l' for 'Rain Filter Test'
Press 'k' to save the current state
Press 'u' to revert to 'saved state' or undo the last filter

Press 'z' to set light source elevation angle
Press '1' to display zoom, left cabinet view
Press '2' to display zoom, bird's-eye
Press '3' to display zoom. right cabinet view
Press '4' to display zoom, bottom side view

Press '6' to display stitching, left cabinet view
Press '7' to display stitching, bird's-eye view
Press '8' to display stitching, right cabinet view
```

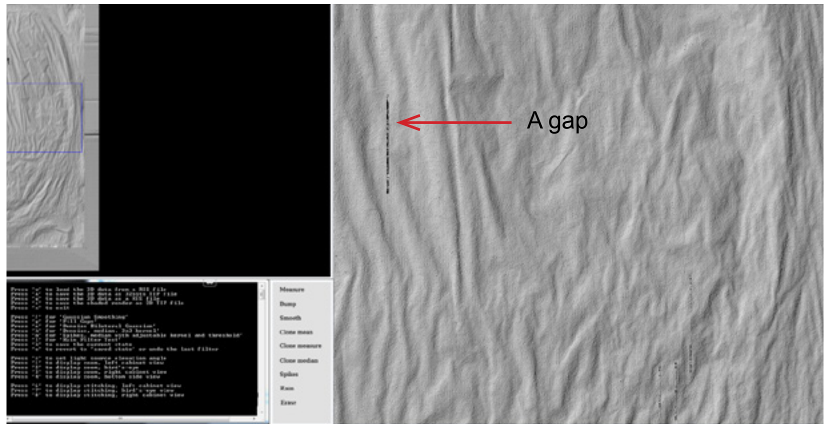
The command window

7 Edit

5.2 Press “**w**” to load the 3D data from a RIS file.



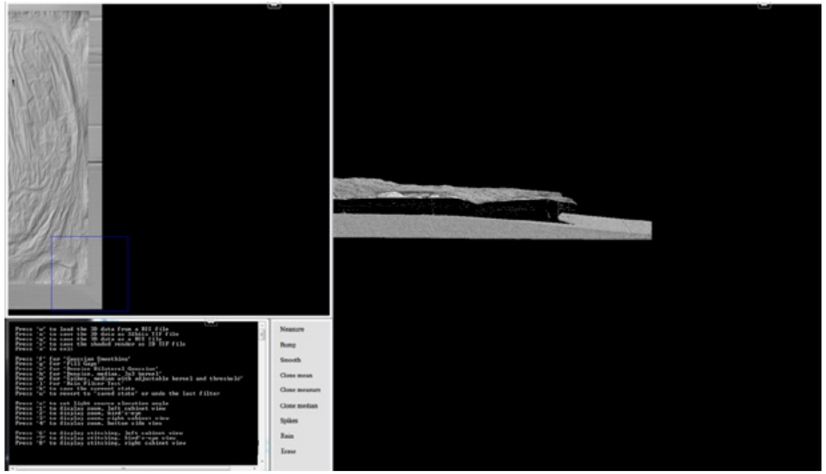
5.3 Begin by filling the gaps (small areas with no data, as illustrated below).



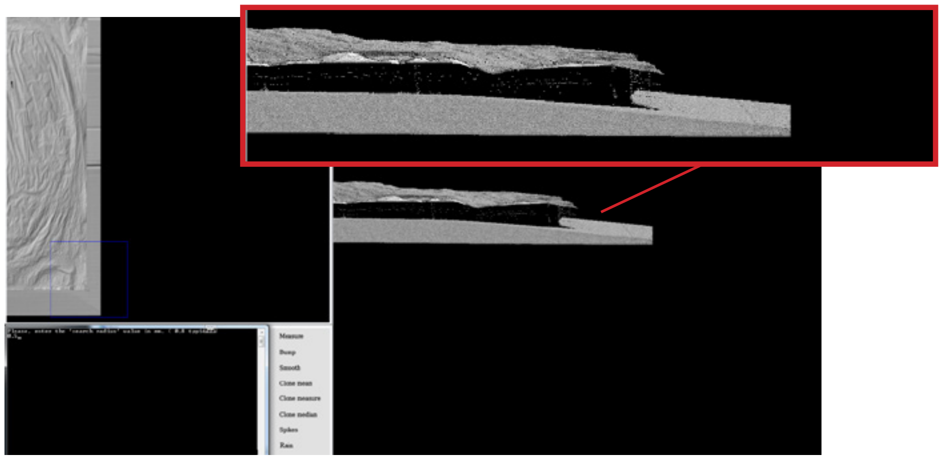
Press “**g**” for “Fill Gaps”. Possible values range from 1-10 mm in diameter. The value should be chosen depending on the size of the holes. If most holes are small, choose a small value, but always take your decision based on the largest hole to be filled. If in doubt choose a mid-range value (e.g. 5 mm).

7 Edit

5.4 Remove the floating particles surrounding the scan using the 'Rain Filter Test' command. Pay particular attention to the edges by using the side view. Select an area in the render view window and press “**4**” to display zoom, bottom side view in order to make the floating particles visible.



Press “**l**” for Rain Filter Test and enter the search radius value in mm.

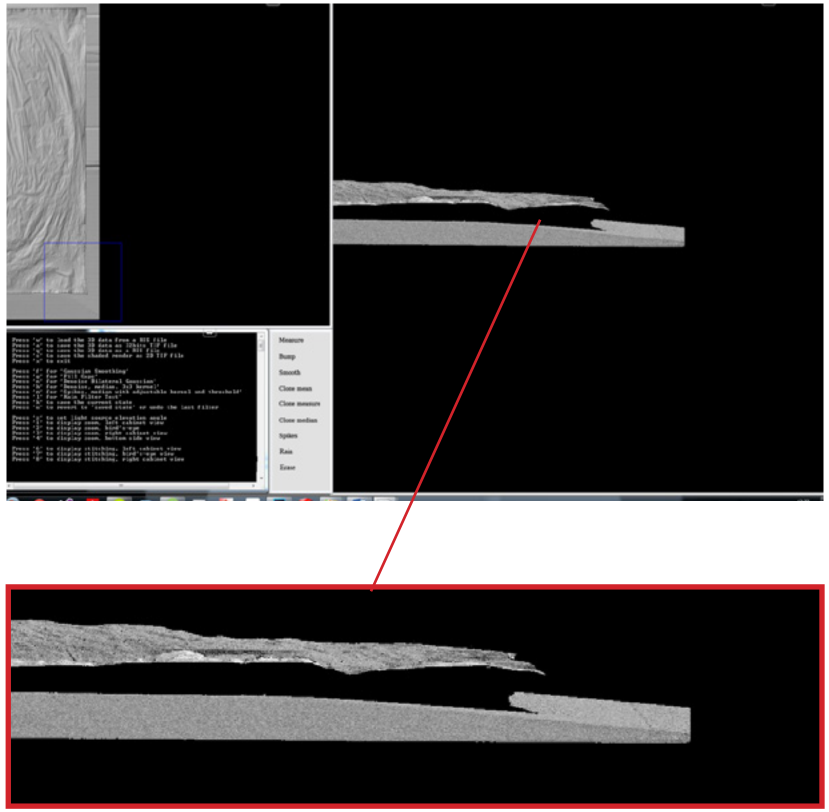


7 Edit

This value represents the radius from the surface above which particles will be removed. Possible values range from **0.1 to 0.8**.

You will then be prompted to enter the percentage threshhold value as an integer. The threshold represents the frequency (of rain?) - for scans with more floating particles use a higher threshold value. The value used is subjective, but 75 is typical. For this example the search radius value was 0.5mm with a 60% threshold.

Final result:



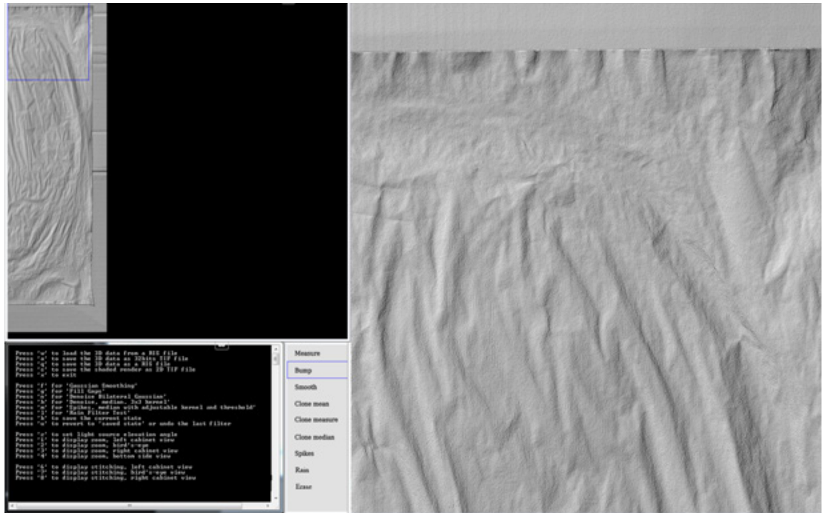
7 Edit

5.5 Revise the scan for any other holes that were not apparent earlier. It is normal to find more holes appearing as some of them were covered by floating particles now removed by the rain filter. If applicable, press “**g**” for “Fill Gaps”.

5.6 The next step varies for different scans depending on their texture and the amount of relief present.

For textured surfaces press: “**h**” for denoise median 3x3 kernel
For smooth surfaces press: “**n**” for Denoise Bilateral Gaussian

This example requires the “**h**” command because the texture is rough.



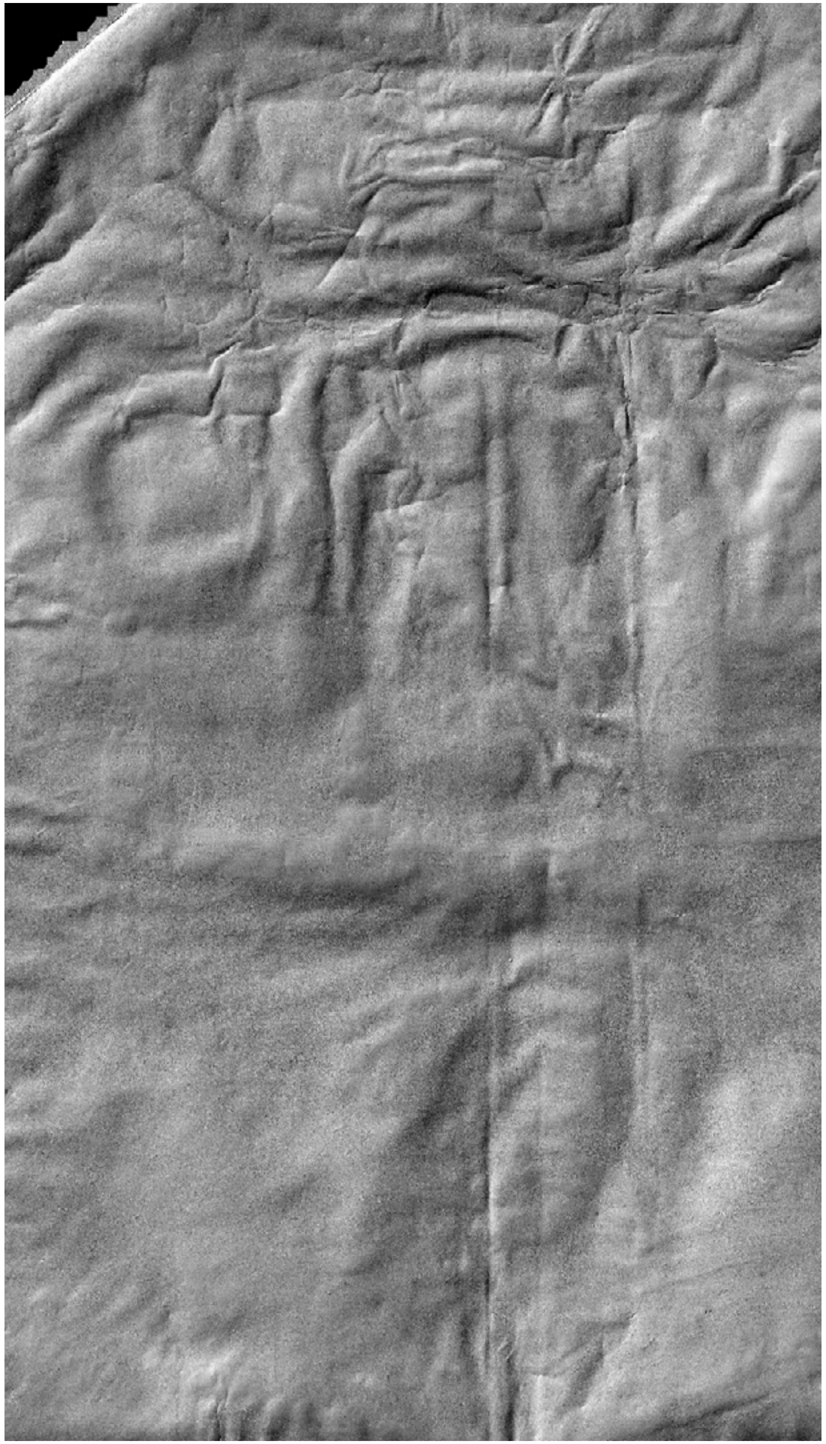
7 Edit

5.7 The final step involves saving the file in three different formats:

Press “**q**” to save the 3D data as a RIS file
Press “**a**” to save the 3D data as 32bits TIF file
Press “**s**” to save the shaded render as 2D TIF file

Press “**x**” to close the Application.

After all tiles have been edited, they are ready for aligning using PTGui.



8

Stitching with PTGui

8 Stitch

Stitching with PTGui

This tutorial describes the process of stitching various edited Lucida tiles using PTGui Pro 9.2.0 on Windows 7

First, apply a transparency filter in Photoshop.
Then create a shaded panorama in PTGui through the following steps:

1. Open the PTGui software

2. A number of PTGui options must be configured since in the default settings the images cannot be stitched successfully.

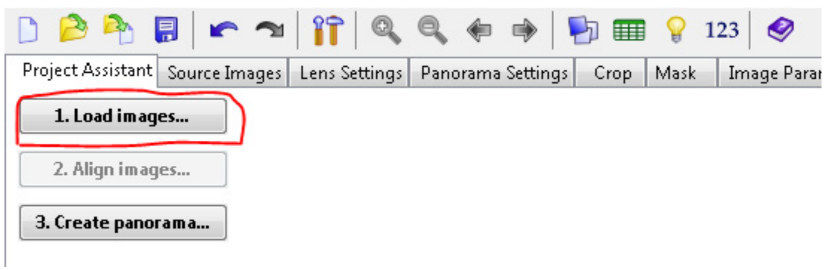
2.1 On the menu bar open the **Options** tab (under a tool icon).

2.2 Go to the **Advanced** tab and uncheck “load 16bit files as 8bit”.

2.3 On the same tab, check “Allow stitching even if estimated TIF/ PSD size is over 4 Gb” and “Disable SSE / AltiVec acceleration”.

3. On the top right of the software interface, click on the Ad- vanced tab in order to have access to the advanced options.

4. Open the tiles to be stitched in PTGui: Project Assistant > “1. Load Images”

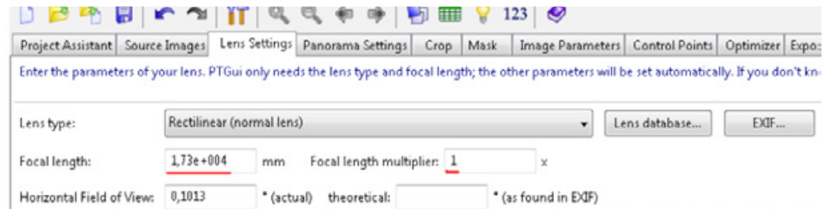


8 Stitch

5. A window will pop up saying that no EXIF data was found.
Do not worry about this message: unlike most DSLRs, the Lucida scanner does not attach EXIF data to its files. Close the window. This issue will be addressed in the next steps.

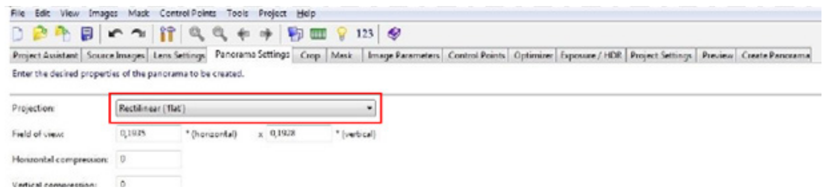
6. When the images have loaded, click on the Lens Settings tab.

6.1 Lens type should remain “Rectilinear”. Set the “Focal Length” to 17.300



6.2 Lens correction parameters should remain 0. This will avoid any warping to the images.

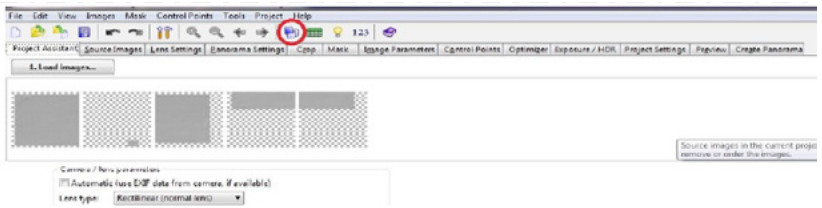
7. On the Panorama Settings tab “projection” should be set to “Rectilinear” to keep the lines straight.



8 Stitch

8. Click Align images

It is recommended that the user visualize how well the panorama was stitched by clicking on the “Panorama editor” icon on the menu bar or using the shortcut Control + E.



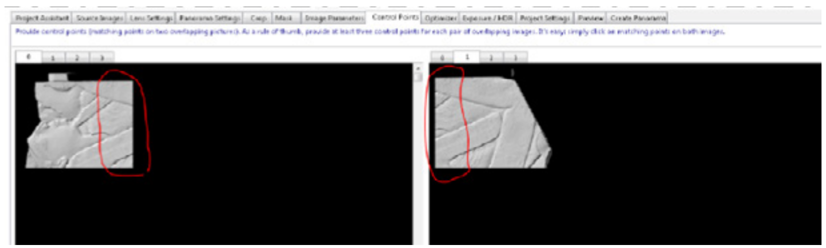
9. Control points

PTGui calculates the translations and rotations required for an image to fit with its neighbour by using a minimum of four 'correspondence points'. This can be done automatically by the software but to ensure accuracy it is better to do it manually.

Note: the accuracy of the control points should be sub-pixel. To identify whether this is the case, use the Optimize button (step 15).

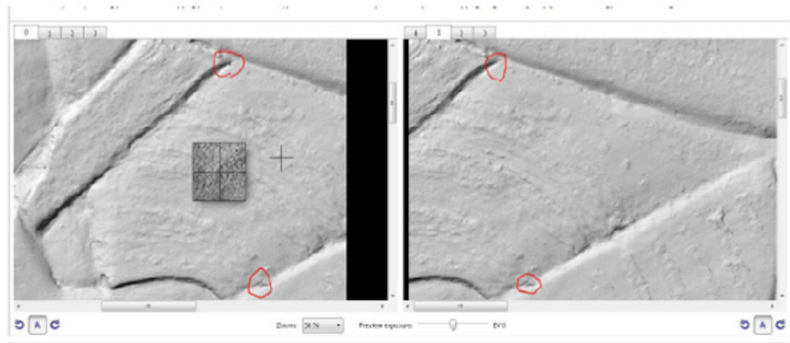
9.1 Click on the **Control Points** tab.

9.2 Select a pair of overlapping images, for example: Image 0 and Image 1

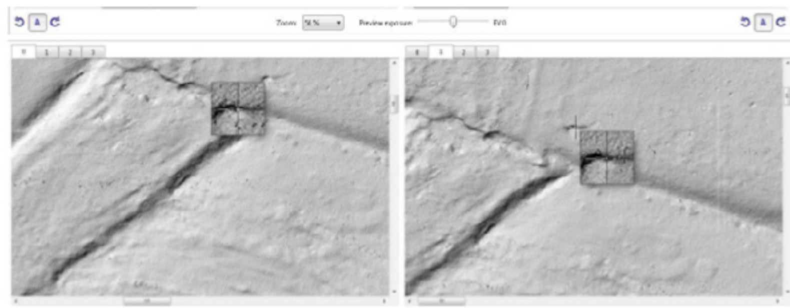


8 Stitch

9.3 The pair of images as currently displayed in the viewer are too small to achieve a good pixel correlation. Adjust the Zoom to around 50%. Locate any clear visible features, as shown in the example.



9.4 Once features have been located, increase the Zoom level until the chosen feature can be clearly identified. In the example below, the Zoom is set at 200%.

