Viewpoints of engineers within COSCH KR and COSCH ASM

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Main Motivation

- Exchange knowledge between engineers and users to:
  - Define the list of devices and of algorithms adapted to each specific study case or any set of study cases.
  - Define the list of parametric factors, constraints, requirements, and limitations to take into account by users to avoid any inappropriate solution.
  - Minimize users interactions and experts assistance by developing automatic process.

=> Tools: COSCH KR and COSCH ASM.

Main Motivation

- Categories of processing tasks covered by the Working Group 3 (Algorithms and procedures) :
  - ✓ Calibration,
  - ✓ Acquisition and Measurement,
  - ✓ Processing chain
    (e.g data fusion of 3D data (laser scan) and 2D data (photogrammetry))
  - ✓ Data Analysis,
  - ✓ Characterization,
  - ✓ Quality evaluation,
  - ✓ Documentation,
  - ✓ Data storage and transmission,
  - ✓ Retrieval,
  - ✓ Visualization and Reproduction,

Main Motivation

Problem: interdependence between processing tasks.

As example : the accuracy of the 3D-2D data fusion task is correlated to:

- Calibration,
  - Acquisition and Measurement,
    - Processing chain,
      - Data Analysis,
        - Characterization,
          - Quality evaluation,
            - Documentation,
              - Data storage,
                - Visualization.

Main Motivation

How to select the best chain of algorithms for a given task ?

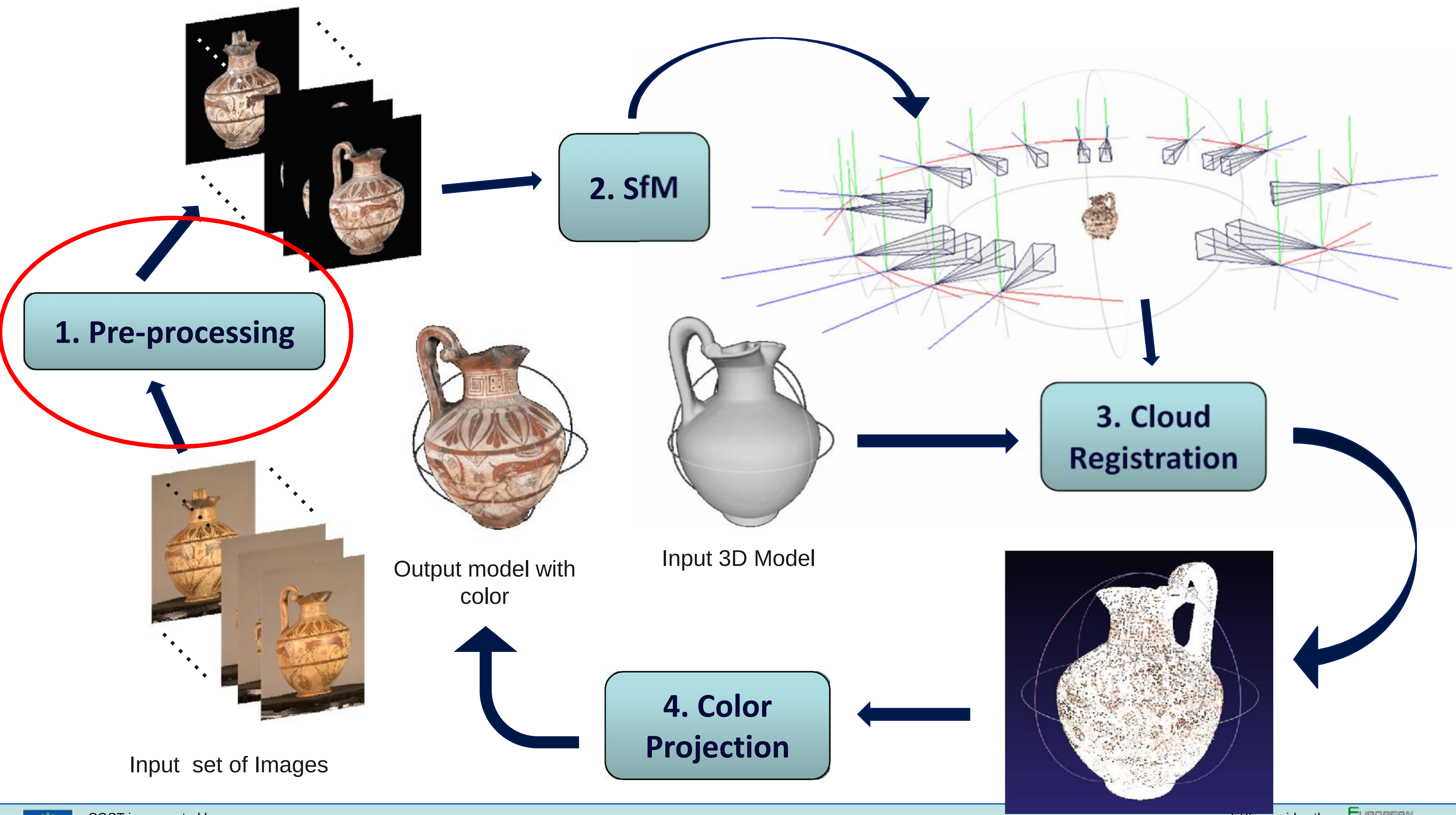
How to select the best algorithm for a given processing task ?

Which selection criteria to use ?

- Computational time ?
- Number of acquisitions ?
- Quality of the 3D reconstruction ?
- .../...

=> A documentation based on experts and users knowledges is necessary.

Data fusion of 3D data and 2D data



Data fusion of 3D data and 2D data

Stage 1. Image pre-processing

1. Color calibration

2. Background extraction
   - Avoid false matches
   - Reduce noise

3. Image enhancement.

   e.g. Histogram equalization.

   - Better contrast and more details
   - Generate + keypoints
   - **Important** for next step to be able to **recover a better geometry** of the object.