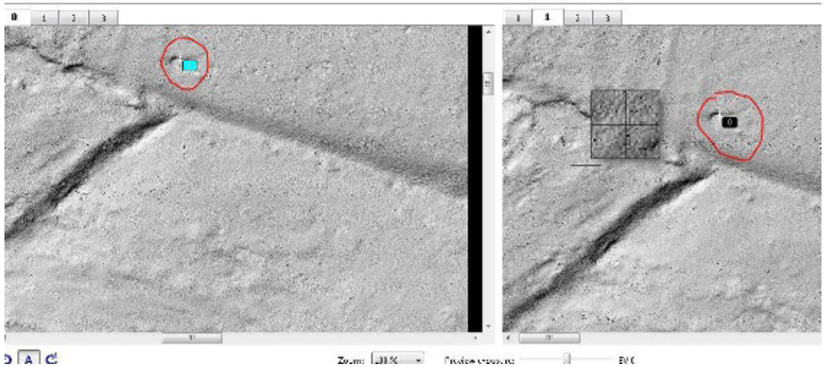


9.5 Once the corresponding features have been located, go into the left-hand viewport and left-click on the feature

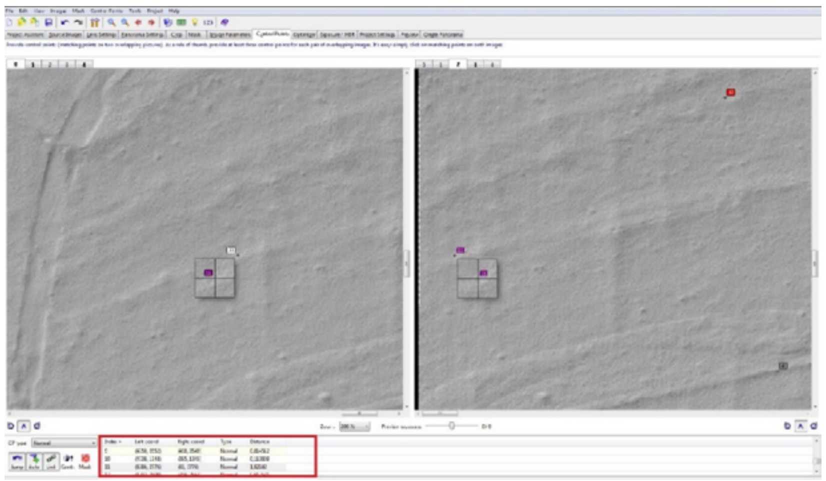
Note: it’s fine if you forget where you've clicked exactly because PTGui will anchor these 'small windows' for you

8 Stitch

9.6 Within the right-hand viewport, click on the same feature as in the left. Guide your eye using the 'small' anchored window.



9.7 The first control point (CP) will now show up on the lower part of the interface. The distance value will be displayed once the project is optimized. From this value, it will be possible to determine whether it was accurate enough.



8 Stitch

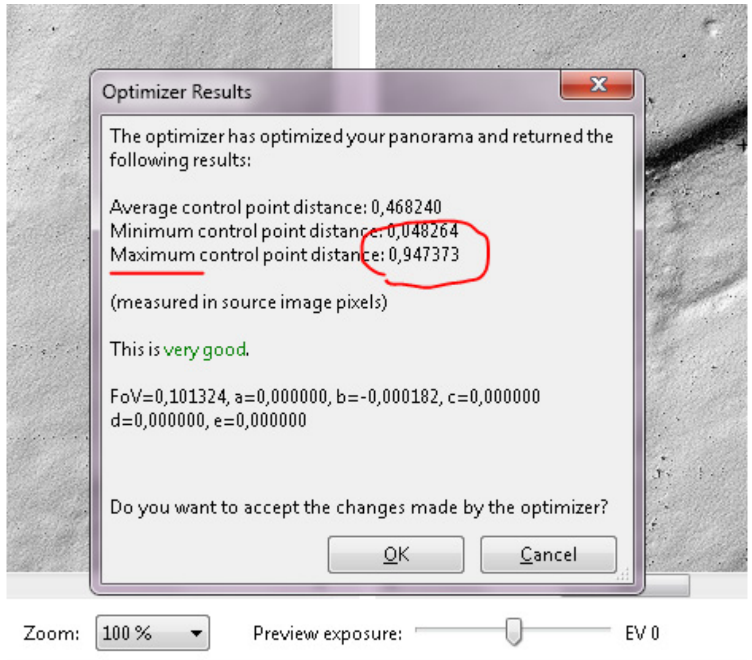
9.8 Repeat this process 4 times for each image pair.

Note: Once you have set 2 corresponding points manually, PTGui will be able to automatically estimate the rest for you.

10. Click on the Optimizer tab and click on “Optimize” in the bottom left corner or press F5.

10.1 The average error should be sub-pixel (i.e. lower than 1). If the average error ir higher or equal to 1.00, repeat the placement of the control points until the error is lower than 1.00.

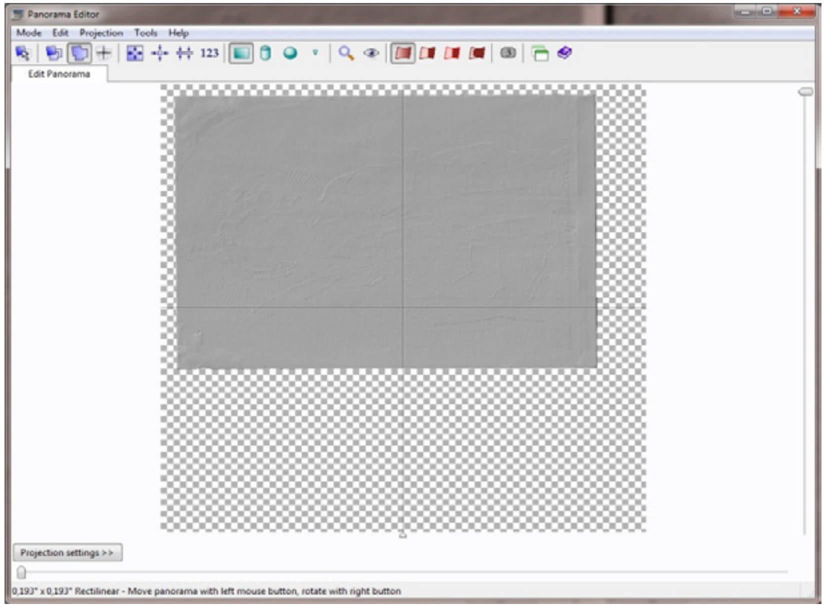
You can manage the control points by clicking Tools > Control Points.



8 Stitch

12. Visualising how well the panorama has been stitched is recommended at this point. Click on the “Panorama editor” icon on the menu bar or Control + E.

The tiles below have been succesfully stitched together:



13. Now go to Create Panorama tab

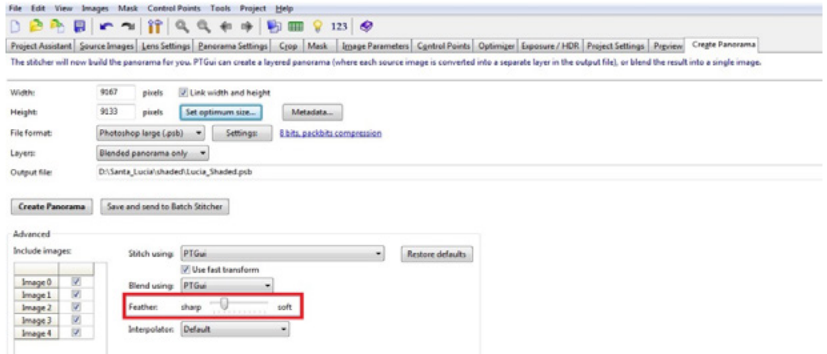
13.1 Click on “Set optimum size” and then click on “Maximum size” (to make sure there is no loss of any details)

13.2 Set the “File format” to “Photoshop large file .psb”

13.3 Now click on “Layers” > “Blended Panorama only”

13.4 Adjust the “Feather” to be close to the sharp side (see next page)

8 Stitch

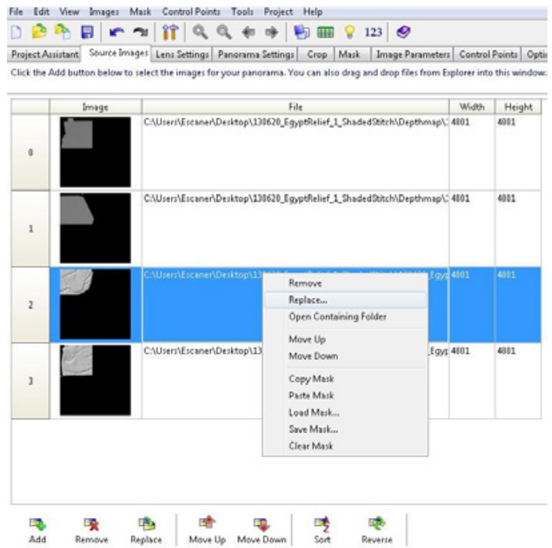


13.5 Click on “Create Panorama”

14. Open PTGui >> open the stitched project.

15. Go to the Source Images tab. Right click “Load Mask” on each image. Load the corresponding saved mask from Photoshop.

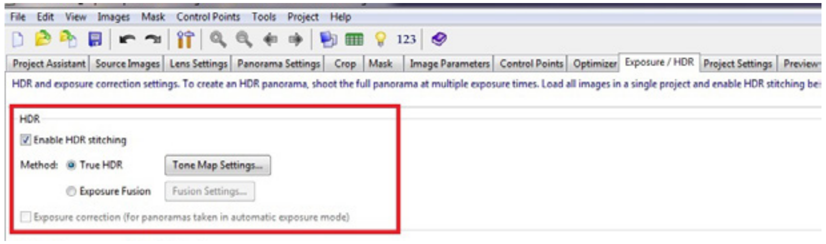
16. Go to Source Images and right click “Replace” on each image to replace them with the corresponding



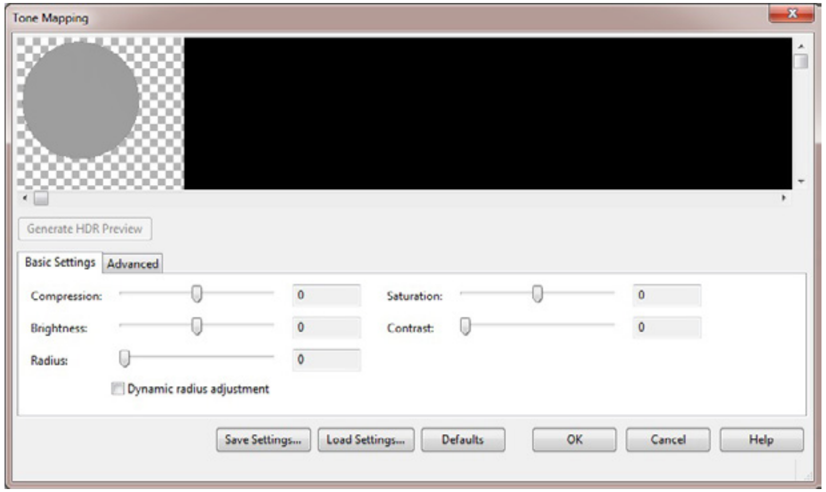
8 Stitch

17. Once all the tiles have been replaced with their corresponding depthMap files, click the Exposure/HDR tab.

17.1 Check “Exposure correction” and “Enable HDR stitching” and select “True HDR”.

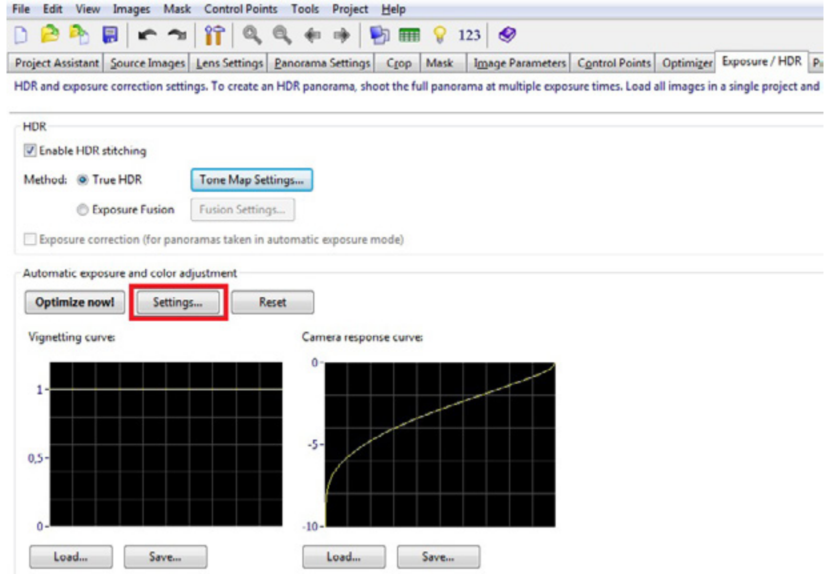


17.2 Click “Tone map settings” > Disable “Dynamic radius adjustment”, set “Radius” to 0.

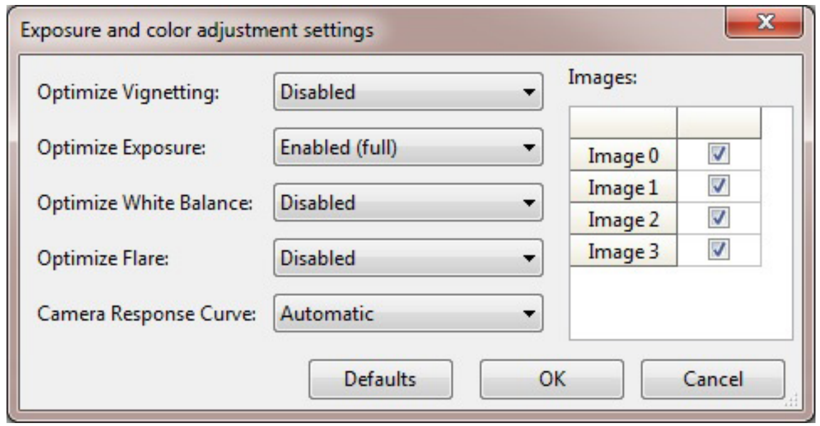


18. Within automatic exposure and colour adjustment click on “Settings”

8 Stitch



18.1 Disable “Optimize Vignetting”, Enable full “Optimize exposure” and click



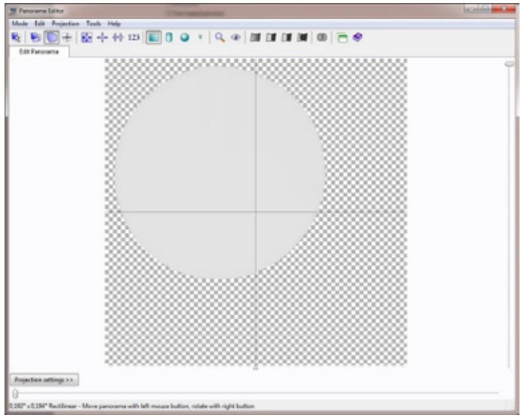
8 Stitch

19. Within automatic exposure and colour adjustment click on "Optimise now". The Z values of each tile should have been compensated.

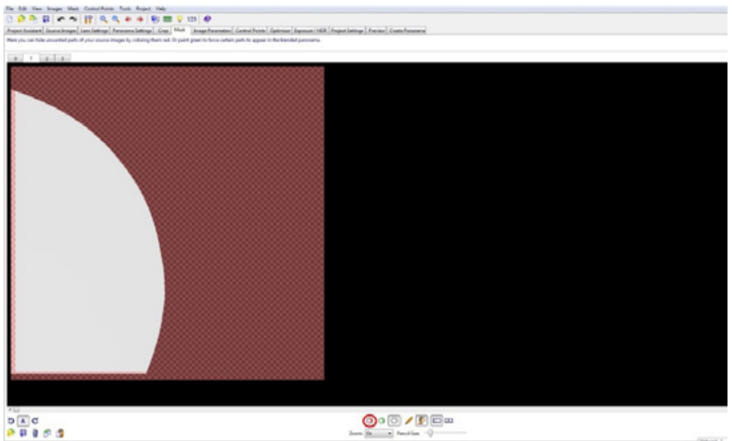
20. At this point, check whether the exposure has been compensated correctly is recommended.

Press Control + E. All transformations are linearly done.

21. Some black straight lines might be visible on the edge of the tiles within the Panorama editor.



21.1 Press Control + E. All transformations are linearly done.



8 Stitch

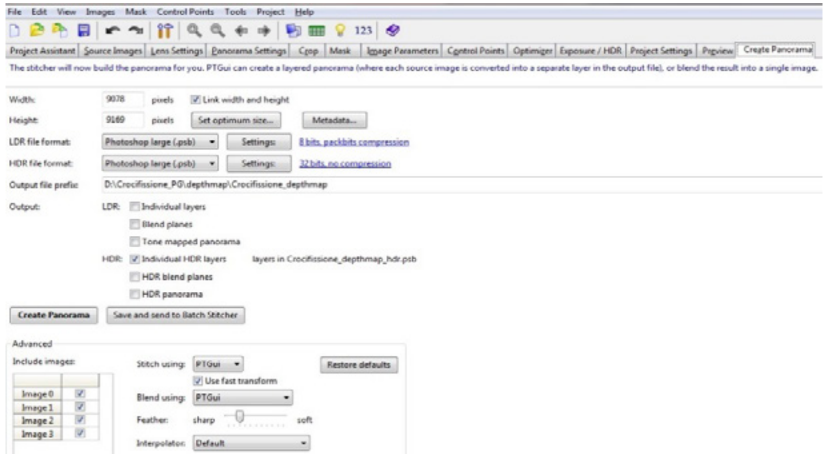
22. Go to the Create Panorama tab (see below).

22.1 Click on "Set optimum size" and then click on "Maximum size (no loss of detail)"

22.2 "HDR file format": should be set to Photoshop large (.psb)

22.3 "Output": should be set to – HDR – Individual HDR layers (disabled all the other options)

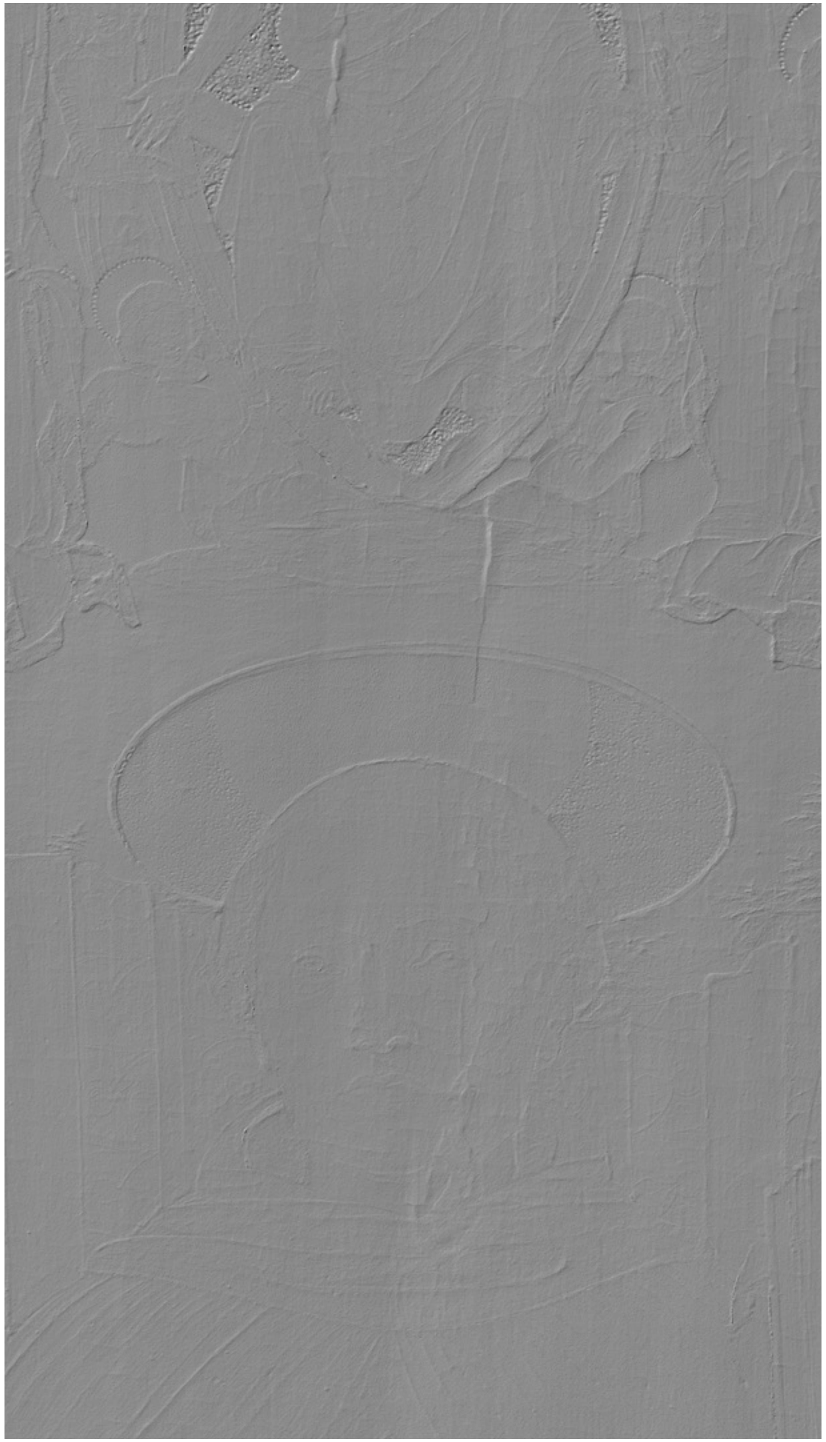
22.4 Put "Feather" close to the sharp end of the scale.



23. Click "Create Panorama".

The user can now move onto the last step in the processing: 'Blending'. In PTGui the file has been aligned on the XY plane. On the Z plane, the tiles have yet to be aligned and attached.

In the final Lucida processing stage, the file is aligned on the Z plane.



9

Blending App

<<<
3D render of San Vincenzo Ferrer, by Francesco della Cossa c. 1473, detail

9 Blend

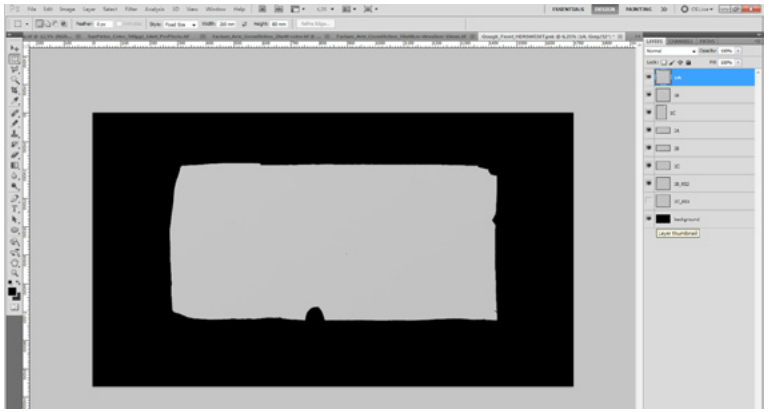
Lucida Blending Application

The final processing step for Lucida data involves blending the tiles. Once all the scanned tiles have been aligned in the x-y axes (using PTGui or a similar stitching software) this step is necessary to ensure a continuous surface between the tiles through alignment on the z-axis.

It is the final step in creating the 3D files used for rematerialisation (routing, 3D printing etc). This tutorial is divided into three sections:

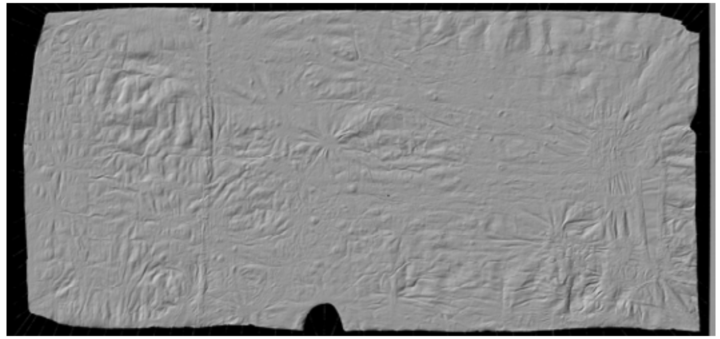
1. Preparation of the files in Photoshop
2. Input into Lucida Blending Application
3. Preparation of the file for prototyping and other processes

The example used below comprises 6 tiles. It serves to illustrate the required steps but should be used only as a guideline as each project will differ.



32 bit depthmap

9 Blend



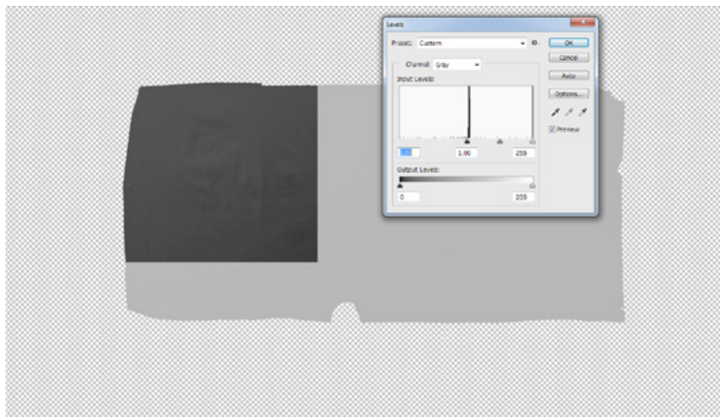
8bit TIFF shaded render

1. Preparation of the files in Photoshop

In order for the files to be processed by the Blending Application, they must have been prepared in Adobe Photoshop (CC version or higher).

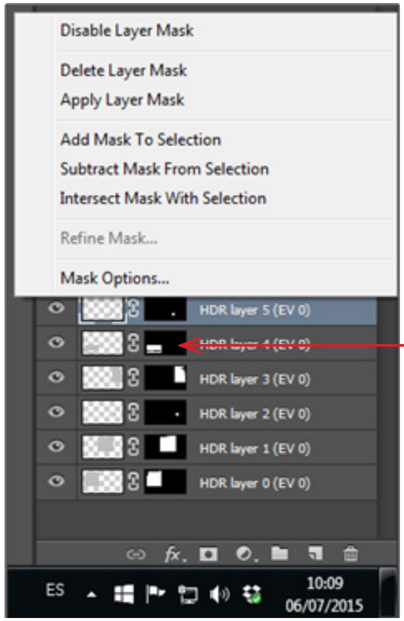
1.1 Open the PSD file that contains the panorama with each tile in position as an independent layer. This file must have been previously generated with PTGui.

1.2 Check that you have the correct file by selecting any layer and going to: Image > Adjustments > Levels and change the values to ensure that the relief looks as expected.



9 Blend

1.3 Delete all layer masks that may have been created in PTGui. Right click on Layer Mask > Delete Layer Mask

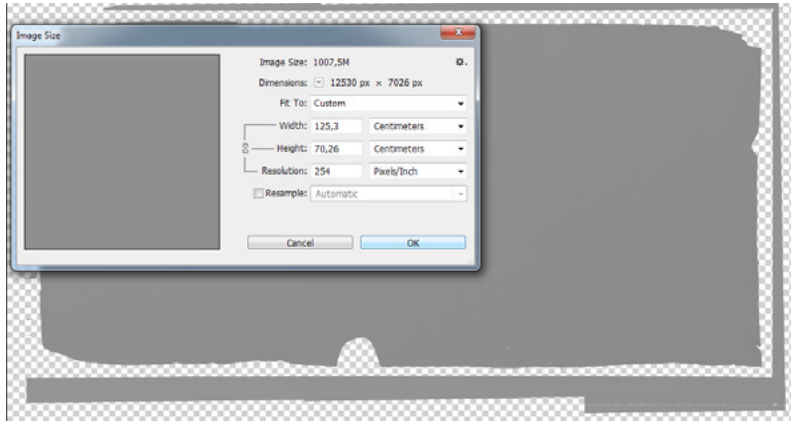


Layer mask

1.4 Check that 32 Bits/Channel is on: Image > Mode > 32 Bits

1.5 Adjust the resolution: Image > Image Size > Resample: Off (un-checked) > Resolution: 254 pixels/inch

9 Blend



Note: When ´Resample´ is off, changing the resolution will change the width/height dimensions accordingly and not the overall ´Image Size´.

1.6 Image > Mode > Grayscale > Merge layers?... > Don’t Merge

1.7 Edit > Colour Settings: Working Spaces: Gray: Gray Gamma 2.2 > OK

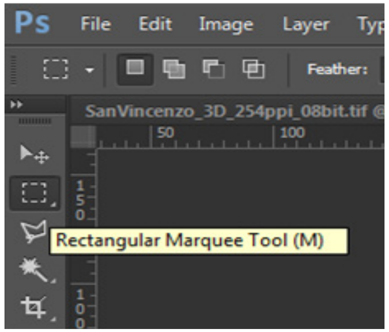
1.8 Edit > Assign Profile > Profile: Linear Grayscale Profile > OK

1.9 Change the canvas size: Image > Canvas Size > New Size: Width: 17000 / Height: 9602 px

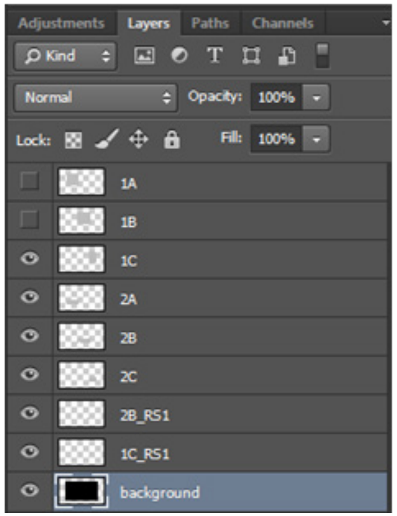
Note: If the file that has been stitched is larger than the new size listed above, the file must be split into sections. With the current Blending App this is the maximum file size.

9 Blend

1.10 Create a 100% black or white background layer in order to make the tile overlaps more visible.
Layer > New > Name: Background/ Colour: Black > OK.
With the new Background layer selected, use the Rectangular Marque Tool (see below) and outline the whole canvas. *Right click > Fill: Black.* Drag Background Layer to the bottom of the Layer Panel.



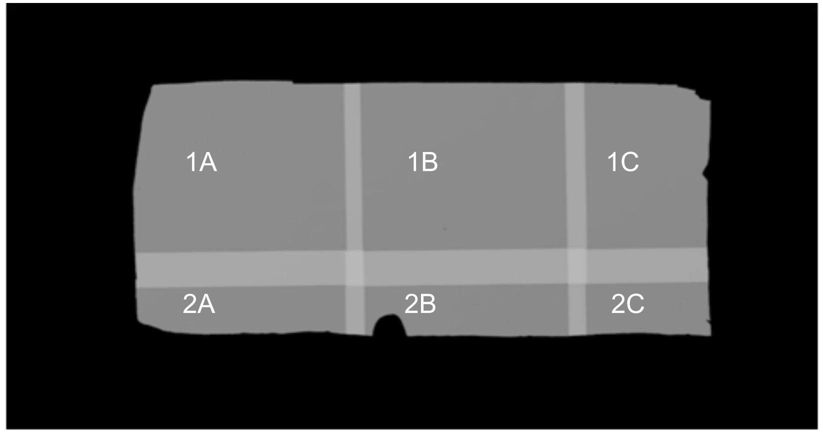
1.11 Change the name of each layer to its corresponding tile name e.g. 1A (or 01A), 1B, 1C, 2A, 2B, 2B_RS1 (RS = re-scan) etc. The horizontal dimension (rows) is marked with letters and the vertical (columns) with numbers.



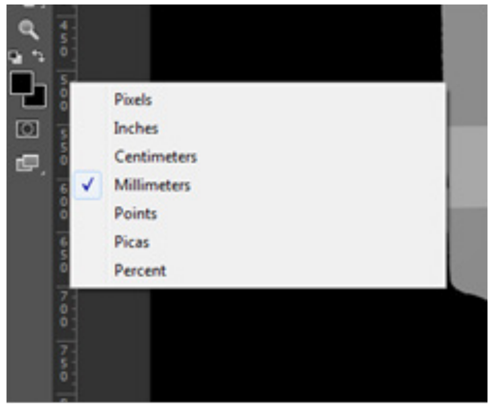
Note: The eye button on the left of each layer will show/hide each layer making its location clear on the canvas.

9 Blend

1.12 Reduce the opacity of the layers (e.g. 50%) to illustrate the overlap between tiles. The standard overlap between tiles should be ≈ 50 mm.

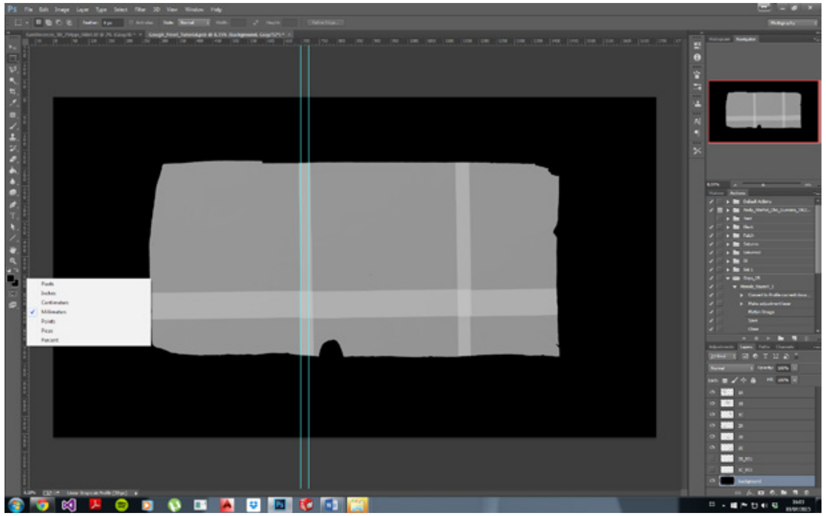


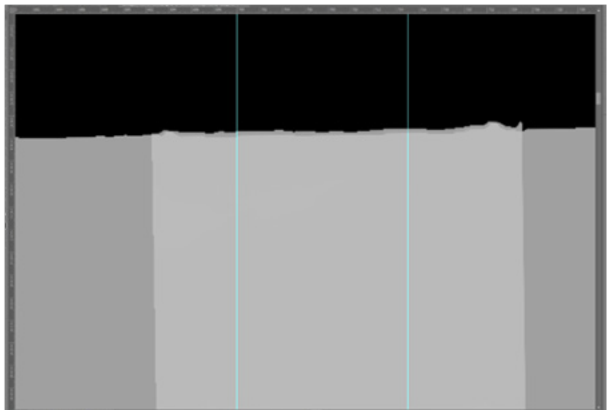
1.13 Check that the vertical and horizontal guides are in millimeters by right clicking on them.



9 Blend

1.14 Drag the guides from their corresponding horizontal and vertical axes and place them onto the overlapped area to outline a space that is ≥ 10 mm and ≤ 25 mm. It is best to zoom in at this point to ensure accuracy and check that the overlapped area does not include any holes as they may be problematic later on (see p. 5).



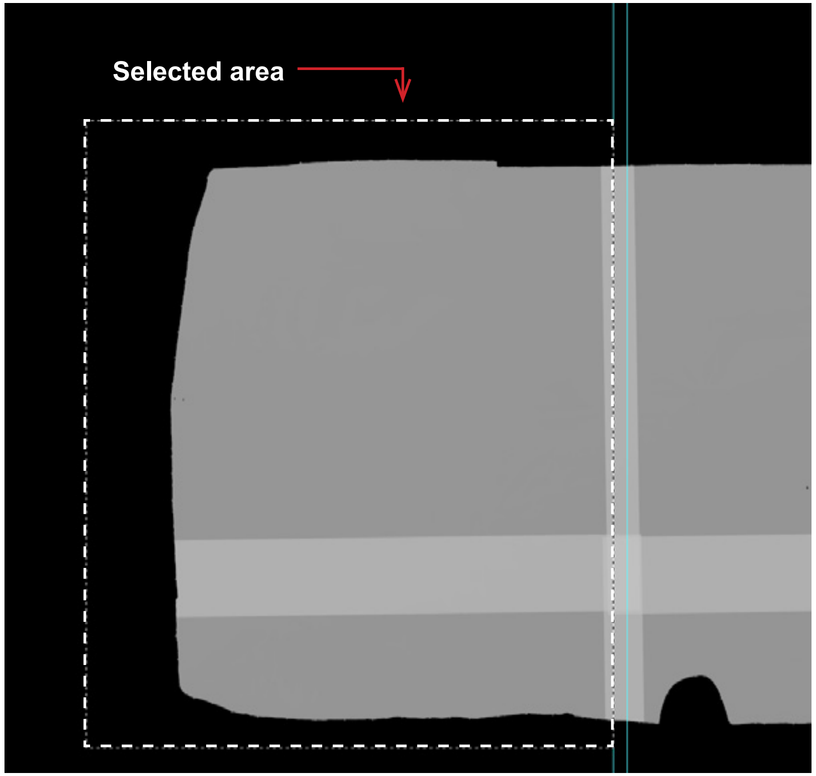


Zooming into the overlapping area to check for holes.

9 Blend

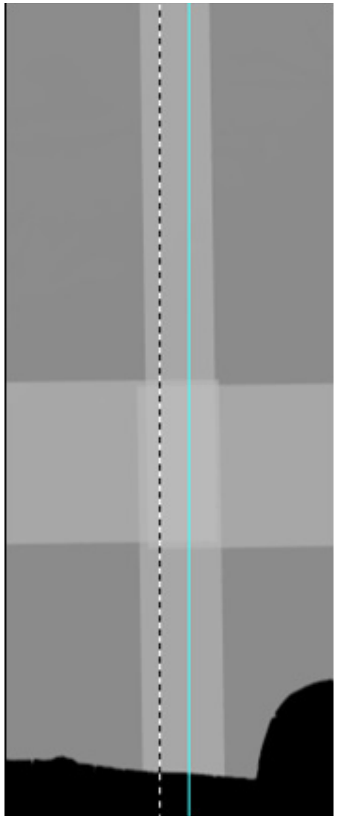
1.5 After marking all overlapped areas within the correct range (≥ 10 mm and ≤ 25 mm), use the Rectangular Marquee Tool select an area that encompasses the excess overlap. Then delete the excess area from the selection adjacent to the tile.

Each tile should be treated separately, starting with the vertical overlap.

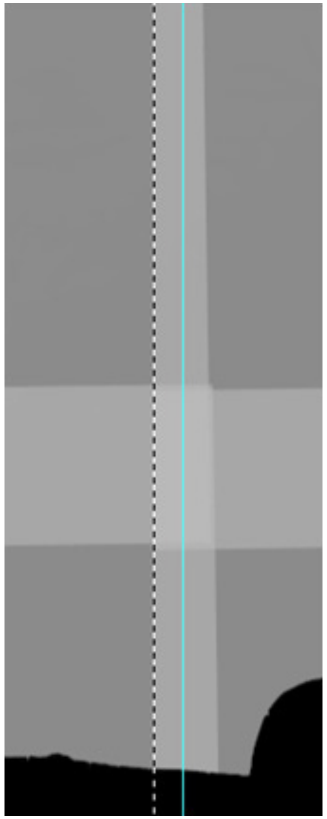


Delete from tiles 1A and 2B

9 Blend



Before

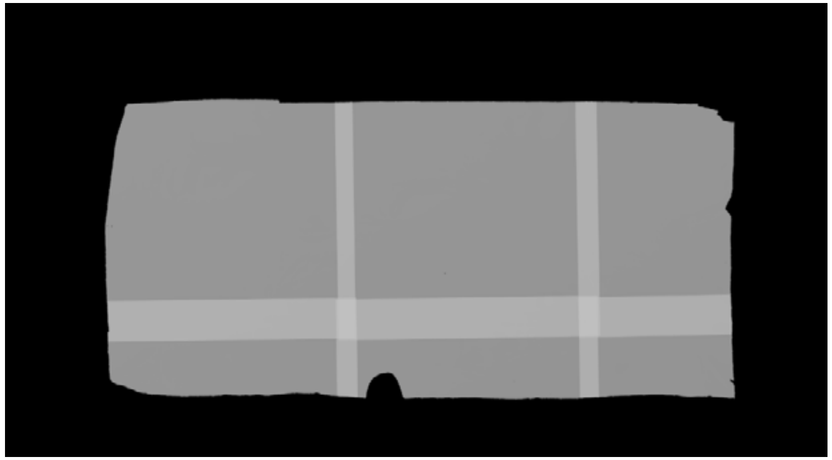


After

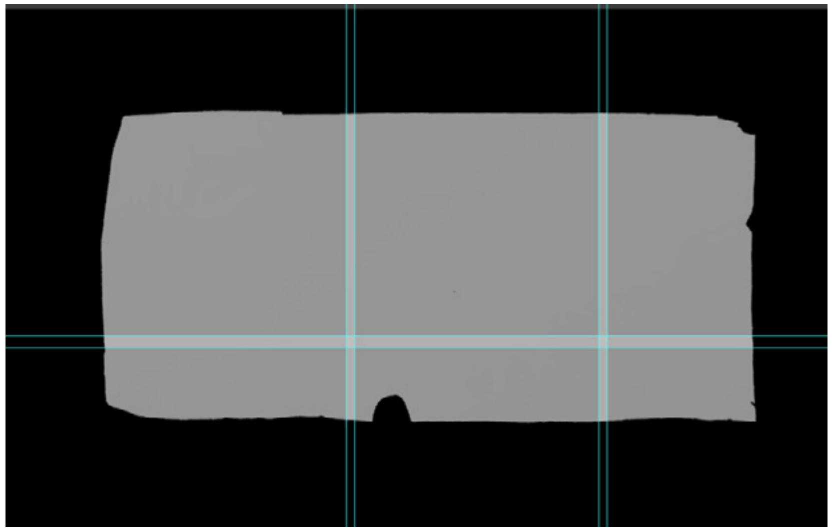
1.16 Repeat this step for the horizontal overlapped tiles.

The images on the next page illustrate the final product following the removal of excess overlap.

9 Blend



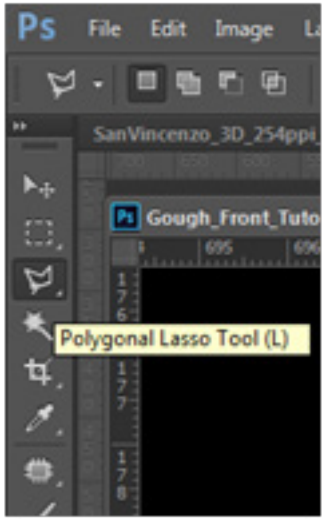
Before

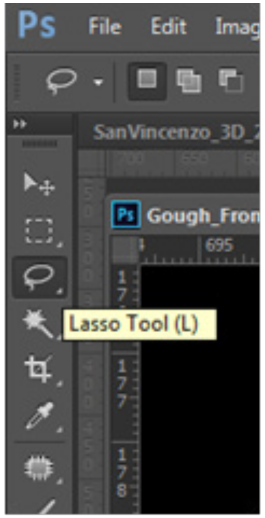


After

9 Blend

1.17 In order for the Blending App to work correctly, the borders of the overlapped tiles must be evened out. With the guides still in place, zoom in at the edge of an overlapped area and use the Lasso or Polygonal Lasso Tool to remove any uneven edges. Do this for all vertical and horizontal overlapped tiles.