Data fusion of 3D data and 2D data

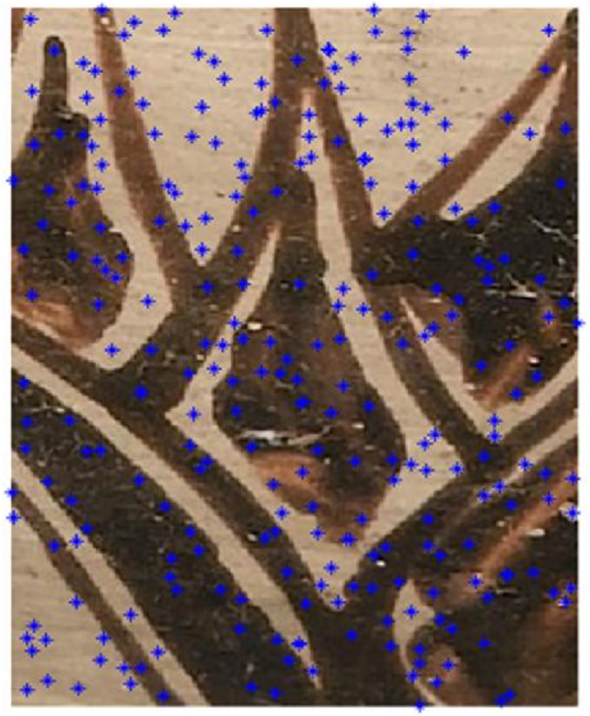
Stage 1. Image pre-processing

Problems with textureless areas, shadows, color edges

Image enhancement by histogram equalization.

a) Original image

b) SIFT keypoints in original image (29,183 keypoints)



c) SIFT keypoints in enhanced image (29,930 keypoints)

Data fusion of 3D data and 2D data

Stage 1. Image pre-processing

Problems with uncalibrated color images, highlights, shadows

Photo set of the same object acquired from several viewing angles (**Photogrammetry)**

Data fusion of 3D data and 2D data

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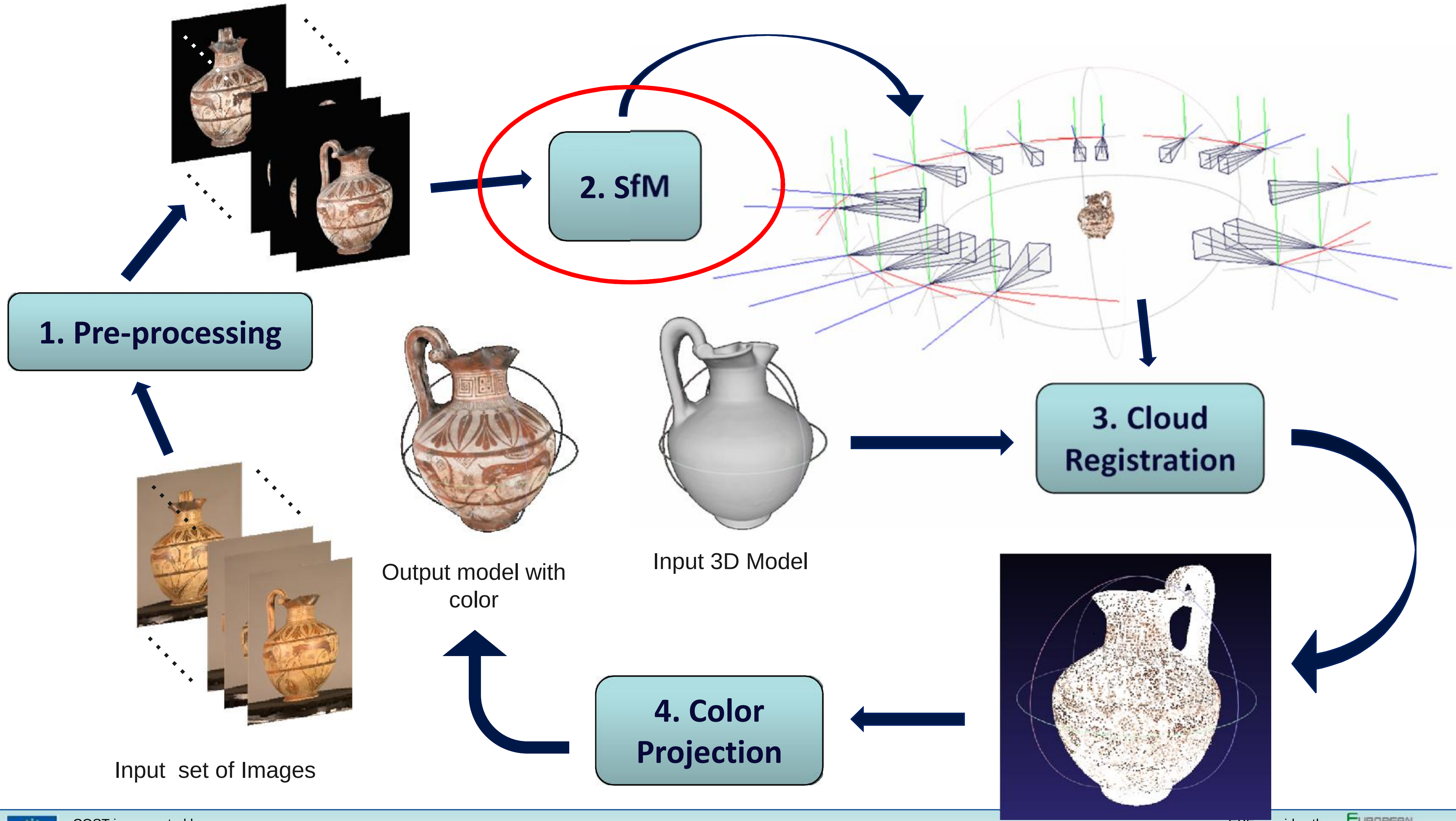


Data fusion of 3D data and 2D data

Stage 2. 3D Reconstruction from un-calibrated cameras.