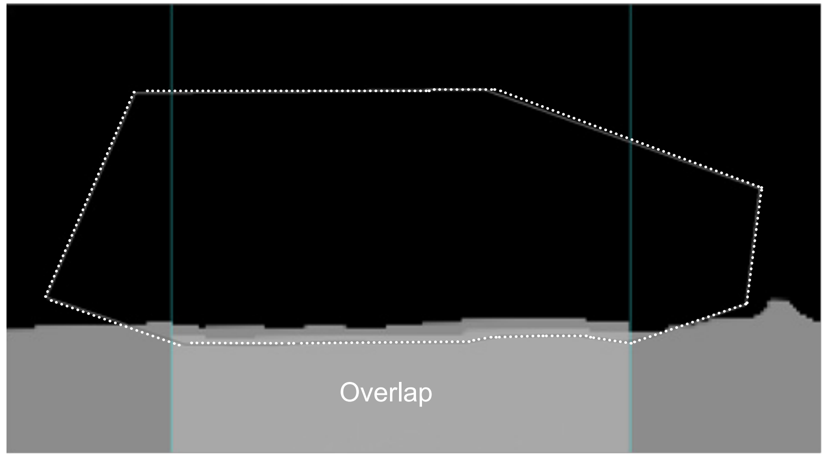




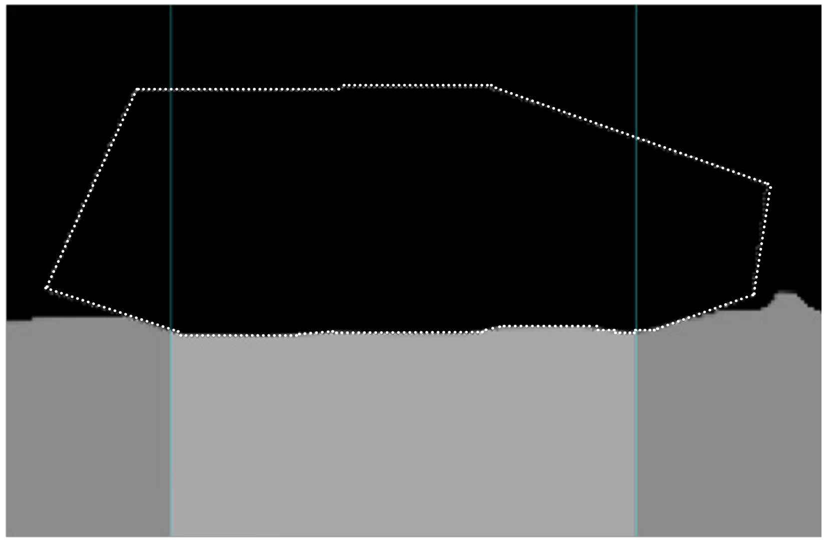
In order to preserve as much data as possible follow the contour of the overlapped border.

With the Lasso tools, enter the area at an angle (see next page) to ensure a smooth transition between tiles. Delete the selected area

9 Blend



Before

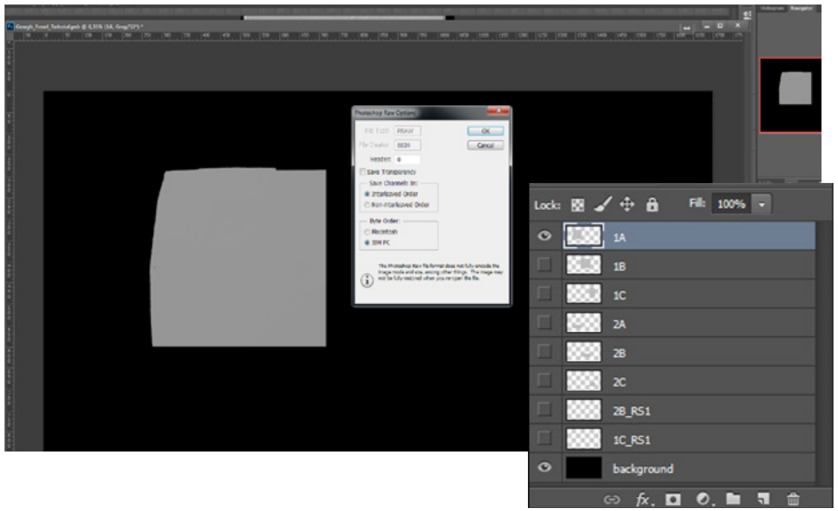


After

9 Blend

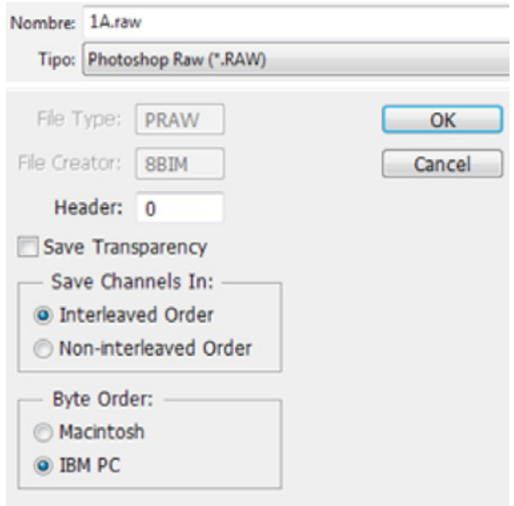
1.18 Change the opacity of the layers back to 100% and remove guides: View > Clear Guides.

1.19 Save one RAW file for each independent tile. To do this, turn off all layers except the tile to be saved and the background layer. Your Photoshop version must be able to save 32 bit RAW files (Photoshop CC or higher).



9 Blend

1. 20 File > Save As… > Save as the corresponding tile name (eg. 1A) and as a RAW file.



Specify under Byte Order that it is for IBM PC.

After all tiles have been saved, the files can now be blended in the Lucida Blending Application.

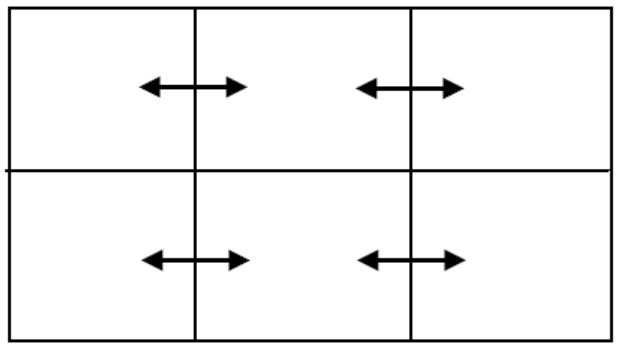
1.21 Save the Photoshop file in case you need to go back and make corrections.

9 Blend

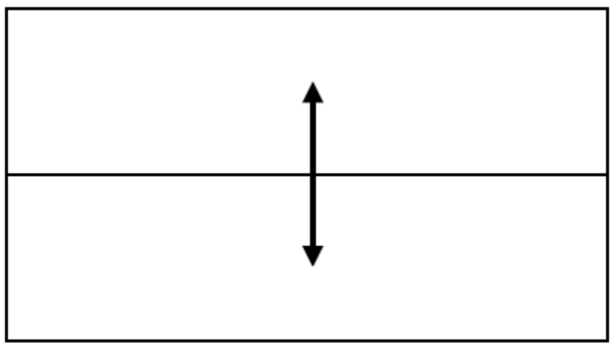
2. Input into Lucida Blending Application

The Lucida Blending Application blends the tiles by aligning the z-axis. Usually, the tiles are first blended horizontally in terms of each row. The results are then blended vertically to create a complete 3D file. The order of blending may vary depending on the nature of the project.

Step 1: Horizontal Blending



Step 2: Vertical Blending

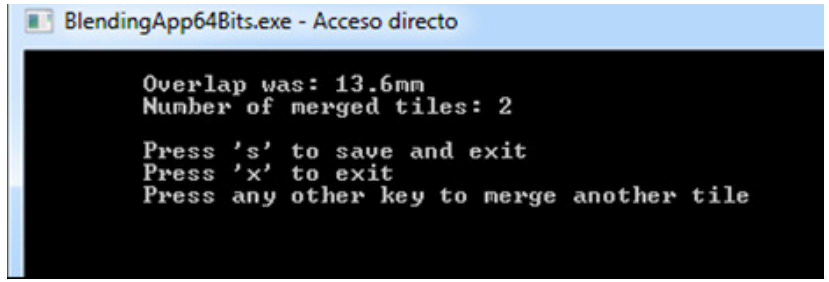


9 Blend

2.1 Start the Horizontal Blending Application: BlendingApp64bits.exe

2.2 The message 'Please load the first file' will appear. Navigate to the correct folder and load tile1A.

2.3 When prompted load tile 1B.



Note: the overlap amount falls comfortably within the 10-25 mm range (in this example: 13.6 mm). If the value is out of range it means there is a problem with the preparation of the files in Photoshop. If this is the case, go back to the Photoshop file and review.

2.4 Press any key except '**s**' and '**x**' and load the last horizontal tile for row 1, 1C.

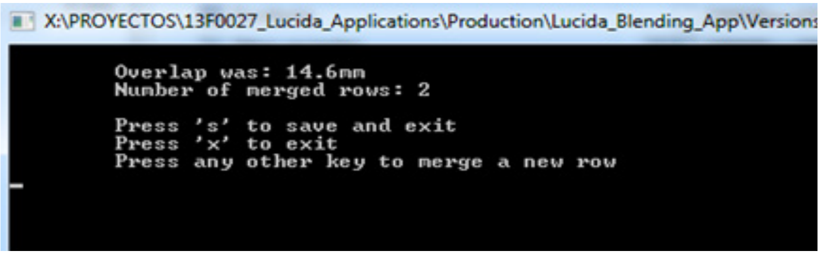
2.5 When all horizontal tiles have been blended for this row press '**s**' and save as '**1.raw**'. The saved file should be in RAW format, although this will not be an option on the computer. This must be inputted manually by adding ´File_Name.raw´.

2.6 Repeat this process for row 2 (tiles 2A, 2B and 2C) and save the row as '**2.raw**'.

9 Blend

2.7 Blend the two rows using the Vertical Blending Application: 23000Blend2Rows.exe

2.8 Open the Application and load '**1.raw'** into the App. When asked, load '**2.raw**'.



Again, note that the overlap is between 10 and 25 mm. This means the files have been successfully blended.

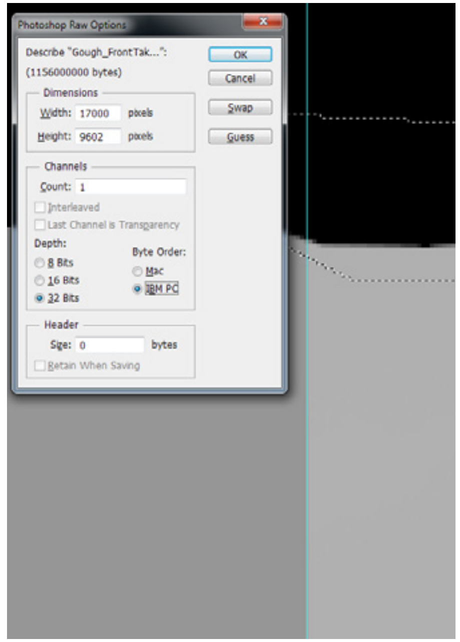
2.9 Press '**s**'and be sure to add '**.raw**' to the end of the file name.

2.10 Open the final RAW file in Photoshop. Note that Photoshop will not recognise the file in this format. In order to open the file, alter the following parameters in the Photoshop Raw Options tab (illustrated on the next page):

Width: 17000 pixels
Height: 9602 pixels
Depth: 32 bits
Byte Order: IBM PC
> OK

Specified image is smaller than file, open anyway? > OK

9 Blend

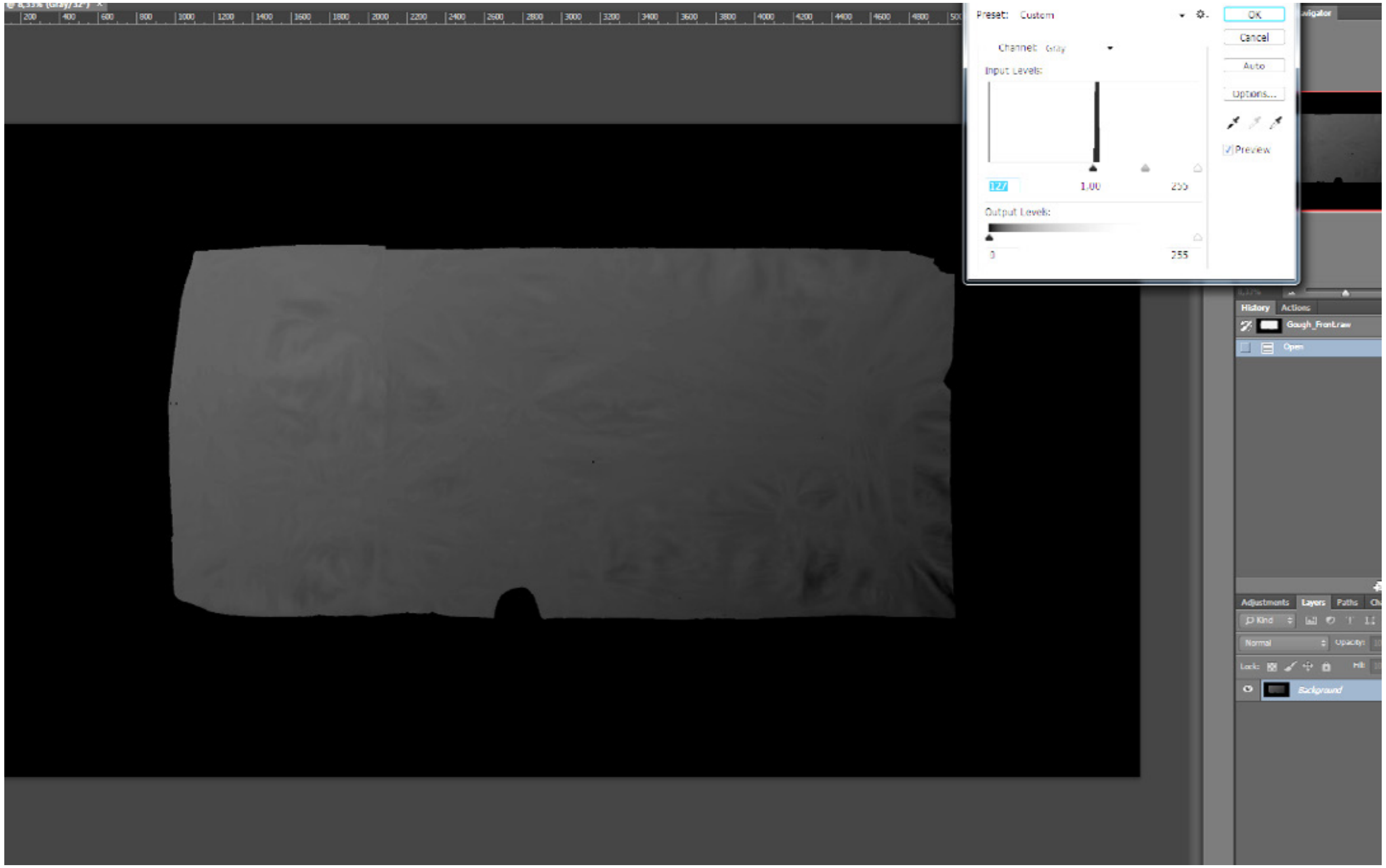


2.11 Use the levels to check that there are no mistakes in blending. Go to Image > Adjustments > Levels.

Move the black arrow on the left (under Input Levels) closer to the middle arrow and notice the change in levels of the image. By doing this you will be able to see the relief of the file (see next page).

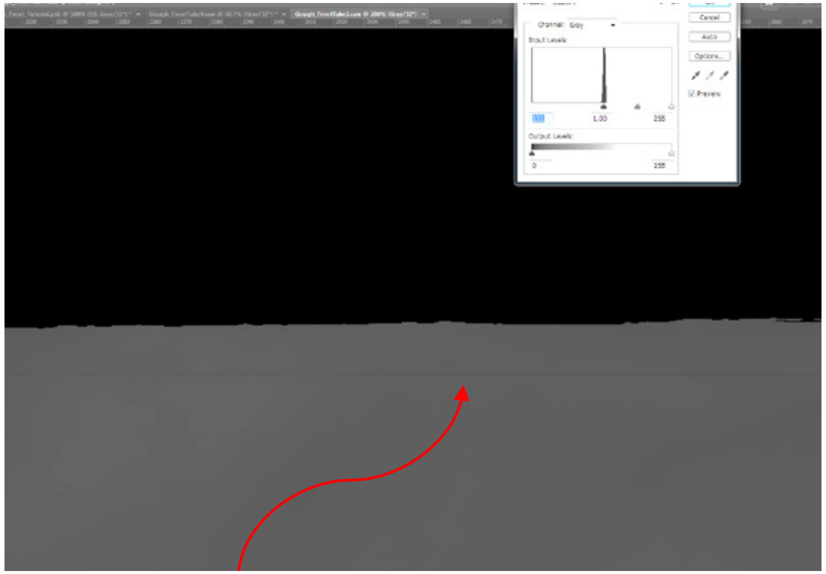
9 Blend

9 Blend



2.13 Highlight the adjustment shadow input level number (box on far left) and zoom in close to the image. Use the mouse wheel to adjust the numerical value in the adjustment shadow input level box. Simultaneously adjust the levels and navigate across the image (especially the borders) in order to view any discrepancies.

9 Blend



The image above shows that there was a problem with the blending procedure, indicated by the rigid line. When checking for discrepancies be sure to notice anything that seems out of character with the texture of the surface you are scanning e.g. something too uniform or straight, particularily along the edges. If problems are found, return to the preparation of the files in Photoshop and check that the overlapped borders have been evened out and that all the outlined parameters are met.

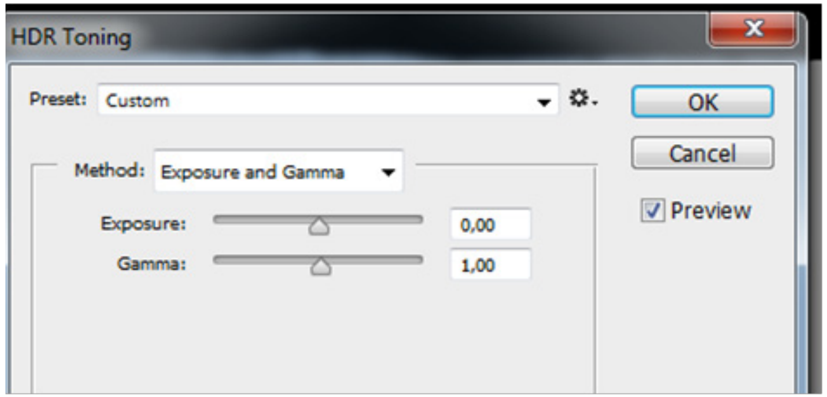
9 Blend

2.14 When happy with the blending, change the resolution. The Blending App changes the resolution of the file to 72 ppi and it must be changed back to 254 ppi before proceeding:

> Image > Image Size > Resample: Off (unchecked) >
> Resolution: 254 pixels/inch

2.15 Save the file as: ´[name of work]_3D_254ppi_32bit ´.

2.16 Go to Image > Mode > Change to 16 bit. In the HDR Toning Window change the following parameters:



Preset: Custom
Method: Exposure and Gamma
> OK

9 Blend

3. Overlap less than the acceptable range

Errors can can occur during the recording phase that result in a miscalculation of the required overlap. This often happens when the surface being scanned is very large and the scanner frame has to be moved between scanning sessions - the distance between tiles might be incorrectly calulated.

In such cases, the blending application will automatically reject a tile and will display the message "*Overlap less than 10 mm*" before terminating. This problem must be solved in Photoshop before the file is sent to the blending application.

3.1 Open the two tiles that share an overlap of less than 10mm in a new Photoshop file.

3.2 Measure the exact overlap between tiles to work out the percentage by which you need to enlarge the image.

For example, if the overlap is 8mm and we want to change it to 11mm, perform the following calculation:

8 : 11
100 :x
x = (100 * 11) / 8 = 137.5 %

This means the file has to be enlarged by 37.5.

3.3 Go to Image >> Image size and take note of the image size – width and height.

9 Blend

Important: keep these figures as they will be needed to return the images to their original size in 4.6.

3.4 In 'Image size' change the dimension units to percent and insert the new percentage. Note the new dimensions of the fi**le.**

The overlap between the two tiles will increase to meet the acceptable range in the blending application.