Example with dataset No. 1

a) Sparse reconstruction (48,336 pts)

b) Dense reconstruction (1,282,014 pts)

Data fusion of 3D data and 2D data

Stage 2. 3D Reconstruction from un-calibrated cameras.

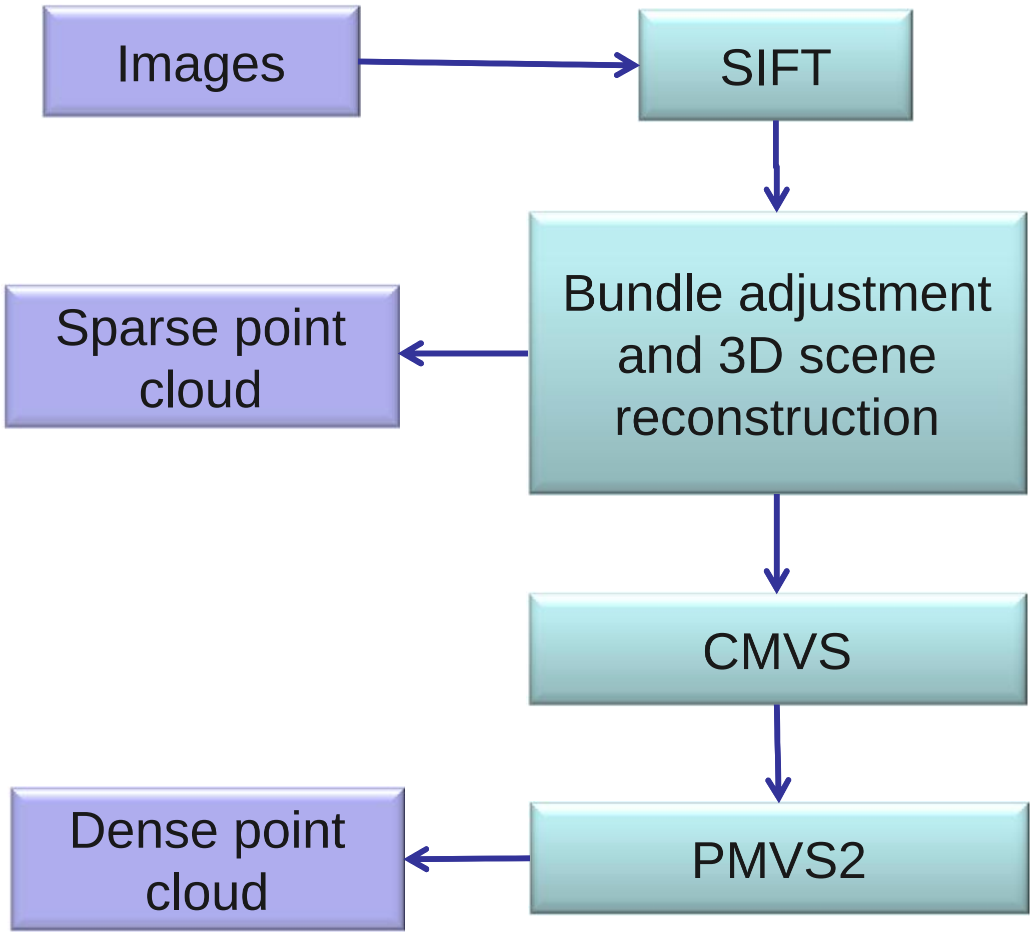
- Sparse point clouds do not provide enough geometry information.
- Dense point clouds are affected by noise which is necessary to remove by manual selection.

No	Dataset	No. Photos	Resolution	Sparse Reconstuction	Running time	Dense Reconstruction	Running time
1	FZ36147	35	**4008x5344**	**48,336 pts**	**53 sec**	**1,282,014 pts**	**5 hrs**
2	FZ36152	17	2152x3232	21,940 pts	14 sec	3,487,617 pts	41 min
3	C2RMF63640	36	2848x2476	39,910 pts	31 sec	1,571,537 pts	5.3 hrs

Table 1. Structure from motion output from 3 datasets

Data fusion of 3D data and 2D data

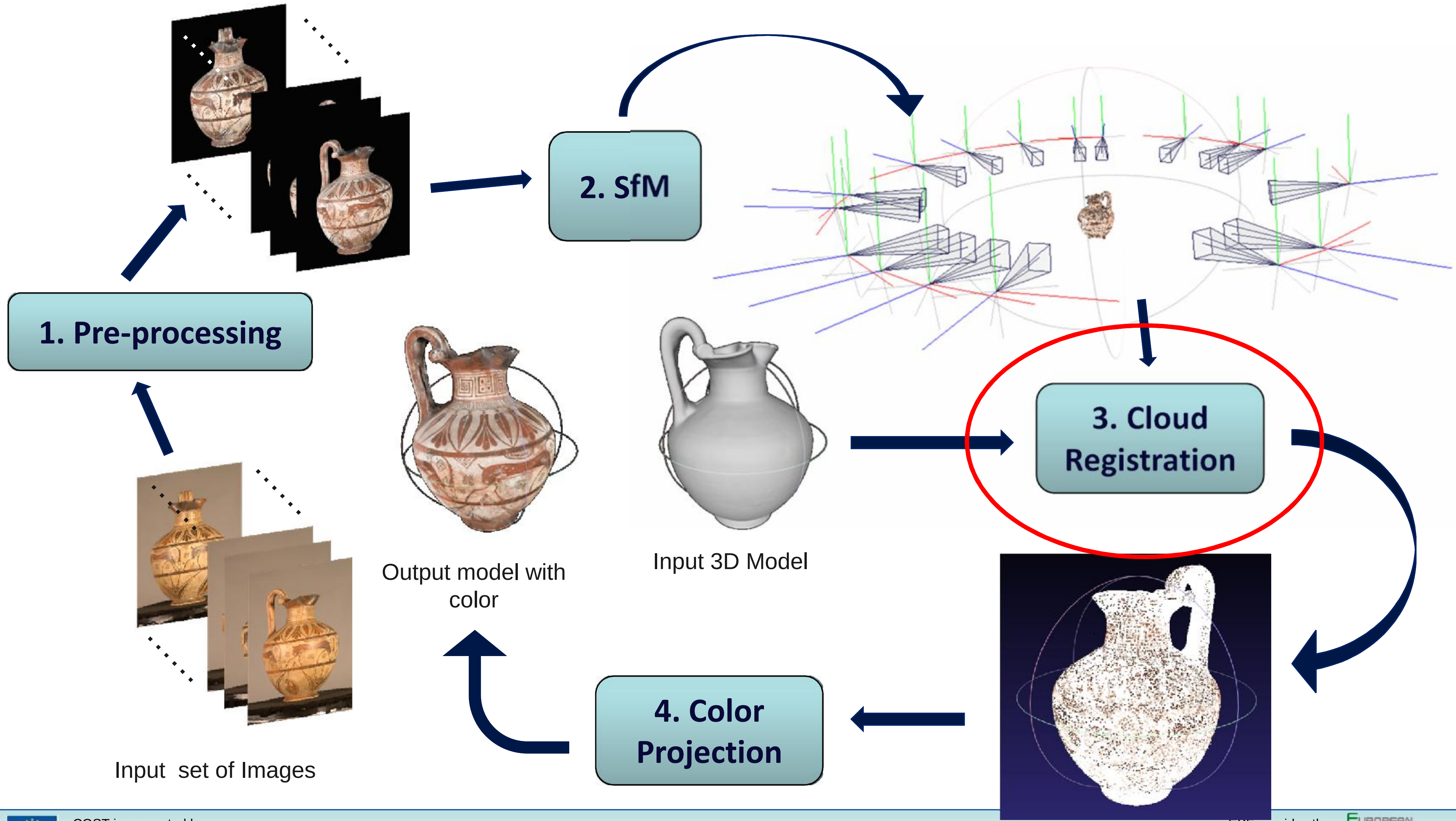
Stage 2. 3D Reconstruction from un-calibrated cameras.



SfM workflow

- Identifies key points in each image
- Matching key points in multiple images using RANSAC
- Estimate camera pose and extract sparce point cloud.
- Clustering Views for Multi-view Stereo (CMVS) decomposes overlapping input images into subsets or clusters
- Patch –based Multi-view Stereo Software reconstructs 3D data from each cluster.

Data fusion of 3D data and 2D data



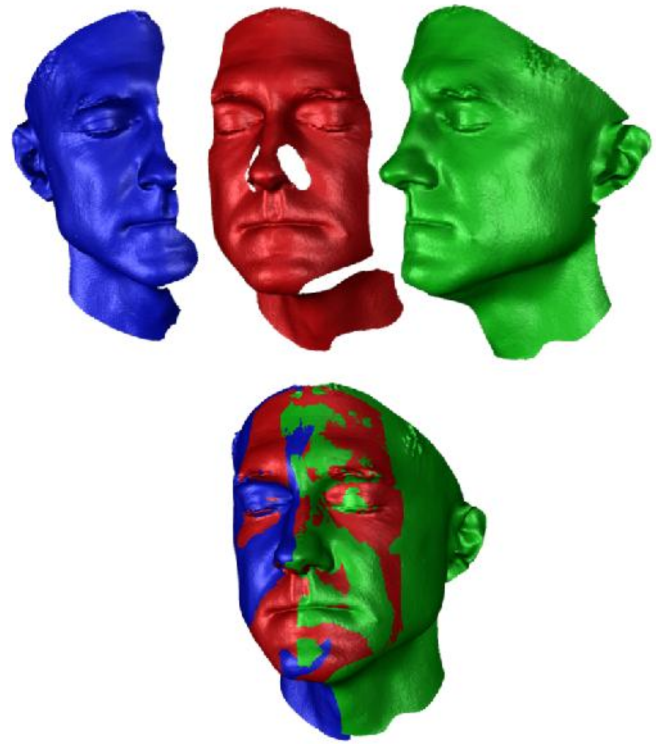
Data fusion of 3D data and 2D data

Stage 3. Cloud Registration

Align 2D data with 3D data

How to find correspondences?

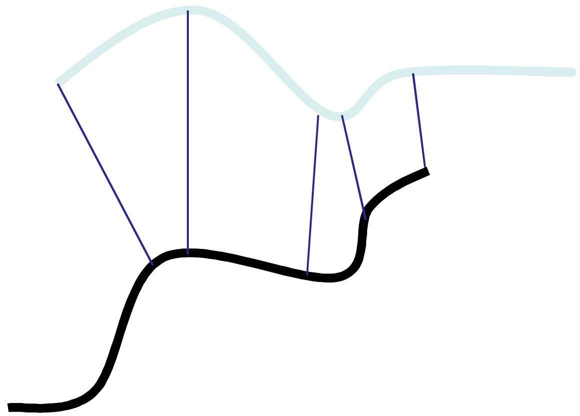
- User input?
- Feature detection?
- Brute force algorithm?

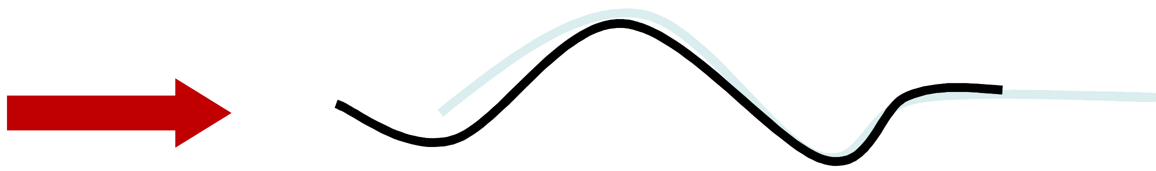


Assume closest points correspond

- ICP (Iterative Closest Point)