3.5 Continue the procedure as stated above – in the following order:

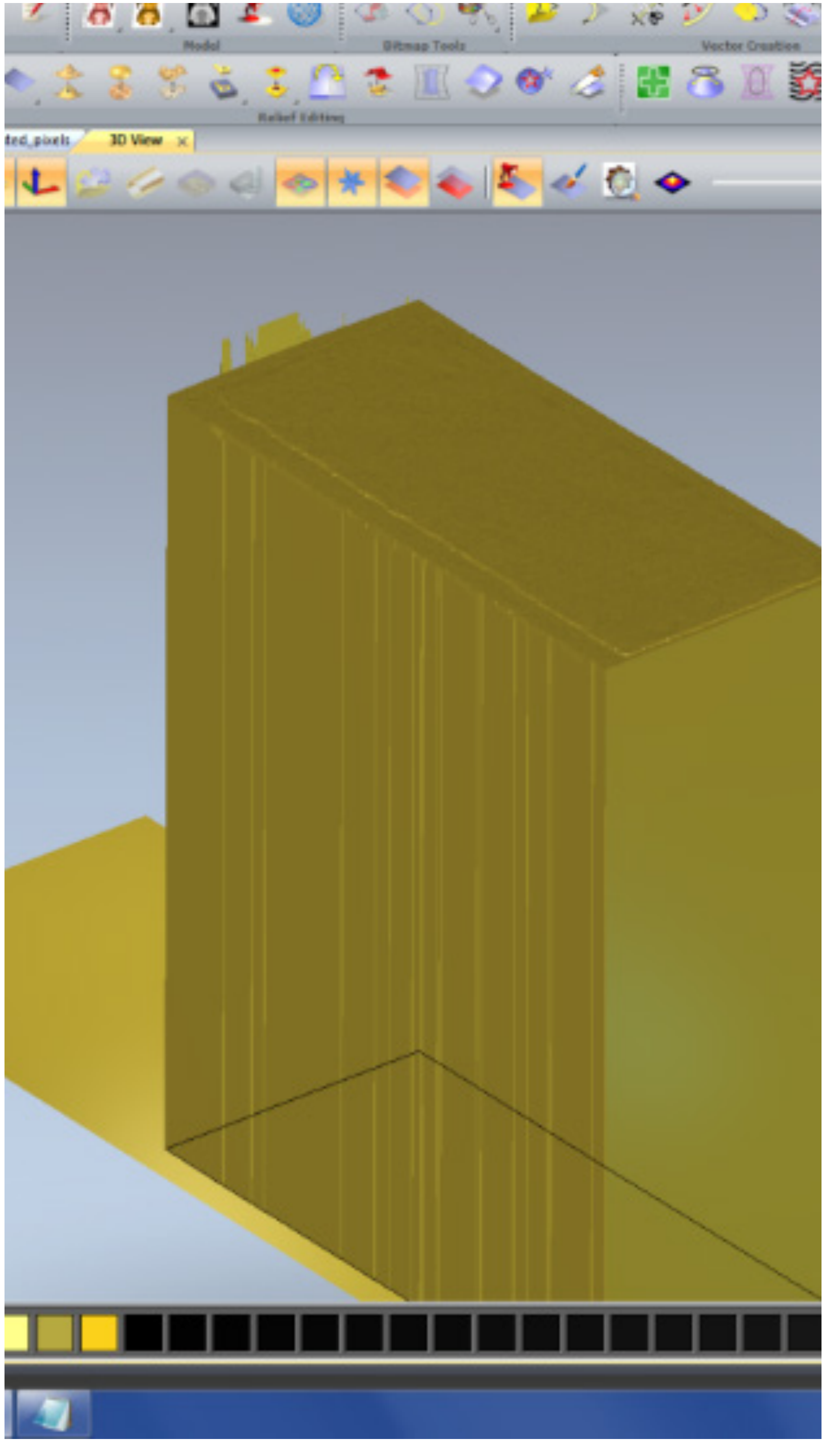
- Trim overlap
- Adjust overlap edges
- Name tiles
- Change canvas size to (17000x9602)
- Save tiles separately in raw format
- Input the tiles into the blending application.
- Blend tiles
- Check result in photoshop

3.6 Open the resultant raw file from the blending application on to Photoshop and return the image to its original size.

Go to Image >> Canvas size. Change the canvas size.

3.7 Place the newly blended tile in its exact location within the main file and continue the file preparation process. Always treat the outcome of

Table of Contents: *Further Processing*



10

Importing to ArtCAM

10 Importing to ArtCAM

Importing Lucida reliefs into ArtCAM

This section explains how to import Lucida reliefs into ArtCAM, an Autodesk software that can be used to edit 3D files in preparation for CNC milling. This tutorial has been written for Artcam 2012 Pro and Photoshop CS6, but similar tools will be available in other versions.

1.1 Prepare the file in Photoshop. The file must be **16-bit TIFF** – this is the resolution used by ArtCAM.

Note: in order to avoid height distortion when working with Lucida reliefs in Photoshop, load the “Lucida_depthMaps_linearity.csf” colour profile. This colour profile is provided with the Lucida software distribution. To load the colour profile:

- Select Edit -> Colour Adjustment
- A dialogue window will appear
- Select “Load”
- Find the Lucida_depthMaps_linearity.csf file
- Click Ok

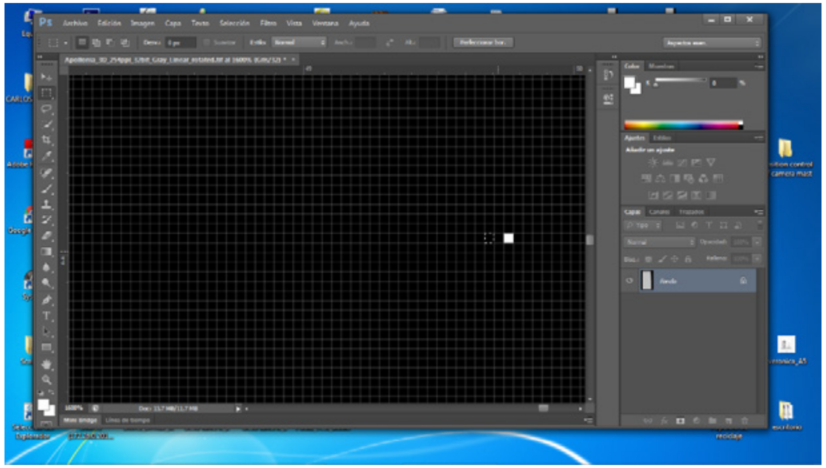
Now, the linear colour profile is selected by default.

1.2 Zoom into one corner of the file until the pixels are visible.

1.3 With the rectangular selection tool select a small number of pixels

1.4 Right-click inside the selected area and press Fill.

10 Importing to ArtCAM



1.5 In the dialogue window,choose ‘**black**’ from the dropdown menu to fill the pixels in black.

1.6 Repeat steps 1.2-1.4 but choose ‘white’ from the dropdown menu to fill pixels in white.

1.7 Zoom out. Zoom into the corner diagonally opposite. Repeat steps 1.2-1.6.

At the end of steps 1.2-1, you will have marked two corners. These black and white marked pixels are used by ArtCAM to establish the depth range of the file.

If at this point you were working on the RAW file then proceed with step 1.8 – otherwise move onto step 1.11.

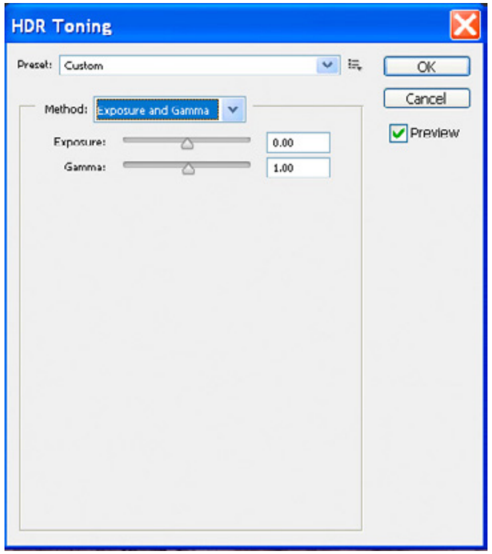
1.8 Select Image -> Mode -> 16bits/channel

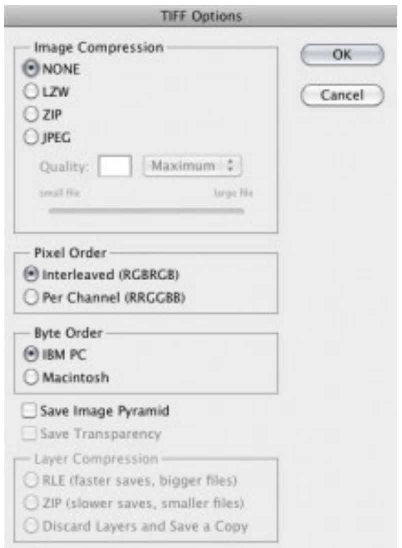
10 Importing to ArtCAM

1.9 The HDR Toning window will appear. On this window select:

Method -> Exposure and Gamma with the following parameters:

Exposure = 0
Gamma = 1





1.10 Save the file as a TIFF file, selecting the following:

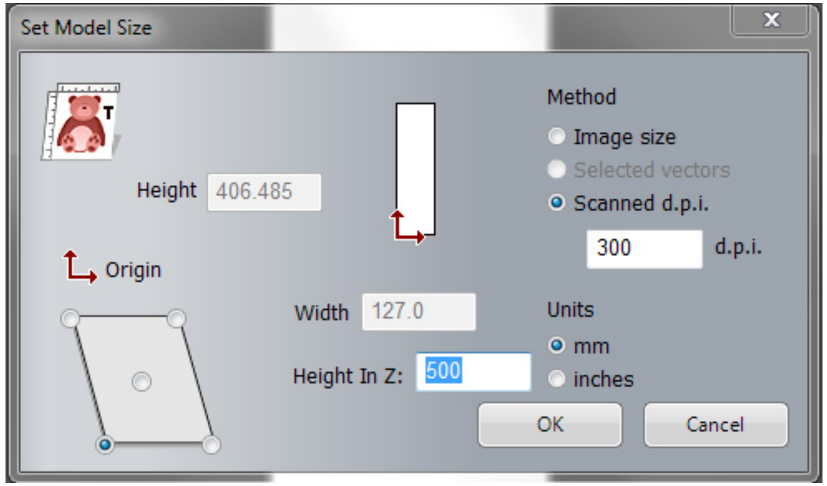
- No compression
- Interleaved px order
- IBM PC byte order

10 Importing to ArtCAM

1.11 Open the Artcam software

1.12 Select File->New->From Image File

1.14 A dialogue window with the dimensions of the relief will appear. Set the “Height in Z” field to 500mm.



ArtCAM will measure the different depths of the grey scale image using the 500mm scale: pure black will mark the lowermost and pure white the uppermost points in the scale.

1.15 Press OK to finish importing the file

11

Rotating reliefs

11 Rotating reliefs

Rotating Lucida reliefs

A seemingly planar surface captured with Lucida may present some degree of tilt due to the fact that the scanned surface and the scanner mast can never be completely parallel. Sometimes, it can be interesting to correct this tilt: for example, in order to save material when rematerializing.

This section describes how to automatically rotate a relief generated with Lucida to correct the tilt.

For doing this a script has been implemented to performs the following actions:

1. Calculates the mean plane of the relief. This is done using a best fit plane algorithm as described in http://www.geometrictools.com/Documentation/LeastSquaresFitting.pdf
2. Calculates the angles of the mean plane to the horizontal plane.
3. Knowing the angles, then applies a rotation to the whole relief to render it horizontal.

Note that currently this script works only with planar or symmetrical reliefs. The script does not work well with irregular reliefs made up of several areas of different heights.

1. Install the script
Download and uncompress the folder BestFitPlane. Inside it is the executable program that runs the script.

In order to run the BestFitPlane program you need to install the Visual C++ Redistributable package in your computer
http://www.microsoft.com/en-us/download/details.aspx?id=14632

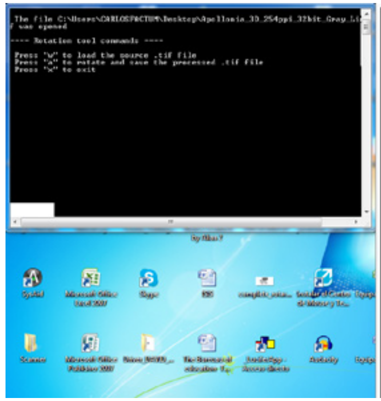
11 Rotating reliefs

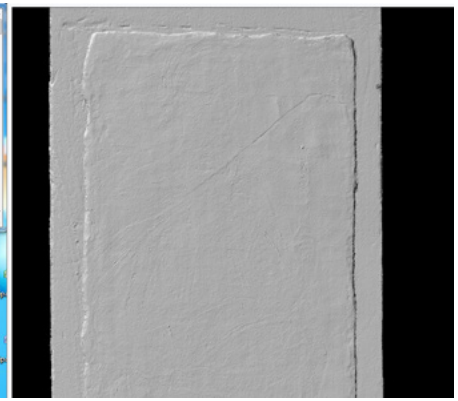
2. Run the file BestFitPlane.exe

3. The program will bring up a dialog window asking the user to select the relief file. It has to be a 32 bit Tif image containing the relief depthmap.

4. Once the file has been selected selected and opened, the user will see a preview window showing the rotated relief.

5. Press “a” to process and save the image. The rotated relief is saved as a 32 bit Tif image.





12
Colour registration

<<<
Detail from colur data of the Selden Map (Bodleian Library, Oxford)

12 Colour registration

Registering colour information onto Lucida reliefs

Start by working on the 3D file...

1. Open 3D shaded file on Photoshop

2. Change to Gray Scale: Image › Mode › Gray Scale

3. Assign Profile to Gray Gamma 2.2: Edit › Assign Profile › Gray Gamma 2.2

4. Change the resolution from 300dpi to 254 dpi. Allow the file to re-siz eautomatically.

5. Take note of the new size of the file: this will be the 'official size'.

Now start working on the colour file...

6. Open Colour file on Photoshop

7. Check that the dimensions of the file are the same as the 'official size' determined in Step 5. If they are not, change them to the 'official size' in Image › Image size

8. Take note of the resolution (it should normally be between 500 - 600 dpi).

Again, work on the 3D file...

9. Set the resolution on the 3D file to be the resolution read on the Colour file. Do not change the size of the 3D image. This can be done by checking the Resample box which unties the relationship between the size and the resolution.

12 Colour registration

10. Adjust mode to: RGB - 16 bit

11. Convert the profile to Prophoto RGB: Edit › Convert Profile › Prophoto RGB › Ok

12. The 3D file can now accept the colour layer. Drag the colour layer onto the 3D layer.

The final steps are carried out with both the colour and 3D files...

13. Record all the actions you perform in the following steps.

14. First, fit the two files onto each other as well as possible without distorting the files.

15. Then enter the Free Transformation mode: Ctrl+T

- First resize
- Then right click distort
- Finally right click Warp

16. After adjusting the image as well as possible, check for local problems and fix them by warping the problematic area using the Local warp tool.

13 Multilayered viewers

<<<
Detail from colur data of the Selden Map (Bodleian Library, Oxford)

13 Multilayered viewers

Creating multilayered viewers

The multilayered viewers created at Factum can integrate different types of data into one easy-to-use Flash-powered internet browsers. It's possible to integrate Lucida 3D data and high-resolution colour but also register, for example, older images or infrared data onto the 3D data. These browsers can be of great use for researchers who want to compare various dataset of one object or painting.

- Get the color and 3D rendering file
- Open the 3D rendering file in Photoshop
- Rotate the file 90°
- (That allocates the file into the orientation it is supposed to be viewed in.)
- Check its real size by
- Menu Image>Image Size
- Uncheck "resample"
- Set resolution to 254dpi (0.1mm per pixel)
- Click "OK"
- Open the Color file
- Check its real size and set units to cm or mm
- Measure a known distance
- Open Image Size
- Change dpi with resampling unchecked
- New dpi= current dpi*(current measure/real distance)
- Measure again the know distance
- Make sure that the value is correct
- Note the new dpi value
- Go back to the rendered 3D file
- Menu Image>Image Size…
- Check "resample", choose bicubic
- Set the resolution value below the value noted above

For example if you have 460dpi for the color file, choose 400dpi. The change is necessary as during the registration process a level of detail

13 Multilayered viewers

will be lost and having a lower final resolution makes sense. In this point use common sense and experience.

- Click "OK"
- Select all and copy
- Go to the Color file
- Paste the 3D rendering

It is important to follow the order as presented and not paste the color on the 3D for the color profile to be preserved, thus the color file is kept and respected.

- Read jdpi by going into menu Image>Image Size
- Uncheck "resample"
- Set resolution to the resolution chosen for the 3D file
- The next steps outline the registration process...
- Register the files in one transformation

It is very important to do the registration in one and only one transformation as several would damage the image quality significantly.

- Stay at 16 bits when doing the registration
- Leave the 3D layer at bottom of file
- Just above create an adjustment Levels layer and compress the histogram

This increases contrast and makes the registration process easier. Note that adjustment layer is nondestructive.

- Change the opacity of Color Layer to be above 50%

The value may differ depending upon the file that one is working on. Try to maintain a suitable for the particular file.

- Select color layer >> layers palette
- Deselect all - Menu select>Deselect
- Start transform by Menu Edit>Free Transform
- Scale the color layer approximately to the 3D layer
- In the status bar of the tool, just under the main bar of Photoshop Window there is a menu "Interpolation". This is where the type of interpolation for the whole transform is chosen.
- Choosing "bicubic sharper" will sharpen a bit when applying the transform, but don't apply the transform yet.
- Right-click in the transform box and choose

13 Multilayered viewers

- "Distort"
- Adjust the 4 corners - one after the other
- Make another round, to register the corners; at this point only corners count. Now all 4 corners are well registered and checked.
- Right-click again in box and choose "Warp"
- Be careful and systematic
- Make only small movements
- Start with center of every edge between the corners
- Register the sections
- Recheck the corners in the process
- Register the center of the painting
- Check again center of edges and corners; check center
- Keep checking and registering the layers

It is important to do this process repetitively because every move may slightly unregister other parts, so when going through the process repeatedly the end result of the file is more precise. Also the registration of the overall file is gets closer to the original and the percentage error is reduced to minimal.

- Check the file one final time
- Validate the whole transform (Free, Distort, Warp)
- Press the enter key on the keyboard.

It might take some time for the transform to reach completion.

- Change the color layer opacity to 100%
- Go around the file at 25-50% zoom
- Keep switching color layer on and off – checking that the registration is ok

If the transformation is faulty in the slightest, revert it in history window to the step before the transformation and the entire transformation process must be repeated.

- Delete the adjustment layer
- Make contrast in the 3D layer, keeping only 3D and color layers in the file.
- Crop the file to a suitable - the 3D layer is the limit
- Save the file under a new name, with
- "Name_16bits" or "Name_8bits"

13 Multilayered viewers

This is your Archive registered file

- Apply some Smart Sharpen or Unsharp Mask filters as needed

Usually a value like 0.8 pixels 80-100% should be reasonable and conservative enough.

- Bring 16bits file down to 8bits
- Convert profile to RGB
- Save under a new name that contains "8bits RGB"
- This file is for the viewers

Creating individual files for layers

These files are used later for creating tiles by KRPano

- Open the file created above to be used for viewers
- Create an adjustment layer "Solid color" >> black
- Put the adjustment layer at very bottom

The adjustment layer is created due to the fact that the Color Layer was distorted to fit 3D and its edges might have come in and create transparency on the edges that we want black.

- Hide 3D layer
- Make sure Color Layer >> 100% opacity
- Save as a Copy
- Uncheck "layers"

Unchecking "layers" will flatten the file for the save.

- Name the file: color.psb or color.psd or color.tif
- After Saving hide the color layer
- Show 3D layer
- Make sure 3D Layer >> 100% opacity
- Add an "adjustment Levels" layer

The adjustment Levels layer aims to slightly contrast the 3D layer for the viewer

- Save as a Copy; Uncheck "layers"

Unchecking "layers" will flatten the file for the save.

- Name the file: 3D.psb or 3D.psd or 3D.tif
- Keep this file in the color profile
- After Saving:
- Show all layers
- Set color layer opacity >> 30-50%
- Adjust the adjustment levels layer to add contrast to the 3D layer

13 Multilayered viewers

This makes the 3D layer underneath more visible and displays the present information clearly.

- Save as a Copy

Once the composite Color-3D file looks as you want it to for the"50%" layer in the viewer.

- Uncheck "layers"

Unchecking “layers” will flatten the file for the save.

- Name the file: color3D50pc.psb or
- color3D50pc.psd or color3D50pc.tif

Just "color3D50pc" for the name is fine

- Close your file WITHOUT SAVING

Only save if you are sure you didn't flatten anything and want to keep added information, such as the adjustment layers.

Creating the individual viewers with krpano

- Download KRPano.
- http://www.highres.factum-arte.org/downloads/
- Unzip the KrPano folder
- Use only the file by the name "MAKE PANO
- (MULTIRES) droplet.app"
- (However, keep all together as it is.)
- Create 3 folders >> "3D" "color" and "color3D50pc"
- Place the corresponding files created above into their respective folders
- One after the other, drag and drop these files onto
- "MAKE PANO (MULTIRES) droplet.app"
- The app opened a Terminal Window that will ask you if the file is a flat partial panorama, that should be the choice "1".

Then the terminal window will show the progress as tiles and other files are created in the folder where the dropped file was.

- Do the same process for all 3 image
- Now you have the three folders check that the above steps have been conducted correctly by launching the html file within each folder
- Encrypt the jpeg tiles
- *This is done so that the images cannot be accessed without the licensed viewer.*
- Open the "krpano Protect Tool.app": "krpano Protect Tool.app" is found in the KRPano folder.

13 Multilayered viewers

- Go to the "License Setupo" tab
- Check that the fields for license are filled with
- "Registered to: greg@factum-arte.com
- Branding free license is not filled
- Go to "Encryption-Tool" tab
- Uncheck all boxes at bottom of window
- For each folder produced above:
- Click "Add Folder"
- Choose the folder called "*.tiles"
- The tiles in that folder are loaded in the File list in the window
- Click "Encrypt Files"
- Repeat with each of the viewers folders to upload
- Close the encryption application

Uploading the viewers to the server

- You will need to create a tar archive file to upload because uploading tiles as folders like this can take a very long time. Place all your viewers into a single folder called "viewers". Make sure the large image files used for
- producing the viewers are out as we don't want them uploaded.
- Open Terminal in OSX and type "cd "

Include a space after cd. - cd meaning "change directory"

- Drag and drop the folder containing the folder containing your viewers (called "viewers")
- *You will find the folder in the Finder onto the terminal window.*
- The Terminal window active, press enter or return

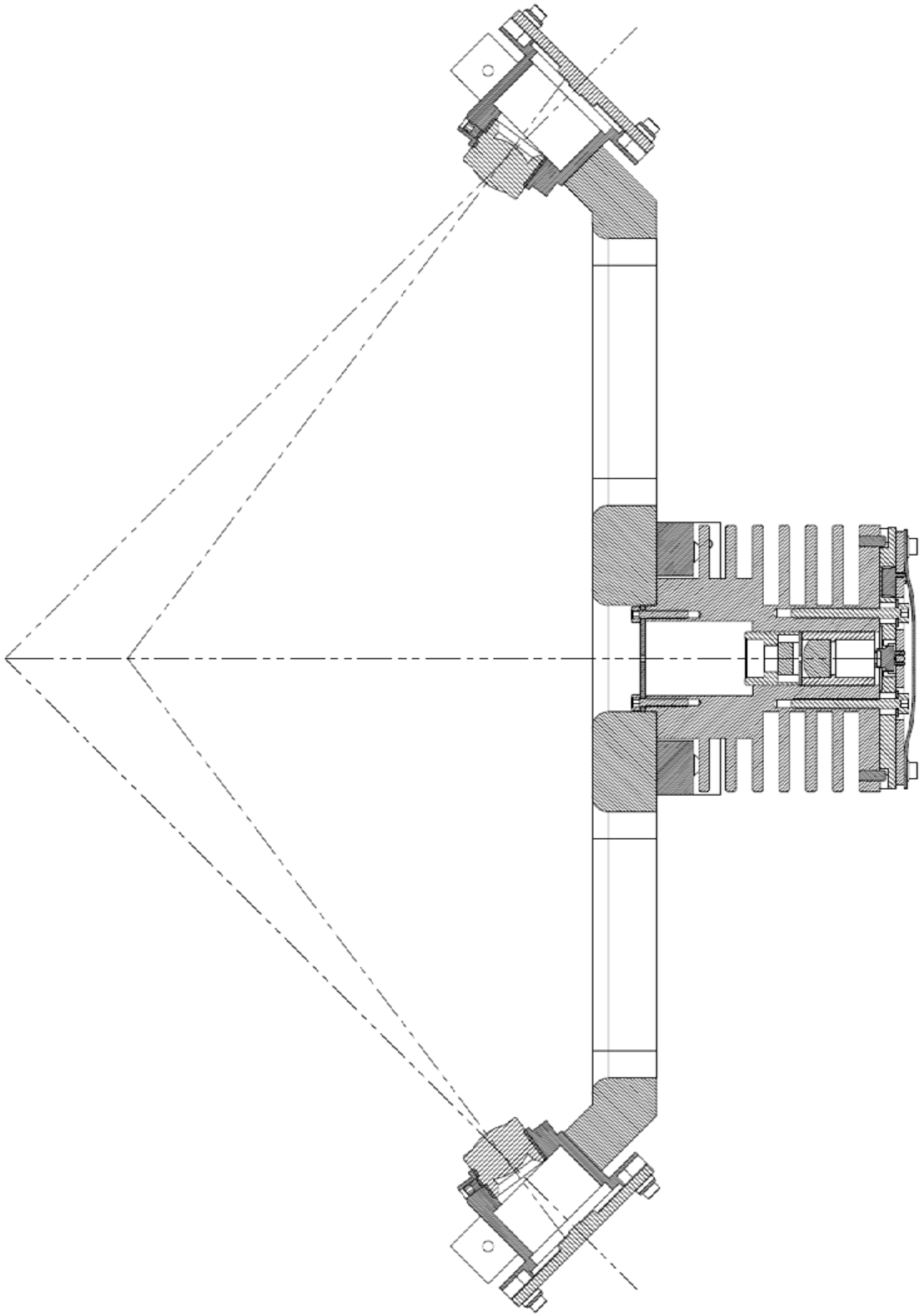
We just told the terminal to change root director so operations will happen in that directory (folder).

- Create the archive tar file with a name related to the viewer "virgin.tar", no space or spacial characters in the name. Now type in the terminal: "tar cvf virgin.tar viewers"

That means: create a tar file called virgin.tar, of the folder called viewers that sits within the cd we just did before.

- Use an ftp client (Cyperduck on Mac OS: http://cyberduck.ch):
- Open a connection to: ftp.factum-arte.org with username: "factumar-vie" password: "xxxxxxxxxx"
- When connection is established, upload the tar file in that ftp.

Table of Contents: *Component Assembly*



14

Assembling the scanning head

<<<

Diagram of the Lucida scanning head showing the positioning of the cameras

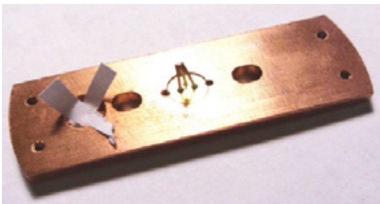
14 Assembling the head

This tutorial is designed as a reminder for someone who has already assembled several heads with the help of one of Factum's operators. It takes the user through the steps required with the aid of pictures.

1. Mounting the laser board

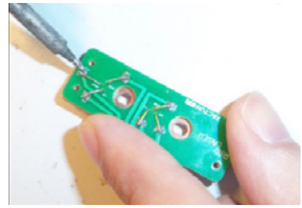
Components:	
PCB Board	Temperature sensor
Laser diode	Copper Plate
Plain white paper	Tin (0.5mm)
4 M1.6x3 screws	6 pin male header strip
Tools:	
Solder Allen Key	

1.1 Star by mounting the laser diode and temperature sensor onto the copper plate. Make sure that the pins of both components correspond to the positions of the holes on the PCB board.

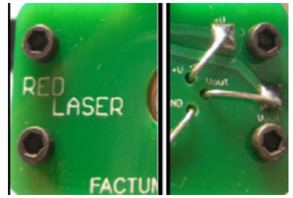


Before placing the temp. sensor onto the copper plate, cut 3 thin, short strips of plain white paper (approximately 2mm wide). Then add glue to one edge of each strip and glue them to the bottom of the temperature sensor groove. The paper forms a basket-like structure which insulates the temperature sensor from the copper plate. Now you are ready to attach the temperature sensor. Once it has been attached, cut off the extra paper.

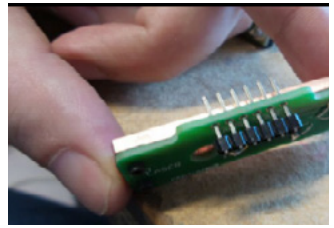
14 Assembling the head



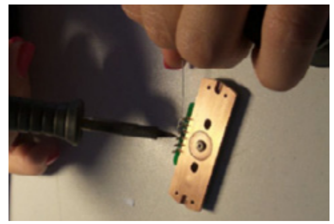
1.2 The copper plate be joined to the PCB board. Place the PCB board onto the copper plate the three laser diode pins and 3 temperature sensor pins through their corresponding holes onto the PCB board. Solder them onto the PCB board using tin (0.5mm) and a solder.



1.3 To secure the PCB board onto the copper plate use 4 (M1.6x3) screws to attach its four corners.



1.4 Now, take the 6-pin male header strip and press the plastic part to one side of the pins, in order to make them longer so that they can be attached properly to the trigger board.



1.5 Finally, attach the 6-pin male header strip to the top of the PCB board through its six holds and solder it to the board.

14 Assembling the head

2. Mounting the laser module

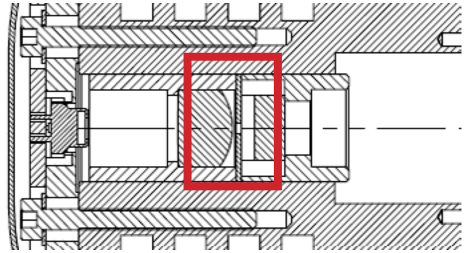
Components:	
Laser Structure	Convex Lens
Convex Lens Holder	Polarizing Plate
Aspherical Lens	Aspherical Lens Holder
Araldite glue	2 M2x5 screws
Tools:	
Allen Key	Cutter
Plastic Tube	

2.1 Place both the aspherical and convex lenses each into their corresponding lens holder. Note that the curved part of the convex lens must have an upward orientation

2.2 To secure both lenses in place, carefully apply Araldite glue on to the edges of the lenses using a thin tool – for example, a pin. For the aspherical lens, the glue is applied onto the sides through two holes on the lens holder; but for the convex lens the glue is added from the top in the area between the edges of the lens and the edges of the lens holder.

14 Assembling the head

2.3 Once the glue is dry, position the polarising plate on top of the convex lens holder.

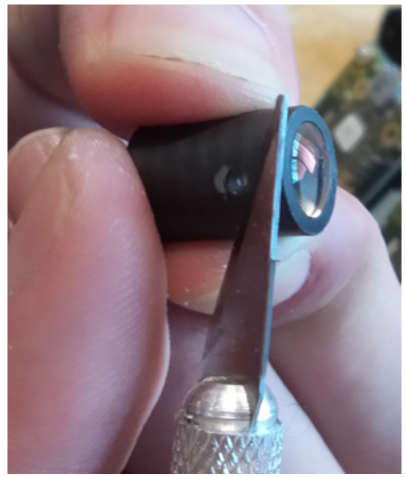


Now the lens holders can be joined onto the laser structure...

2.4 Start by positioning the convex lens holder in place, while maintaining a vertical orientation for the polarising plate – the same orientation through which the laser beam will be projected onto the surface of the scanned object. Push the lens holder into the hole of the laser structure using a plastic tube of the same size as the lens holder.

2.5 Scrape off any extra dry glue from the aspherical lens-holder – so that it can fit easily – then push it behind the convex lens-holder.

Note: It is very important to keep the lenses clean at all times using a cleaning air pump



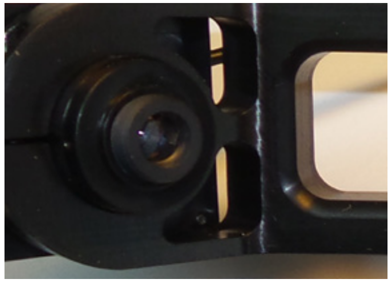
14 Assembling the head

3. Assembling the cameras

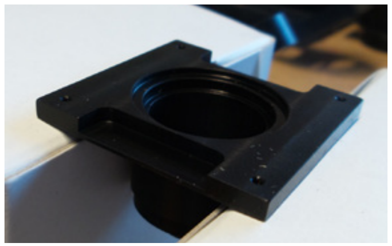
Components:	
Camera Bar	Isolator film
Camera Board	Lens
Lens Holder	Hexagonal star screwdriver
2 M3x16 screws	4 M1.6x6 screws
4 plastic washers M2x3	
Tools:	
Lens Handling tool	Cleaning Air Pump
Allen Key	

3.1 Make sure that the two lens-holders are facing one another as they are symmetrical. Positioning them correctly before assembly prevents errors such as inserting the cameras in the wrong orientation (see image).

3.2 Then, screw the lenses onto the lens-holders. The image shows the camera lens fastened onto the lens holder.

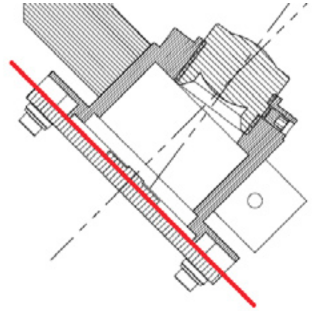


3.3 Place the lens holder in a well-supported position.



14 Assembling the head

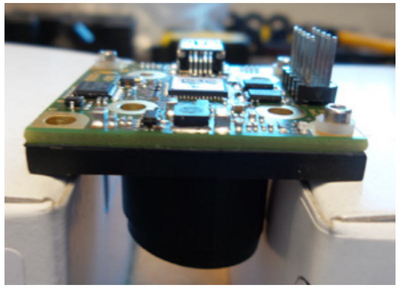
3.4 Place the isolator film on top of the lens – this is done so that there is no contact between the metal body of the lens-holder and the camera.



3.5 Use the hexagonal-star screwdriver to unscrew the four interior screws from the camera board that attach it to its protection.

3.6 Quickly and carefully remove the plastic cover from the camera board and place it on the isolator film. *This procedure should happen quickly because leaving the camera into the light, air and dust weakens its sensors and could damage it.*

3.7 Prepare four M1.6x6 screws and M2x3 washers. Place the washer in the correct position onto the board. Start adding the screws in a diagonal order for stability purposes. Finally, fix the camera holders to the camera bar using three Mx16 screws.



Note: The plastic washers are relatively longer than their screws thus it is necessary to cut the extra material and shorten the plastic washers

14 Assembling the head

4. Assembling the structure

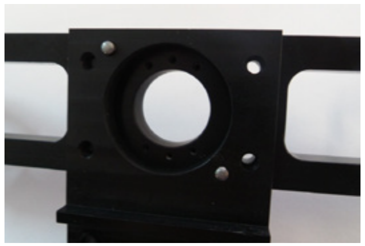
Components:

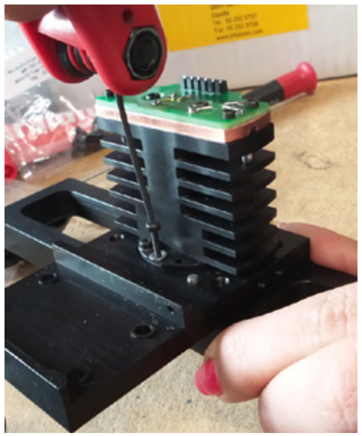
Camera Bar	Connection Plate
Laser Module	Cable-tray Bracket
Internal Clip	Protection Plate
6 M2 washers	6 (M2x10) screws
4 (M4x12) screws	2 (M3x5) screws
2 (M1.6x3) screws	1 (M2x5) screw
2 (M2x5) Grub screws	

Tools:

Allen Key	Hammer

4.1 To begin with, attach the camera bar to the connection plate using a set of 4 (M4x12) screws and two dowel pins.



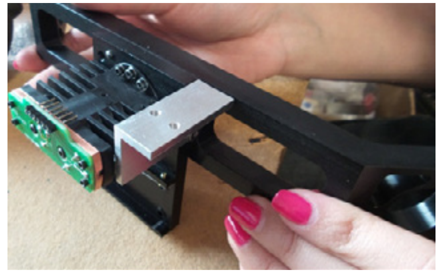


4.2 Now fix the laser module onto the connection plate using 6 (M2x10) screws and 6 M2 washers.

14 Assembling the head

4.3 Then, attach the cable-tray bracket to the side of the laser module using 2 (M3x5) screws. At this point, the scanner-head assembly is almost complete. Attach the internal clip to the connection plate using an (M2x5) screw.

4.4 Before proceeding any further, connect the Arduino board to the scanner head using a flatribbon cable and mount the scanner head onto its stand.



The scanner head is now ready for testing and laser alignment.

4.5 The laser beam must be adjusted to ensure that it can project in a vertical, centred line. Install the scanning head onto a horizontally placed backing frame – which will house the Perspex tool for laser

4.6 Place the LBR tool onto the horizontal guide beneath the scanner head and tighten it. Now with the same plastic tube that was used to insert the lens-holders, adjust the orientation of the convex lens-holder, making the slit on the polarizing plate completely vertical.

4.7 After adjusting the laser beam, tighten the two screws place the protection plate on the Laser structure and fix it with two (M1.6x3) screws.

14 Assembling the head

5. Configuring the laser

Components:
2 (M2x5) Grub screws

Tools:
Allen Key
Laser Adjustment tool
Laser Lens Adjusting Plastic tube

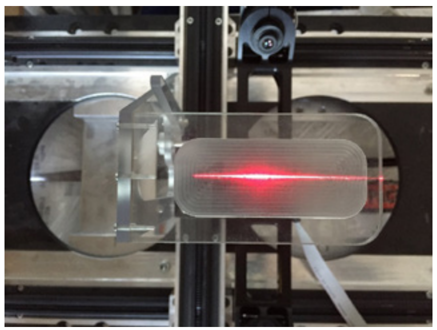
There are two main steps for adjusting the laser, the first of which is to make the laser line completely vertical.

5.1 To start, loosen the two grub screws at the side of the laser structure and place the laser adjustment tool on the horizontal guide. This tool is made of transparent acrylic; it has a grid of vertical engraves onto which the laser is projected.

5.2 Look at the laser on this grid: the laser lens adjusting plastic tube should be used to lightly rotate the convex lens until it reaches a completely vertical position. Now tighten the two grub screws.

The second step involves centring the laser beam projection onto the laser adjustment tool.

5.3 In order to centre the laser beam, untighten the two M2x5 screws at the back of the laser control board and shift the board slightly, until the laser beam projection reaches the centre of the laser adjustment



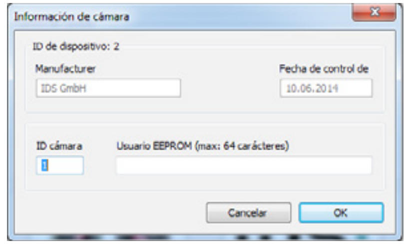
14 Assembling the head

6. Configuring and adjusting the cameras

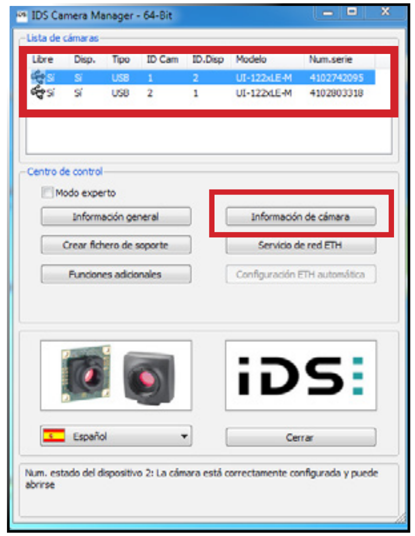
Components:
2 (M2x5) Grub screws

Tools:
Allen Key

6.1 Access the IDS Camera Manager software. This enables the user to change the ID number corresponding to the camera and allows the software to read it.



6.2 On IDS Camera Manager software, open the Camera Information tab and change the Camera ID to the necessary port number, For example Cam1 – Port 1 and Cam2 – Port 2.



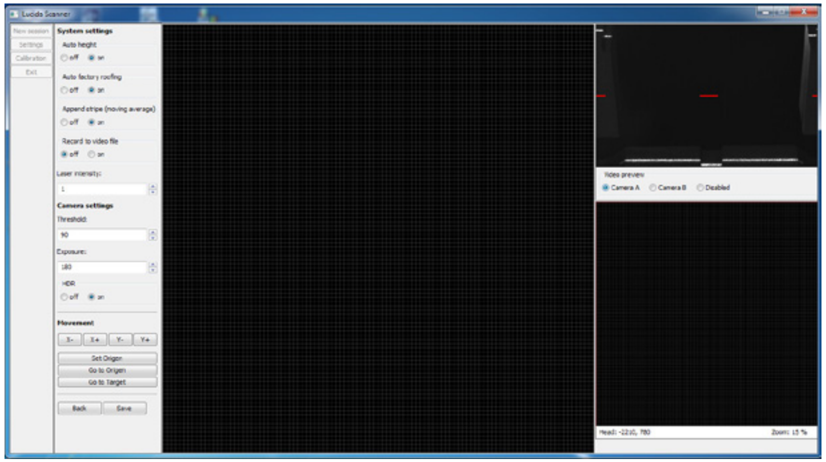
You can check the port number by unplugging one of the cameras. Then check the Camera View on the Lucida Application and the results will display immediately.

14 Assembling the head

6.3 After mounting the scanner head onto the horizontal guide and checking the necessary connections, open the Lucida Application. In the settings tab, check the camera window: start by identifying Camera A and Camera B.

Once identified, carry out the following steps with Cameras A and B:

- Adjust the focus of the lens by screwing it in/out: loosen the grub screw at the side of each Camera holder. Remember to re-tighten the grub screws once the focus is adjusted.
- Adjust the rotation angle by rotating the lens holder.
- Adjust the view-window by unscrewing the four screws at the back of the camera board (just enough to allow free motion). Shifting the camera board horizontally will appear on the live view window as vertical motion and vice versa.



14 Assembling the head

7. Troubleshooting

What if the scanner head is connected to the computer but the laser is not appearing?

There could be two problems: either the ribbon-cable connecting the trigger board to the Arduino or the USB cable connecting the Arduino to the computer are malfunctioning. Start by checking the connection of the two cables. If they are well connected and do not show any problems then check the trigger board and Arduino board connection through the shielded flat ribbon cable.

What if the Laser Line appears but is not projecting as a clean line?

This problem is very common once a scanner head has been finished and is and ready to go on the horizontal guide. The first step towards solving it is to unscrew the laser control unit and take out the laser lenses. Start by checking whether the glue has touched any part of the lens (the aspherical lens or the convex lens) edges. If the glue has found its way onto the surface of a lens, then this lens must be replaced. Otherwise clean both lenses thoroughly. The laser line should be clean again. For Changing the Laser Lenses Please refer to the section: Mounting the laser Module

What if the Laser intensity is lower than it should be?