Rotation
Translation

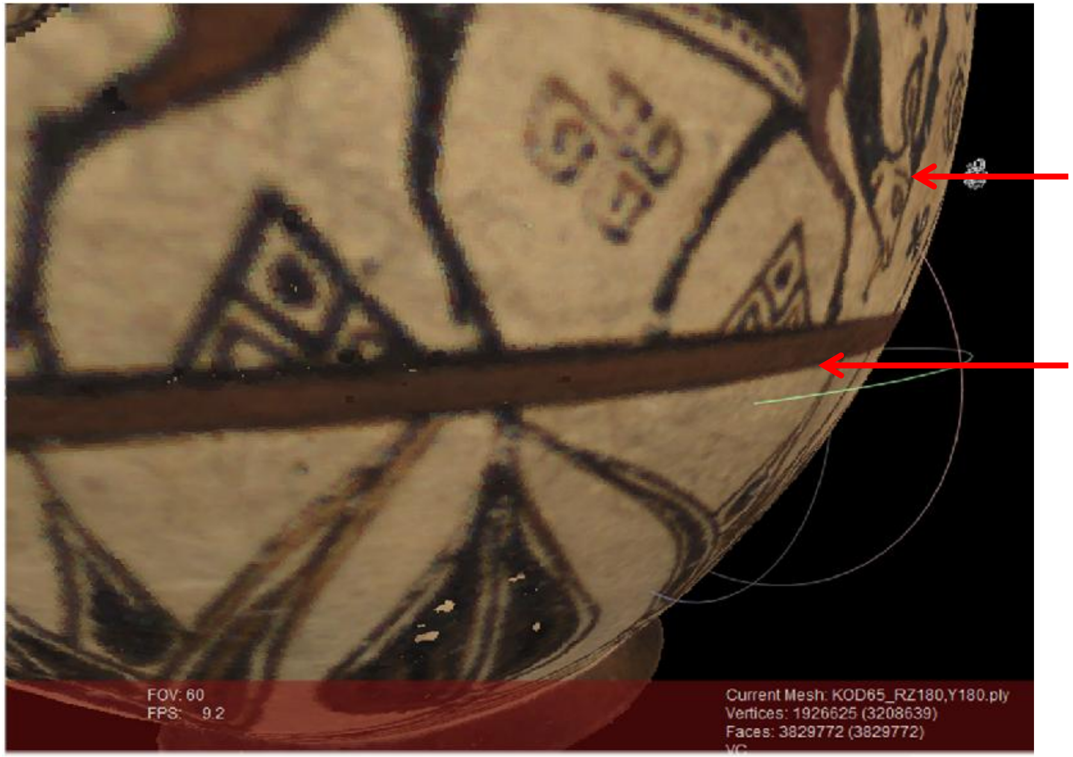




Data fusion of 3D data and 2D data

Stage 3. Cloud Registration

Problems with scale difference and Cloud alignment



'Image space' coordinate system

Point cloud from SfM

Point cloud from laser scan

'Object space' coordinate system

Data fusion of 3D data and 2D data

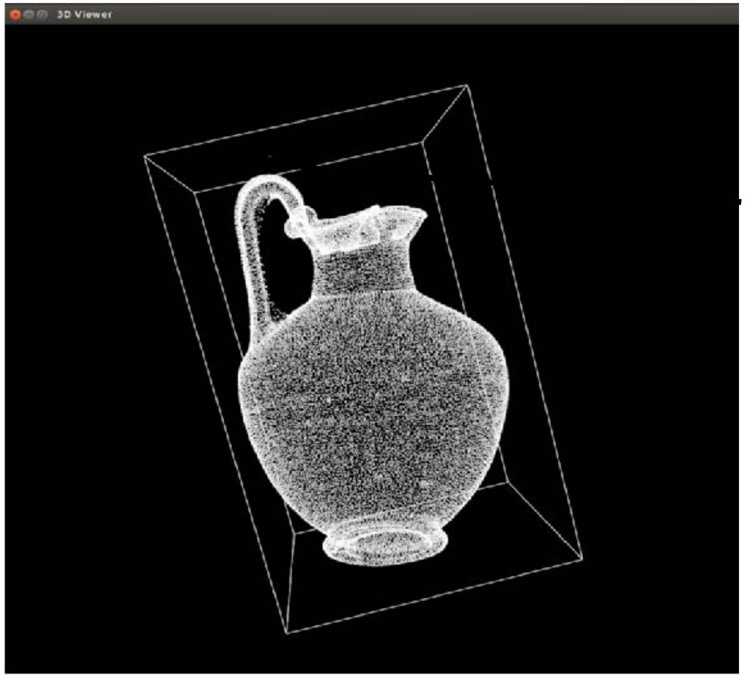
Stage 3. Cloud Registration

1. Scale problem
- Bounding box
- SICP
- Extension of 4PCS

Scale Iterative Closest Point

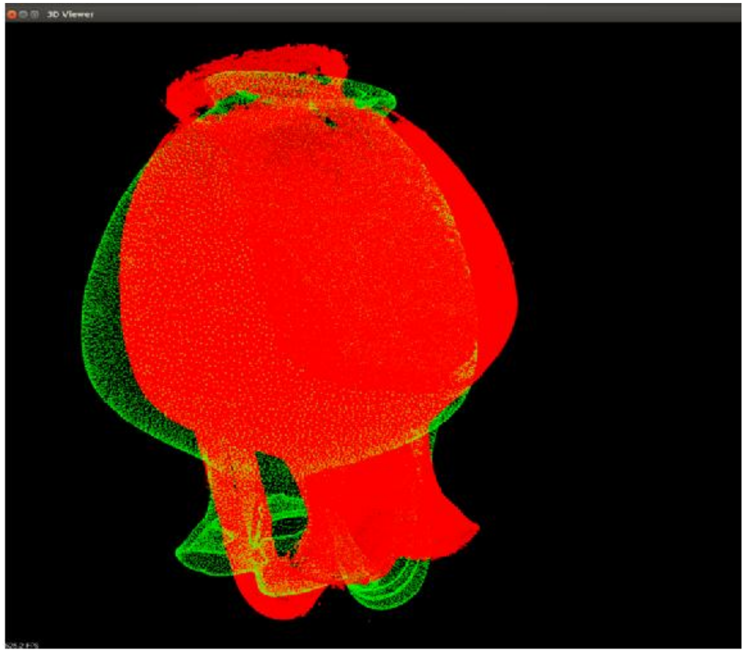
2. Cloud Alignment
- ICP
- SICP
- 4PCS

Rotation
Translation
Scale



a) Bounding box

Sensitive to outliers



b) ICP

Initial guess → Position clouds not far from each other

Data fusion of 3D data and 2D data

Stage 3. Cloud Registration

a) Sparse point cloud

b) Dense point cloud (Reference)

c) Point clouds aligned

No	Dataset	Sparce point cloud (SfM)	Dense point cloud (Scanner)	SICP Running time
1	FZ36147	48,336 pts	1,926,625 pts	**4.77 hrs**
2	FZ36152	21,940 pts	1,637,375 pts	4.17 hrs
3	C2RMF63640	39,910 pts	2,092,801 pts	5.26 hrs

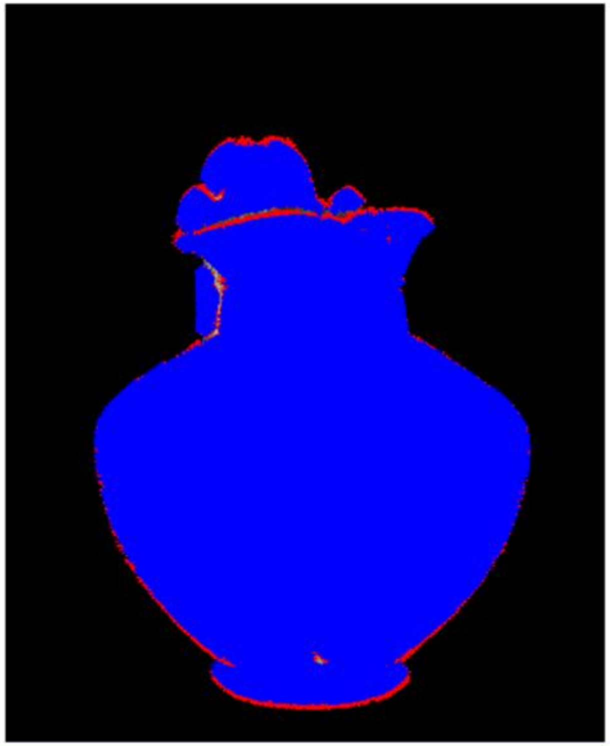
Table 2. Performance of the SICP in the datasets

Data fusion of 3D data and 2D data

Stage 3. Cloud Registration

Problems with

- Camera parameters found with SfM
- Alignment of point clouds



Blue = Scanned point cloud
Red = Photogrammetry point cloud

Both point clouds are not exactly the same → **No perfect alignment**

Data fusion of 3D data and 2D data

Stage 3. Cloud Registration

Problems with camera parameters found with SfM and alignment of point clouds

Solution : find the displacement for each point

Problem : most of methods are time consuming for very high resolutaion images.