This kind of problem can only be spotted once all the preparation steps are done and the scanner head is ready for calibration. At this point the laser intensity must be lowered to its minimum value which is “1” (this is why the calibration plate has a shiny metallic surface – the intensity value of “1” should be enough)

14 Assembling the head

The laser should appear as a clearly defined white line in the camera window. There is a problem if the line is dim or dark grey. However, it is best to carry on with the calibration and make sure that there is really a problem. When there is an evident problem no response will occur on the screen after pressing the “Pulse” button and the software will crash. Now you are sure there is a problem with the laser diode. If the process is repeated at a higher laser intensity, the calibration should work – but this not a solution.

A weak laser will later affect the scanning of dark surfaces and lead to data loss in the darker shades of the spectrum. The only solution is to change the laser diode.

Note: It is not necessary to change the entire copper plate or PBC board and would rather be considered a waste. For changing the laser diode please refer to section 15.

What if the scanner head – including the laser – was perfectly assembled but during calibration or scanning the software crashed or the scanner head moved without any information showing on the screen?

In this situation, the problem is probably related to the video wires connecting the two cameras to the trigger board. To ensure that the problem is coming from the video wires, test another scanner head with the wires from the malfunctioning head. If the problem persists then the video wires must be replaced.

Note: If you test the wires using the voltmeter, they might show positive results but if they are not functioning properly with the head, then they must be changed

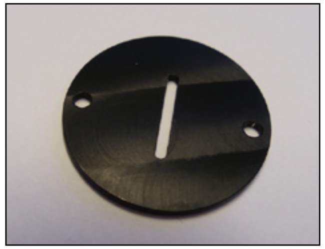
14 Assembling the head

What if the camera view in the settings tab detects the signal more slowly than it should?

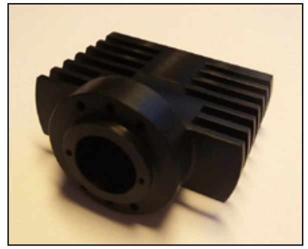
In this situation check the USB port that is used for the slow Camera(s), as the problem could be that the USB ports used for both cameras are sharing the same power supply on the computer and this will show a failure in detecting the signal. In this case, the cameras start performing poorly. You can solve this problem by plugging the camera USB in a different port.

8. Assembly components

This section lists the major components required to assemble the Lucida scanning head.

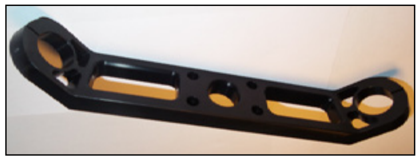


1. Camera bar



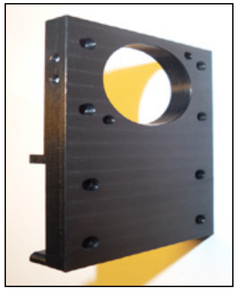
2. Laser structure

3. Laser lens protection plate

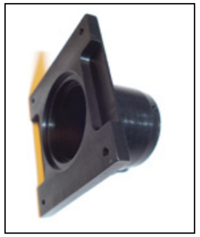


14 Assembling the head

4. Camera bar on connection plate



5. Connection plate

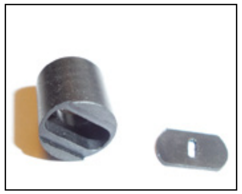


6. Camera holder

7. Aspherical lens-holder

10. Laser diode

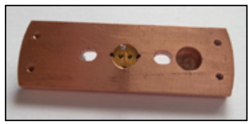
8. Convex lens



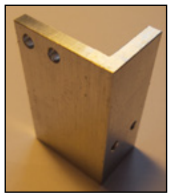
9. Convex lens-holder

11. Camera lenses

12. Copper plate - front



13. Copper plate - back



14. Cable tray bracket

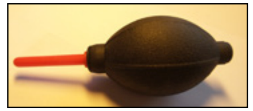
14 Assembling the head

9. Assembly tools

1. Lens handling tweezers

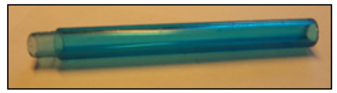
2. Allen key set

3. Cutter



4. Cleaning air pump

5. Hammer



6. Laser lens adjusting plastic tube

7. Solder and tin

8. Araldite glue

15 Assembling the control unit

15 Assembling the control unit

As with the previous tutorial on assembling the Lucida head, this tutorial is only designed as a reminder for someone who has already assembled several control units with the help of one of Factum's operators. It takes the user through the steps required with the aid of diagrams.

Assembling the Lucida control unit

Components:

3 controllers	An Arduino Board
10 M3x8 Screws	An Acrylic Base
Power Supply Cable (200 cm)	Flat Ribbon Cable (15 cm)
4 Conductor Cable (600 cm)	1 Ferrite for Power Supply Cable
1 Ferrite for Flat Ribbon Cable	
2 Ferrites for Flat Ribbon Cable divisions	
3 Motor connectors	

Tools:

A solder	Tin
Allen Key	Flat head screw driver

1. Place the three controllers and Arduino board in their corresponding locations on the acrylic base, then attach them using the 10 M3x8 screws. Tighten the screws.

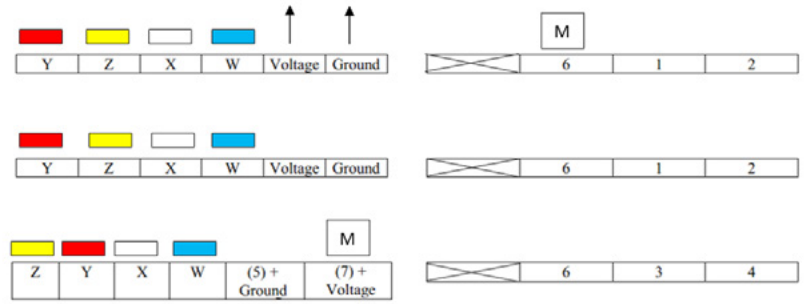
Note: Make sure that the Acrylic Base is placed on the right before positioning the screws.

2. Prepare 15 cm of flat ribbon cable.

3. On one end of the cable place a Ferrite and fix a connector, placing the red cable on the right side while connected to the PBC board. The flat ribbon cable will have 10 wire divisions, but only the first seven will be needed.

15 Assembling the control unit

4. Separate the first seven wires, starting with the red edge as N. 1 and place them in the sockets at the head of the 3 Controllers in the order shown in the diagram below:



5. Once each wire is placed in its location tighten the screw. For wire N. 5 and wire N. 6 fit on them a small Ferrite to reduce signal noise before placing them each in the corresponding socket.

6. Now prepare two 2.5 cm sections of the power supply cable

7. The power supply cable is made of two divisions one black and the other red. The black one will be used as the ground cable and the red one as the voltage cable. Separate the voltage and ground wires that you have prepared then place them in their sockets, as shown on the diagram above.

8. Then prepare 2-meter-long power supply cable. Place one end of the cable in the sockets on the third controller where the arrows are located on the diagram. Then solder the other end to the round connector.

Now start working on the motor wires...

15 Assembling the control unit

9. Prepare 3 sections of a conductor cable each 1.5m – 2m long (the length is dependent on the job that the set will be used for).

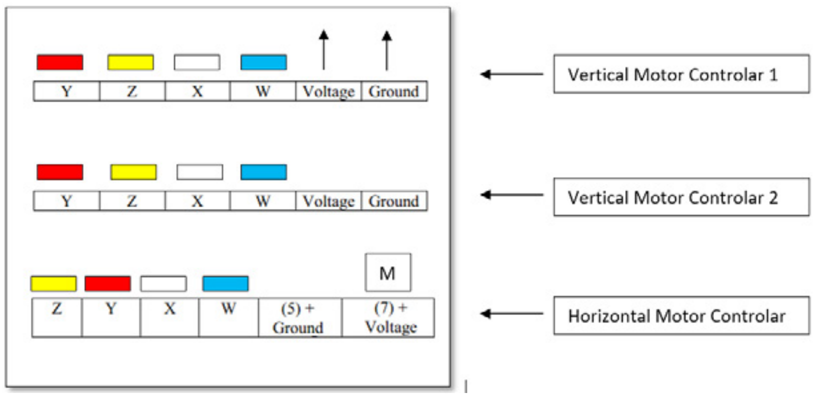
10. When the 3 wires are ready remove from each side 3cm – 4cm of the plastic coat, exposing the four inner wires on each side.

11. Then remove a section of the coat around 0.5 mm long to expose the copper wire. Solder the wires onto the connectors in the following order:

Red	Red
Red + White	Yellow
Green	Blue
Green + White	White

Note: if the colours are different try coming up with the best fit combination and remember to note it down

12. For the other end, place each conductor cable in a controller following the order shown below:



Appendix I: Types of 3D Scanning

It is essential that the right type of 3D recording isundertaken for each heritage site or object and that the application is considered prior to the recording phase of a project. A facsimile, for example, requires the acquisition of very high-resolution data, with particular attention paid to the surface of the object. However, in general, the more complete the dataset – a good dataset would comprise, for example, high-resolution colour, high-resolution surface texture as well as an accurate rendition of shape – the more uses it will have for academic, conservation and research purposes.

All systems used by Factum Arte and Factum Foundation are 100% non-contact and meet the highest conservation standards. The lighting used does not affect colour and at no time during the recording is there

A note about resolution

At Factum, we use the term resolution to refer to the level of detail held in a 3D file. We evaluate the resolution not just through a theoretical or mathematical description of the sensor of the scanner but by the degree of correspondence between the scanned data and the original surface (see image below). A close-range scanner has greater correspondence to the surface of the object than a longrange scanner. The main variables that affect the resolution are the lenses, the sensors, the area that is being scanned and the software

Comparison between the maximum resolution possible with the Faro LiDAR scanner (left) and a normal recording with the Lucida - King Seti I from the tomb of Seti I, Luxor

algorithms that process the data. Somewhere in this mix of elements is the sweet-spot that will result in data that passes the 'mimesis test': if it looks like a sweet that has been sucked it has failed - if in direct comparison with the original it looks the

Long-medium range 3D scanners (LiDar)

Long-medium range 3D scanners are used to record the general shape of objects and surfaces with the aim of obtaining accurate metrological information Long-medium range scanners use time-of-flight or laser-pulse based systems in which a laser light is bounced off the target at a distance. A laser range-finder calculates the distance to a surface by timing the round trip of a pulse of light using the known value for the speed of light. In cultural heritage documentation, long-medium range scanners are normally used in combination with closerange 3D scanners to generate models with both global metrological accuracy and high resolution surface detail.

What we use it for: topography and the recording of buildings: we have used the FARO Focus3D X 330 in conjunction with ScanLAB Projects, London; to record the façade of San Petronio in Bologna; The Last Supper by Leonardo da Vinci; and the whole of the refectory at Santa Maria Delle Grazie, Milan; 'mapping' the tomb of Seti I (see below)

We don't use it for: recording the subtle detail of surfaces – data that is required to make an accurate facsimile or for epigraphic study.

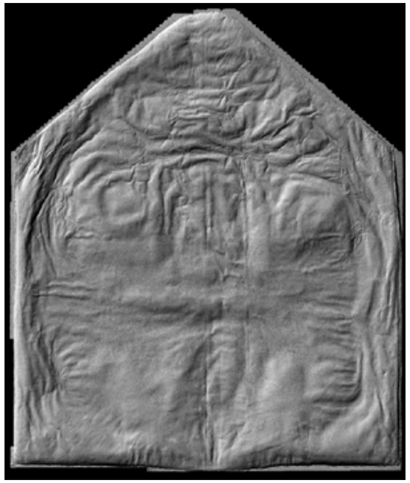
Render of FARO 3D data from the Tomb of Seti I, Luxor, made in 2016

Close-range 3D scanners

Close-range 3D scanners (working distance greater than 8 cm and less than 100 cm) are used to record the shape and surface of objects in great detail. A shorter record ing distance is associated with higher resolution. Close-range scanners use either a laser or a structured light system. Triangulation based 3D laser scanners use a laser light and one or two cameras to record a subject. The distance of the object to the scanner is calculated through trigonometry to create a precise map of the surface. Structured light scanners use projected patterns of light instead of a laser for triangulation – the camera(s) records these patterns and calculates the position of every point in the field of view.

The output can be used both for study purposes – with screen-based applications – or for rematerialisation in a range of different ways, including as tactile objects for the blind and partially sighted, facsimile production and exhibition display.

What we use it for: scanning the surface of paintings and reliefs like the Hereford Mappa Mundi (see image) and Goya's Black Paintings.



Render of 3D data of the Hereford Mappa Mundi recorded with the Lucida 3D Scanner

Recording shape and surface of sculptures and complex forms like the tomb of Tutankhamun, the hieroglyphs on Tutankhamun's sarcophagus, monitoring the decay on the surface of the sculptures on the façade of San Petronio or in the crumbling Romanesque cloisters in Tudela.

What we don't use it for: To record large structures for screen-based viewing. Close range scanning is slower than long-medium range scanning or photogrammetry, which has to be taken into account when planning a recording session.

Photogrammetry

Photogrammetry is the science of making measurementsfrom photographs to obtain 3D information about an object or landscape. It has been used since the birth of modern photography in fields such as topographical mapping, architecture, and archaeology – examples of long-range photogrammetry. Factum's work and research is currently focused on close-range photogrammetry as a means to record the form and texture of surfaces and objects at high-resolution. Data is being recorded with commercially available cameras that are used to capture multiple shots of the entire surface of an object; it is possible to obtain high quality data with very little equipment. Due to the composite nature of the image capture, both colour and form can be extracted from the data – it is important to note, however, that software limitations currently mean that high-resolution colour data is difficult to extract. Although basic processing is required in the field, the recording process is less time-consuming than with close-range scanning systems.

What we use it for: quick recording of vulnerable and relatively inaccessible sites it is the ideal method for obtaining 3D information in situations where it is not possible to use 3D scanners, or when high-speed recording is required. It can also be used for recording translucent surfaces such as alabaster and marble. Factum has

3D rendering of the Stelae to Esarhaddon 688 - 699 BC in Nahr El Kalb, Lebanon; recorded and processed with photogrammetry.

applied this technology to record the Stelae at Nahr el Kalb in Lebanon and the alabaster sarcophagus of Seti I in Sir John Soane's Museum. A nine-camera system designed and built in-house at Factum – the Veronica Scanner – is capable of recording objects up to 50x50x50 cm in approximately 4 seconds.

What we don't use it for: the highest resolution recording of surface for facsimile production; featureless, reflective or very dark surfaces also pose problems for photogrammetry.

Factum Arte considers it very likely that, with software development currently underway, photogrammetry will soon become the dominant method for recording at risk cultural heritage in 3D and colour.

Scanning systems used by Factum

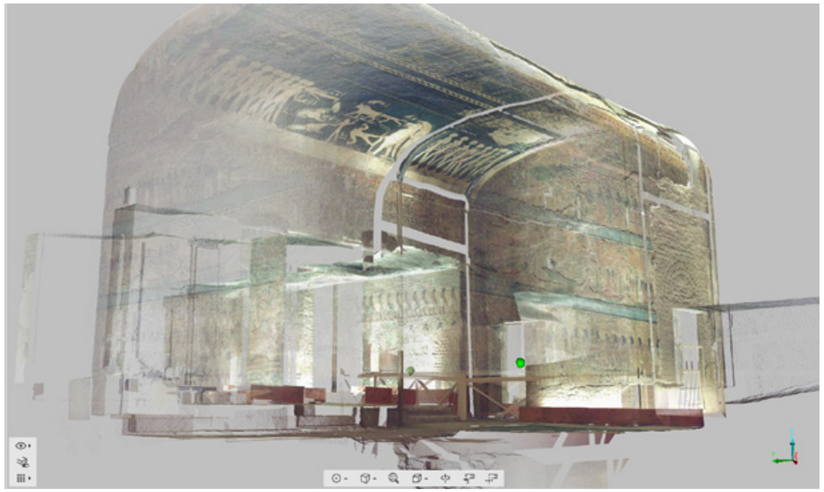
A catalogue of scanners used and an evaluation of their performance

1. Faro Focus3D X 330

The FARO Focus3DX 330 laser scanner (a LiDAR scanner) records a 360° environment of its surroundings.

At Factum Arte, the FARO has been used, in conjunction with ScanLAB Project, as a complementary tool to create an accurate digital canvas of a space, on to which high-resolution surface scans are placed.

The Faro Focus3D X 330



Scans generated from FARO Focus3DX 330 in the tomb of Seti I Valley of the Kings, Luxor

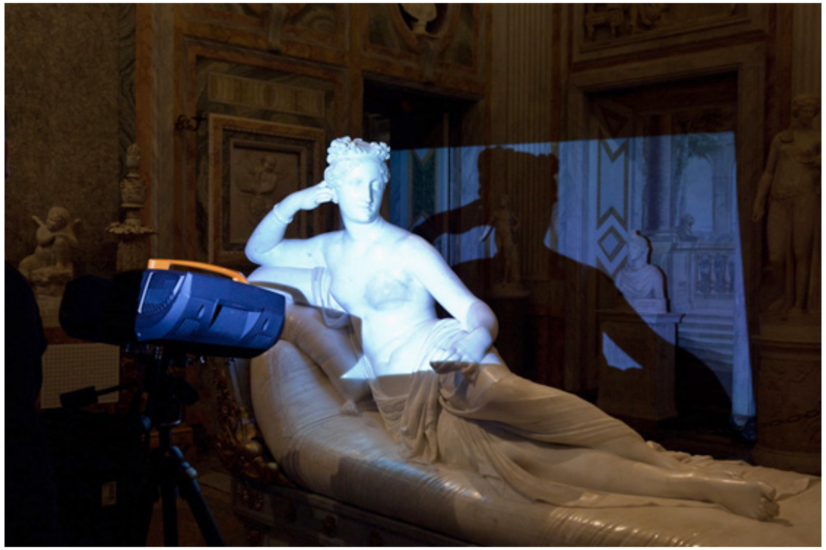
Technique: Time-of-flight / laser pulse-based 3D scanner	Operation: 1 person. Skill level: Moderate; survey and geomatic based background required/
Recording distance: Long-medium range (0.6 m-330m)	Processing: Extensive and requires both skill and artistry. Skill level: Expert; geomatic and digital visualization experience necessary
Resolution: Dependent on the level of detail required and proximity to object; 1 million to 750 million points per scan	Applications: Documentation of indoor/outdoor environments e.g. archaeological sites, buildings
Correspondence to target surface: Relatively low	Advantages: • Small, lightweight instrument • Long range, non-invasive capture of large features • A 70 megapixel camera records colour and overlays photographs for a more detailed
Recording time: Depend ent on resolution and quality settings; 30 seconds – 2 hours per scan/	Limitations: • Does not capture high resolution data of the texture and surface of an object (limiting its use for the production of facsimiles or in-depth study) • Divergence of resolution at range • Processing requires an expert skill level • Glossy, reflective and translucent surfaces are difficult to scan/
Processing time: Depends on the data and desired output but on average very long	Data applications: 3D walkthroughs of environments or buildings, screen based imaging, 3D printing, survey archaeological sites, etc
File formats: Native scan format is .FLS; exports in point cloud format/	Equipment: Terrestrial LiDAR scanner, survey tripod and tribarch, camera and panomaker, reference geometry/targets/
Environmental Conditions: Overcast, even lighting, avoid di rect sunlight and rain	

2. Nub 3D SIDIO Scanner

Factum Arte has worked extensively with Nub3D – a company based in Barcelona, and which developed the SIDIO scanner – since 2006.

The SIDIO is one of Factum's most useful systems because as it captures the full geometry of objects with high surface detail and outputs the data in clean point cloud formats.

Nub 3D structured light scanner recording the west side of the sarcophagus in the Tomb of Tutankhamun, Valley of the Kings, west bank, Luxor, Egypt.



3D scanning of Paolina Borghese using NUB 3D SIDIO Scanner, Galleria Borghese Rome, April 2013.

Technique: Structured light scanner	Processing skill level: Expert
Recording distance: Close range; 30 cm / 60 cm / 1 m (each corresponds to a different area)	Maximum recording size: 50cm² per scan session.
Resolution: 75, 130 or 250 microns	Applications: precision scanning of sculptures, reliefs, rocks, facades etc.
Correspondence to target surface: Very high	Advantages: • Automatically pre-aligns on site with marker system • Accurate and high quality measurement • Data is clean and ordered point cloud • Control over post processing and mesh generation
Recording Time: Dependent on variables such as shutter speed, characteristics of the object etc., but overall quick (a few seconds per scan)	Limitations: • Heavy, a lot of equipment, need space to operate • Not good for dark, translucent, reflective surfaces • Halogen light generates significant heat • Sensitive to vibrations • Needs mains power • Expensive hardware and software • Complex calibration system • Only one camera
Processing Time: The processing time depends on the complexity of the object scanned	Data applications: Screen based applications, 3D printing, re-materialisation, reverse engineering, indepth study.