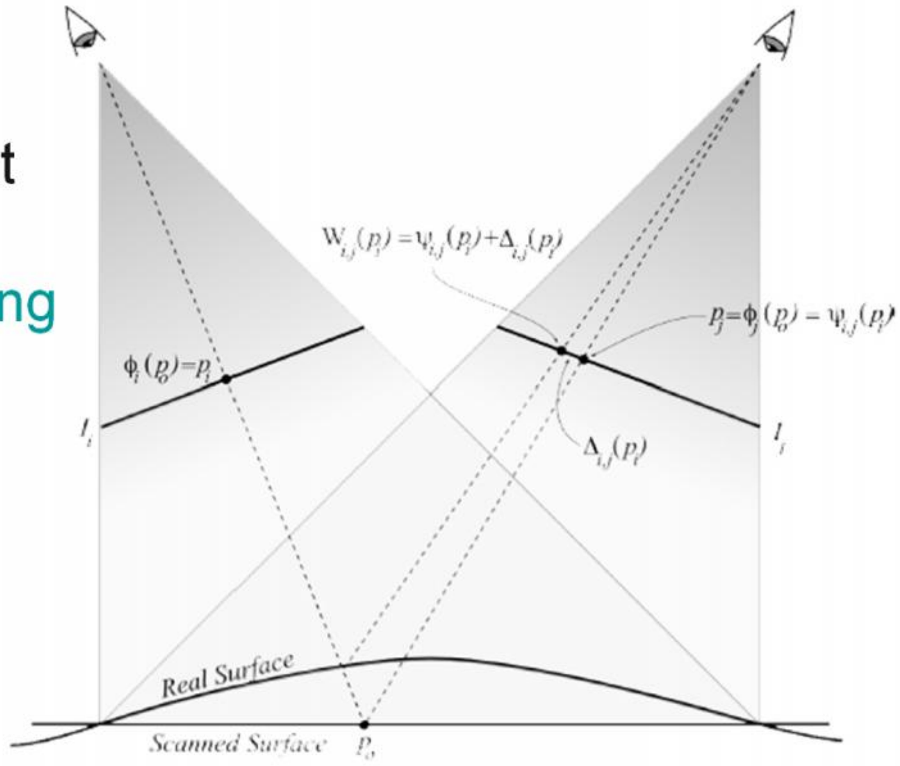
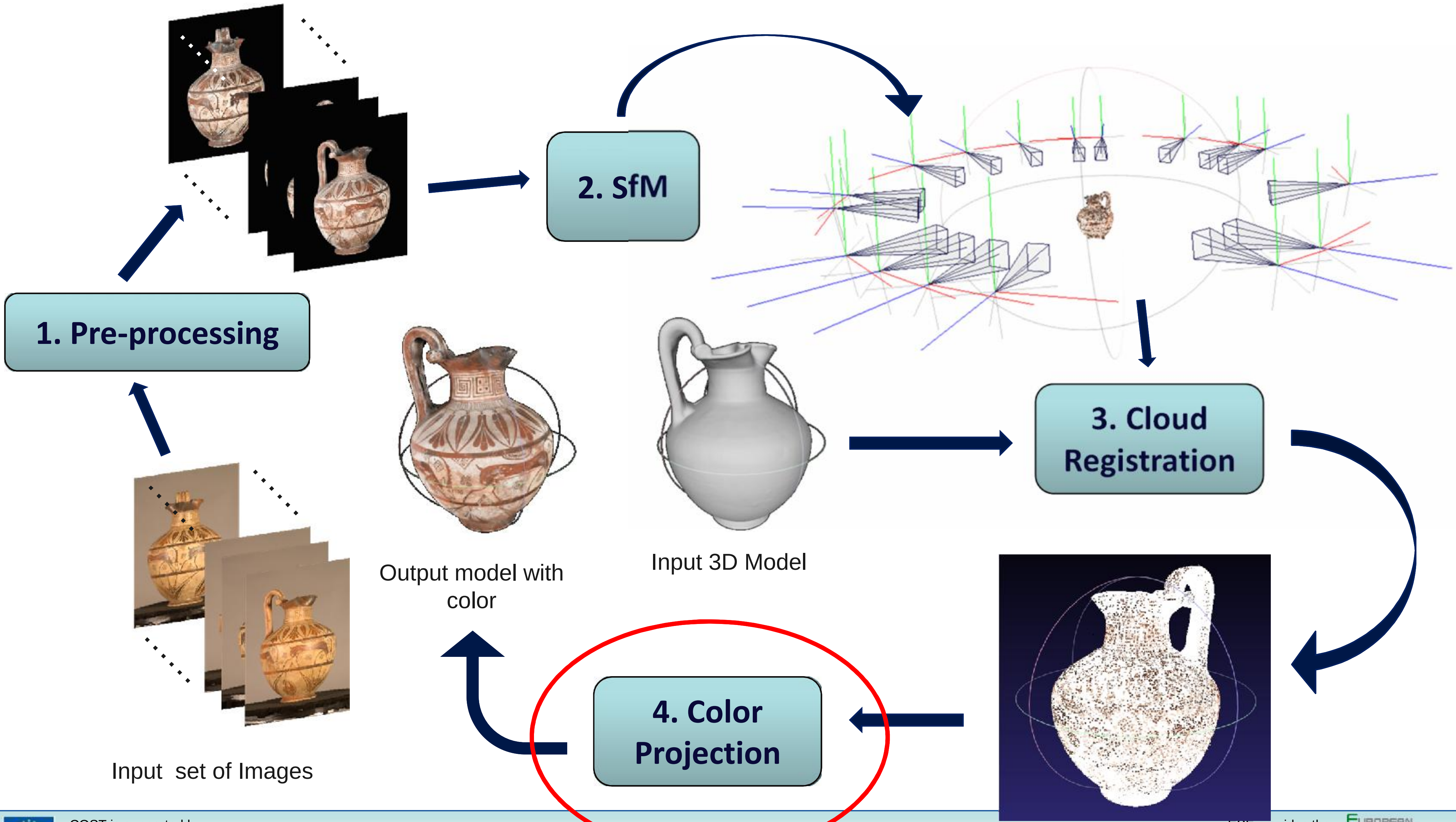


Fig. 6. The notation used to denote correspondence between (warped) points and images. [11]

Data fusion of 3D data and 2D data



Data fusion of 3D data and 2D data

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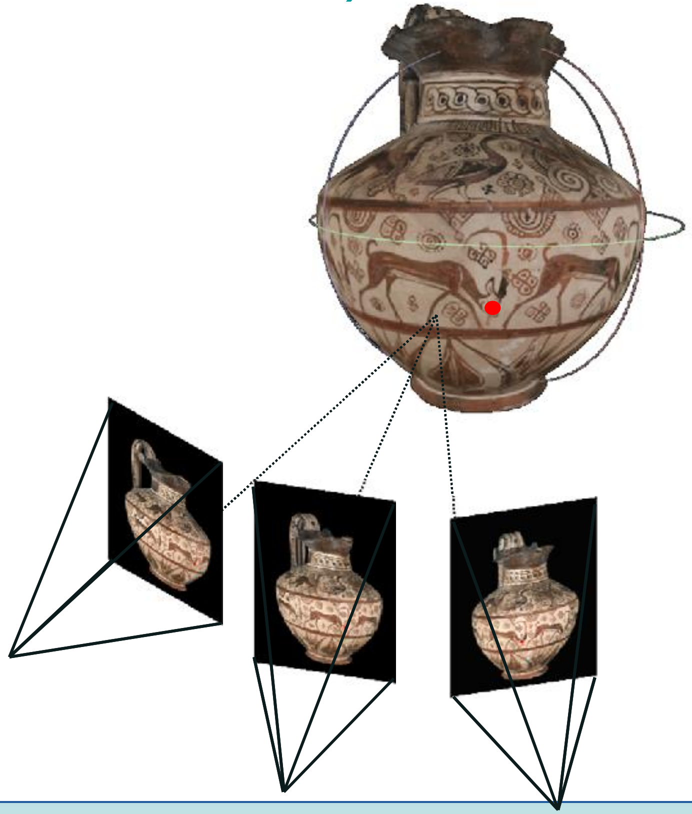
Stage 4. Color projection

Every point is seen by more than one image.

Problems if different illumination, small misalignments, image artifacts (different colors)



How to choose the best color from the registered images?

How are we going to save the color information?

Different technics can be used (e.g. color per vertex or texture mapping) but they suffer from weakness.