Equipment: 3 tripods, scanner, 2 external projectors, powerful desktop, calibration rail, calibration plates	Operation: 1 operator (2 ideal) Skill level: Moderate
Environmental Conditions: low light, no vibrations	File formats: Point cloud; native fo mat: TRI; has to be exported as PIF and input into post-processing software like Polyworks

3. Breuckmann Smart Scan 3D

The Breuckmann outputs high-resolution 3D meshes and is used in Factum Arte for a variety of artistic and conservation projects.

The Breuckmann, and similar systems, are used widely because of their accurate, but simple recording and processing methods.

Setting up a Breuckmann 3D scanner in Henry Hudson's studio to scan a maquette

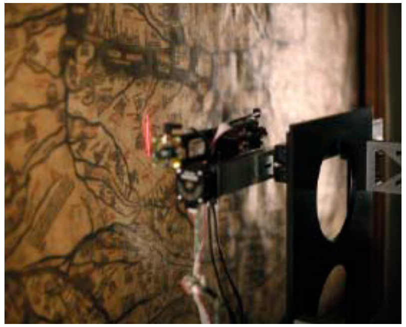
Tests were conducted with the Breuckmann on the Bronze Oak but the tree´s texture made it impossible to record the entire tree using only this method. Photogrammetry was used to complement the data

Technique: Structured light scanner	Processing skill level: moderate (1 person)
Recording distance: Around 1 m	Maximum recording size: $1m^2$ per scan session.
Resolution: 75, 130 or 250 micr 140 microns for 30x30 cm2/shot; 250 microns for a 60x60 cm2/shot.	Sculptures, objects, reliefs, facades etc.
Correspondence to target surface: Very high	Advantages: • Captures colour (res. 0.8-2.0-8.0 MP) • Waits for vibrations to stop before scan • No need to use markers for combingin scans • Two camera system • Can do photogrammetry-structured light combined measurement • LED light does not generate heat • Software aligns scan immediately and offers model preview
Recording Time: Dependent on resolution but overall faster than the SIDIO	Limitations: • Cannot access point clour as the system is designed to output 3D meshes through OPTOCAD software • Calibration plate large • Needs mains power • Expensive
Processing Time: faster than SIDIO	Data applications: Screen based applications, rapid prototyping, re-materialisation.
Equipment: Scanner, tripod, laptop with powerful GPU and min. 32 GB RAM (OPTOCAD software uses RAM memory to build meshes), calibration tools	Operation: 1 operator (2 ideal) Skill level: Moderate
Environmental Conditions: low light, no vibrations	

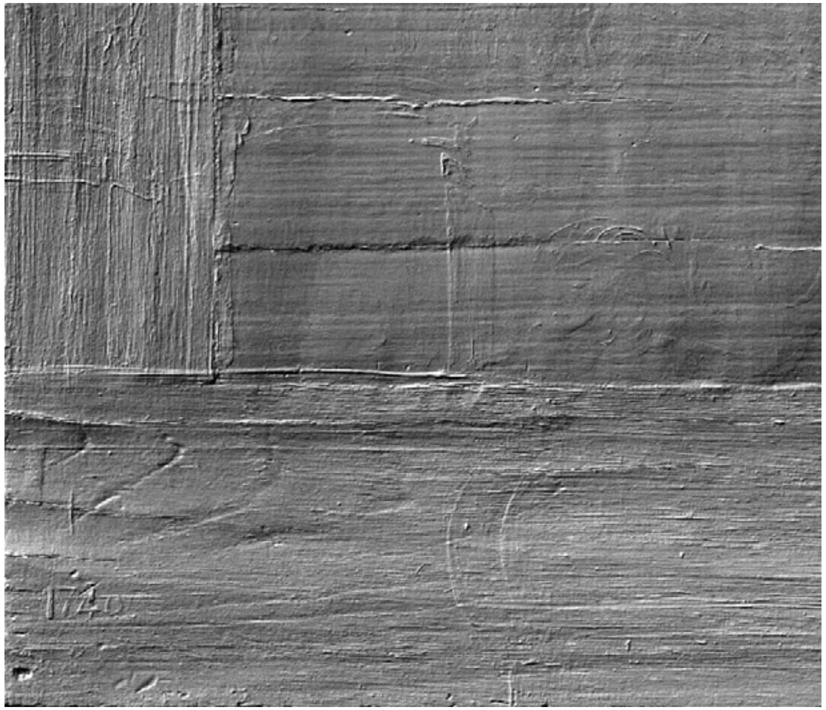
3. Lucida 3D Scanner

Lucida is a 3D laser scanner designed and developed by the artist Manuel Franquelo and custom built by Factum Arte.

It obtains high resolution recordings of the surfaces of works of art and low relief objects. This system has been developed to obtain 3D information of surface and texture, not colour.



Lucida recording the Hereford Mappa Mundi, Hereford Cathedral



The Triumph of the Eucharist by Rubens (at the Prado Museum)over Idolatry, 3D render, from data recorded by Lucida detail of the cracks and paintbrush relief, including detail of perimeter of later addition

Technique: Triangulation based 3D laser scanner	Processing skill level: basic (1 person)
Recording distance:Close range (8-10 cm)	Maximum recording size: Dependent on the structural frame
Resolution: 100 microns (10,000 points per cm^2)	Applications: Walls, frescoes, rock art, paintings (canvas, board etc.), maps, fabrics (tapestries), manuscripts, coins, wax seals etc.
Correspondence to target surface: Very high	Advantages: • Record a variety of surfaces that are problematic for other 3D scanners (e.g. shiny, highly contrasted, gold or metallic surfaces) • Saves data as unprocessed raw video • Automatically outputs 3D data rendered as 2D shaded images • Data can be combined with other datasets (e.g. UV, infrared, colour etc.) • Portable, easy to assemble and operate; relatively inexpensive • Mains or battery operated • The software for scanning, editing and stitching has been designed to be open source
Recording Time: 4 hours per m^2	Limitations: • Sensitive to vibrations and strong directional light • Limited depth of field (2.5 cm); for higher reliefs, several scans at various distances are needed • Slow scanning speed • Cannot record transparent or translucent surfaces
Processing Time: 4-6 hours per m^2 (dependent on computer processing power and experience of the operator	Data applications: Re-materialization of the relief (CNC milling) for the creation of exact facsimiles; screen based imaging in combination with other layers of data (colour, etc
Equipment: Equipment: Lightweight CNC frame and controller, scanning head (pocket sized), laptop	Operation: 1 operator (2 ideal) Skill level: Basic
Environmental Conditions: low light, no vibrations	File formats: AVI (raw video), RIS, 32 bit TIFF, 8 bit TIFF (shaded render)

Appendix II: A selection of projects by the Lucida 3D Scanner

Challenging 3D scanning: How do you scan a black glossy surface that is adjacent to a white glossy surface, or a tooled gold surface? Paintings have specific qualities that require focused solutions. Lucida is the 3D scanner specifically created for recording the surface of paintings and low-relief objects.

Rubens: The Triumph of the Eucharist over Idolatry

The first prototype of the Lucida was used in the Museo del Prado in Madrid to digitise the surface of a painting that was about to undergo a major restoration.

This panel (65 x 91 cm) is one of a series painted by Rubens as preparatory sketches for the tapestry cycle The Triumph of the Eucharist.

Lucida was used to record the relief of the front of the panel at a resolution of 100 microns. The colour was recorded with a Clauss panoramic photography system. The 3D information that was obtained is now of great value as the shape, size and texture of the painting changed significantly during the restoration process.

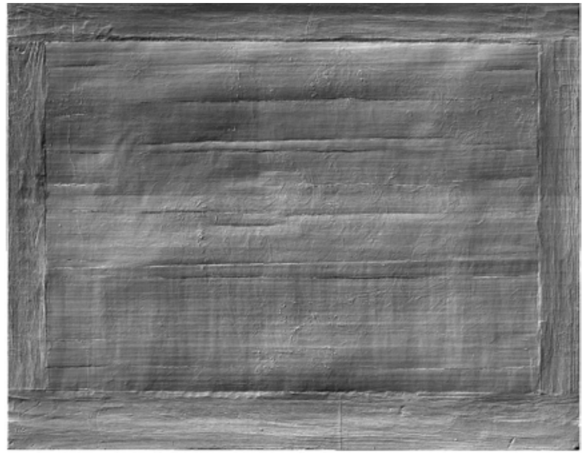
It is unusual that size changes dramatically but in this case a previous addition of several centimetres on each side of the painting was removed. The restoration was intended to stabilize the paint and wooden panel before it was exhibited in front of the tapestry that was based on the design. The recording was done in conjunction with the curatorial and conservation teams at the Museo del Prado.

The data has now become an important part of the history of the painting and was supplied to the museum both as a digital archive and as a physically routed plaster panel.

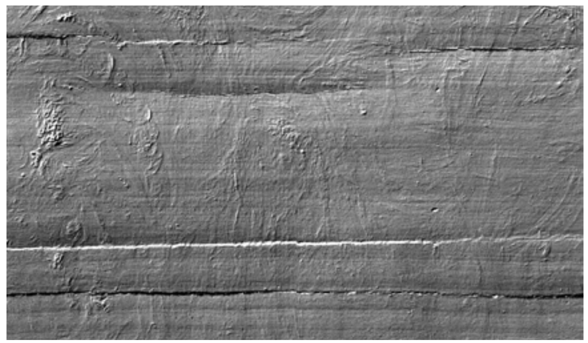
In line with Factum Foundation's commitment to conservation the copyright on this data and on all future applications of the data belongs to the owner of the artwork.

The 3D information of this painting obtained by Lucida is the only accurate record that exists of the shape and texture of the board before its latest restoration, after which the size and curve of the material have changed significantly. This is why it is essential to record the surface of paintings before and after every restoration process.

The Triumph of the Eucharist over Idolatry at the Prado Museum



The Triumph of the Eucharist over Idolatry, 3D render



The Triumph of the Eucharist over Idolatry, 3D render, detail of the cracks and paintbrush relief, including detail of perimeter of later addition

The relief data of the painting recorded with Lucida was CNC routed in high resolution, and then reproduced in plaster. the panel's perimeter.

The plaster cast reproduction was included in the exhibition Rubens: the Triumph of Eucharist in the Museo del Prado (Madrid) in 2014.

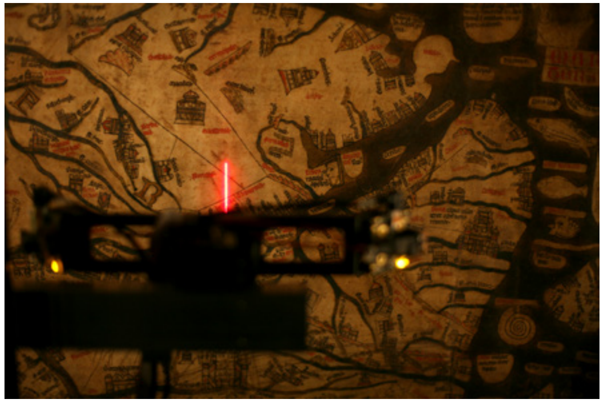
Hereford Mappa Mundi

High resolution digital documentation of our shared cultural heritage is an essential in its conservation. Alongside the duty to preserve and disseminate artworks, we also have the responsibility to faithfully digitise their physical characteristics, thus maintaining a record for future generations. Lucida has been designed to help make this possible.

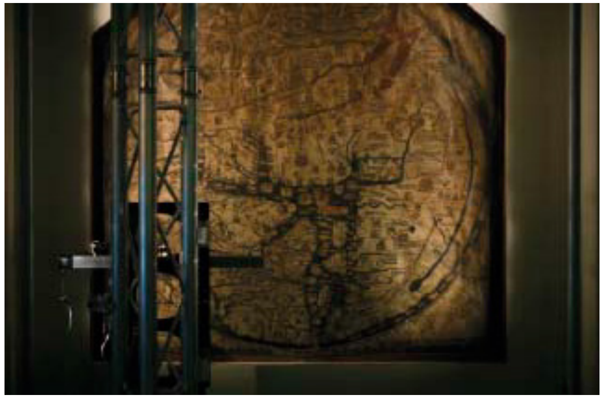
In early 2013, a team from Factum Arte made a high resolution recording of the Hereford Mappa-Mundi (c. 1300) at the request of Hereford Cathedral and the Trustees of the Mappa Mundi. The glass cover is only removed once every two years for inspection, which made studying the map a complex task. The team used the Lucida 3D scanner mounted onto a custom designed structure to provide absolute safety to the map and a firm platform for the highly accurate no-contact surface scanning process. Each frame was post-processed to create the high resolution three-dimensional record. The three dimensional "map" of the surface of the Mappa Mundi will provide scholars, curators and the public with a safe and novel method of studying and looking at this extraordinary object.

The Hereford Mappa-Mundi c. 1300

By studying the 3D recording in conjunction with other methods of forensic study, new discoveries have been made about the map including compass points in the centre of Jerusalem and in the centre of the Labyrinth of Crete. Further research is being carried out on the data, and may suggest that the map was made in Hereford and rather than in Lincoln. Thanks to the physical reproduction of the high-resolution 3D data, visitors to Hereford Cathedral, including the blind and partially sighted, have the opportunity to explore and experience the map as never before. In addition, a new website that features an interactive exploration area for the Mappa Mundi has just been launched, providing access to the Folio Society digitally enhanced version of the Map and the Factum Arte three-dimensional surface scan.



Lucida 3D scanner recording the Mappa Mundi



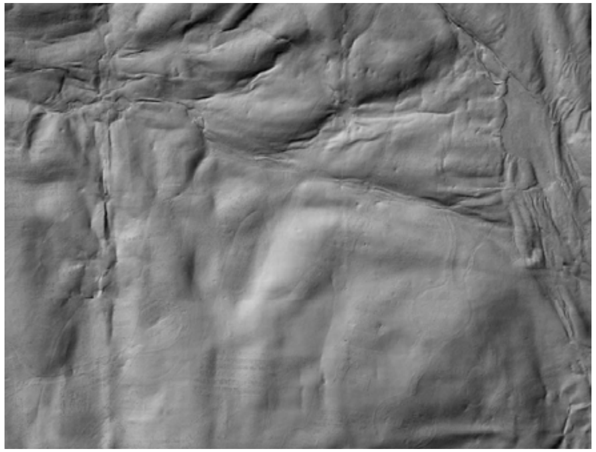
Lucida 3D scanner recording the Mappa Mundi.

Lucida is not just concerned with shape, but with both shape and relief, and the complexity of the surface texture. This intimate understanding of surface is leading to new insights about how an artwork has changed, how it has been looked after, how it has been valued and what has been done to it over the centuries...

The goal is the acquisition of a reliable, high-resolution and dimensionally accurate map of the texture that can be studied on screen or re-materialized in the physical domain. If data can be re-materialized with the exact characteristics of the original, it is clear evidence of the quality of the data.

3D render of the Hereford Mappa Mundi's surface data.

Detail from 3D output – the routed texture in resin



3D render section of the Hereford Mappa Mundi's surface data.

3D facsimile of Hereford Mappa Mundi. Plaster cast of the surface

Installation of the Mappa Mundi's reproduction in the Hereford Cathedral.

The backboard was recorded in 2016 with Lucida and photogrammetry.

Polittico Griffoni: Digital technology applied to re-unify a scattered altarpiece

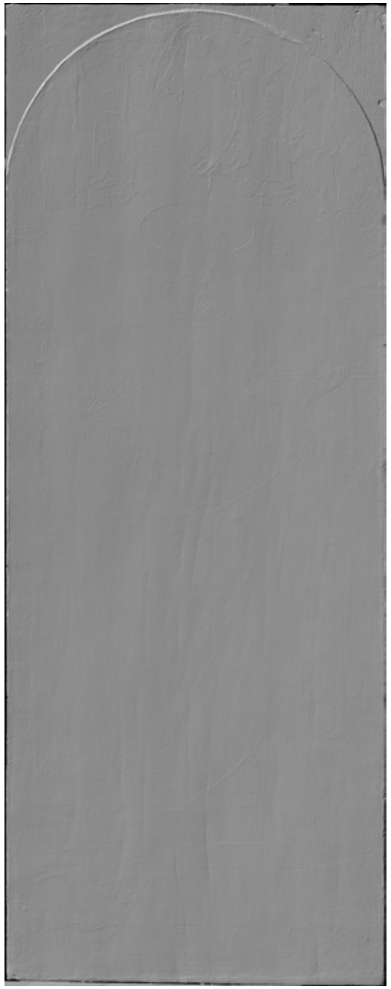
The restoration of the chapel of Saint Vincent in the Basilica di San Petronio (Bologna) has provided scholars with a chance to re-consider an altarpiece originally painted for the chapel: the Polittico Griffoni – one of the most important masterpieces of the Renaissance, painted between 1471 and 1472 by Francesco del Cossa and Ercole de'Roberti. The work was commissioned by the original patrons of the chapel, the Griffoni family, but was removed, dismembered and sold when the chapel came to the Aldrovandi family in 1725. The sixteen surviving panels are in nine museums in different parts of the world.

In the period 2012-2015, the surfaces of the sixteen panels of the Polittico Griffoni were recorded in three dimensions with the Lucida and the colour photographically captured at high resolution. To obtain the high-resolution colour data, Factum Arte used a planar system to record the small panels and a panoramic photographic system to record the larger panels. Large numbers of photographs are taken and stitched together using PTGui software. Recent developments in both hardware and software are opening up new possibilities for macro-photographic recording that allows the paintings to be studied

The Lucida 3D Scanner recording the Annunciation Angel and Annunciation Virgin at the Museo di Villa Cagnola, Gazzada, Italy in 2012

The re-unified panels of the Polittico Griffoni in the Factum workshop, Madrid

Francesco del Cossa, San Vincenzo Ferrer, c. 1473, The National Gallery, London



3D render of data recorded by Lucida

Left: Ercole de'Roberti, Saint George, c.1472, Fondazione Giorgio Cini, Venice

Right: CNC milled; data recorded with Lucida

Front and back of the Ercole de'Roberti; CNC milled into high density resin

Detail from back milled in CNC resin

with forensic accuracy. The resulting archives are evidence that the application of technology can ensure that cultural artefacts can be documented, studied and transmitted in a faithful way.

With the data recorded for all the panels, a physical reconstruction of the altarpiece will be made. This will be symbolically 'returned' to Bologna in October 2017 and housed in the Griffoni chapel where the work will be visible again in its original context.

This project is also an example of how high-resolution data can be used to monitor the state of an object throughout a restoration process. The panels in the Pinacoteca di Brera, Milan, are currently undergoing restoration to consolidate the paint surface and address the curved nature of the poplar. After the restoration process, the panels will be recorded again, to monitor the changes and establish a comparison that will be of great value for historians, researchers and conservators in the future.

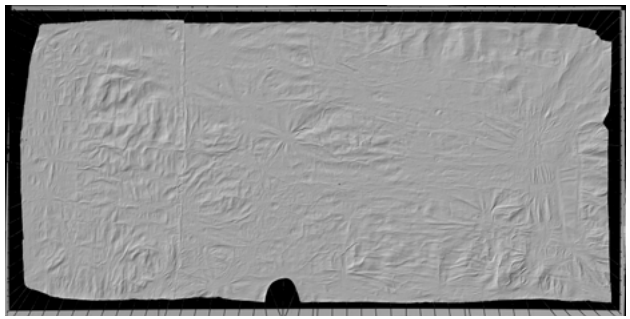
Printing tests for high-resolution colour data at Factum, Madrid. The colour data will be re-integrated with the 3D data recorded by Lucida.

The Gough Map

The Gough Map, kept at the Bodleian Library in Oxford, is one of the earliest maps to show the British Isles in a geographically recognizable form. Dating from the midfourteenth century, it is regarded as the oldest route map of the country. Factum Arte is currently involved in a new initiative involving the Bodleian Library in Oxford and Queen Mary University to scan this fascinating object. Its exact dating, authorship and function are unknown and with the data resulting from the scanning process, researchers are hoping to shed light on these and many other aspects of its creation.

Factum Arte is committed to demonstrating the importance of digital technology in the analysis and documentation of our cultural heritage. Noncontact, high-resolution 3D scanning will provide valuable data of the subtle relief of the map, which can then be combined with other layers of information such as colour in order to monitor its condition and understand its biography.

The Gough Map of Great Britain, original 56 x 115 cm, Bodleian Library, Oxford, combination of 3D render and colour of the front



The Gough Map of Great Britain, 3D render of the front by Lucida

The Teschen Table

In July 2015, a team from Factum Arte recorded the Table of Teschen (pictured on the right) at the Musée du Louvre, in order to make an exact copy to be shown in the Chateau de Breteuil – where the table has been kept since it was given to the family in 1768.

The scanning of the table was carried out using various 3D and colour recording systems. Lucida was used to digitize some of the main decorative motifs across the table's body, as well as one full leg. The recorded data was combined with the general 3D model of the object generated with a structured light scanner. Whereas scanning translucent materials such as crystal or some of the stones is an almost impossible task for most 3D scanners including Lucida, this project demonstrated the ability of the scanner to record data from gilded surfaces, with the highest quality and resemblance to the real texture of the object. In order to record the curved surface on the leg, which exceeded Lucida's depth of field (25 mm), various successive scans were made at different distances, and then merged in the processing phase to complete the model.

Left: Facsimile of the Teschen Table

Right: Render of 3D data of one leg of the table recorded with the Lucida

Contact us

Support

factum@factum-arte.com

If you ever need help with your Lucida, email the address above. To help us understand the problem it is very helpful to include pictures or a video as attachments with your email.

You can also telephone us: +34 915 500 978

Feedback

factum@factum-arte.com

For general questions or for your comments and ideas send an email to the address above.

For more information

www.factum-arte.com
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