Data fusion of 3D data and 2D data

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Stage 4. Color projection

Method	Advantages	Disadvantages
Orthogonal view	✓ Easier to compute ✓ Fast	✗ Produces artifacts • Seams • Shadows • Highlights
Weighting scheme	✓ Color can be corrected due to overlapping areas of images ✓ Slow	✗ Takes more computational time. ✗ Need metrics to evaluate the weight. ✗ Introduces other artifacts: • Ghosthing/bluring effects
Illumination estimation	✓ No artifacts like shadows or highlights	✗ Precise calibration is needed (position of light source) ✗ No realistic effects ✗ Needed controllable lighting setups

Table 3. Survey of color selection methods for 2D-3D mapping

Data fusion of 3D data and 2D data

Stage 4. Color projection

Problem : most of local methods based on local error minimization are time consuming for very high resolution images.

In case of misalignment, global approaches can create ghosting effects in some areas (e.g. the most distant ones in the example shown).

Conclusion

- Working with high resolution images and very dense point cloud requires a GPU implementation to accelerate the computational time.
- Calibration is essential to obtain an accurate 3D reconstruction. Calibration is necessary to minimize artifacts due to the non-accurate camera parameters obtained with SfM technique.
- There is no unique solution for 2D-3D data fusion, as for any computer vision task.
- In many applications, knowledge makes easier the selection of a solution but for several other applications new problems have to be solved.

Conclusion

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- For a given application, users need to know how to select the best solution among all possible solutions proposed by engineers, i.e. what are the determining factors.
  - As example, for color calibration determining factors have been already categorized in the COSCH KR and the processing tasks have been listed in the COSCH ASM.
  - Likewise, thanks to this study on 2D-3D data fusion, we can now enrich the COSCH KR and the COSCH ASM.
- Thanks to semantic rules engineers and users can understand each other and can share their knowledge and enrich these two representations devoted to cultural heritage.

Conclusion

For some applications, it's sometime necessary to confront views of users and engineers by performing comparative measurements and using different devices/techniques.

WG2 (Spatial object documentation) developed a template of documentation form which enables to users and engineers to summarize the determining aspects for a given application in an unique document that can be exploited to enrich the COSCH KR.

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Questions/answers	Explanations
Person who produces this form	Robert Sitnik, Maciej Karaszewski, Warsaw University of Technology, 3D/4D imaging for CH applications
Measurement method principle	Structured light 3D scanning with color measurement (visible range). Automated acquisition of directional measurements
Cost	Equipment: measurement head (3 000€), positioning system (30 000€), PC computer for processing (2 000 €). Total 35 000 €. Working day: energy (about 10 €), operator supervision (40 €). Total 50 €. Service: 0 €
Time constraints	**Preparation**: 10 days (first time), 10 minutes (each next time) Acquisition: 26 days (4822 **measurements**) **Processing**: 5 days
Expected experiences of the operator	Low, due to automated measurement process. Operator's supervision is required as a safety measure, in case of errors in collision avoidance algorithms

Preparation process	Calibration check was performed on a daily basis to assess highest quality of measurement. It was done automatically by measuring calibration unit from few positions and checking results. Calibration was performed routinely after moving robot platform to another position. The calibration procedures is also automated and **no user assistance** is required.
Limitations	Object size was limited in height by robot's operating range (2500 mm). Its diameter was not a limiting factor (for larger objects, more robot platform position changes is required). Weight of an object was not an issue because it was not moved during digitization procedure. Surface of an object should be **diffusive**, reflecting or transparent surface cannot be measured. The shape of a surface is also irrelevant as long as it does not have deep cavities which cannot be measured by structured light system. If the surface of an object is devoid of distinct geometrical or color features, it is not possible to achieve good integration of directional measurements into one, complete model. Second category of difficulties is related to **positioning system**, including supply of power for positioning system (3 phase AC, hardly available in, for example, remote places), the weight of the whole system (almost 500 kg in total – limiting the use of such system for ground level objects only), the size of robot platform and requirements to the free space around and object for maneuvering (therefore it cannot be used in tight places). The final group of limiting factors is related to environmental conditions, which has to be controlled (especially temperature and humidity, darkness is also required).

List of **potential difficulties**	This particular system cannot for example measure objects **higher than** 2000mm because the positioning system has too small range. In fact it cannot measure smaller objects which are placed for example high on building façade – the robot platform cannot be risen. I cannot be used in expositions due to its size. It is cumbersome in maneuvering and requires much space, therefore it probably is not suitable for digitization of excavations, tombs etc. The technology (structuredlight with automated acquisition) cannot be used for transparent or reflective surface. It cannot be used for multispectral imaging (without some modifications) or for objects without distinct geometrical or color features. As maximum achievable resolution is about 10000 pts/mm2 (with inaccuracy lower than +/5um) it cannot be used when higher point density or accuracy is required. This technology is rather suited for digitization of separate objects (with high resolution) than for documentation of whole sites or groups of objects.

Measurement environment Limitations (laboratory conditions, outdoor, indoor, insitu etc.)	For highest quality of results laboratory are required. However this particular system with resolution of 2500 pts/mm2 operated correctly (within allowable inaccuracy) outdoors with some means for environment control (darkened tent, air conditioning units).

Measurement method parameters (resolutions, uncertainties, texture imaging, etc.)	**Resolution**: 2500 points / mm2 **Uncertainty**: +/10um Working volume (single measurement): 50mm x 50mm x 20mm Texture imaging: yes (in visible range), RGB, directly mapped onto measurement points
Example	Sandstone vase from Museum of King Jan III's Palace at Wilanów by J. A. Karinger and J. A. Siegwitz. Radius: 500mm, Height: 2000mm. On the surface rich ornaments showing scenes from Mythology. The color of the object is varied, signs of weather influence can be easily seen. The whole object was measured with the highest possible resolution for the scanner used (2500 pts/mm2). 4822 directional measurements were collected. Output format is cloud of points with RGB color information and surface normal. The **model data size is about 1TB**. More details about the process of automated digitization can be found in the research paper (Karaszewski, 2012).

Robert Sitnik and Maciej Karaszewski Warsaw : « An exemplary description of structured light method with automation of multi-view acquisition ».