PROJECT FINAL REPORT

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4.1 Final Publishable Summary Report

4.1.1. Executive Summary

The EC FP7-SPACE Project De-Montes (Deformation Monitoring by High Resolution Terrestrial Long Range Sensing) aimed at the provision of **an efficient, highly automated, high-resolution, terrestrial, long range sensing measurement and analysis system** which is able to **monitor geo-risk** areas and deforming large man-made objects by means of **non-signalized natural target points –** which is a key to such systems due to the lack of accessibility and the required distance-to-the-object.

The main step beyond currently available techniques lies in the introduction of a novel **modular suite of terrestrial visual survey sensors**, **namely Image Assisted Total Stations** (IATS, used to perform long-range high-resolution measurements on single points) in combination with **Terrestrial long-range Laser Scanners** (TLS, used to survey large areas).

The main objective of De-Montes was to equip the participating SMEs (Small and Medium Enterprises) with a new kind of measurement system for long-range terrestrial deformation measurements, based on **high precision visual measurements** (IATS) which can be combined with comprehensive lower resolution Laser scans (TLS) and digital photogrammetry.

The De-Montes project integrated methods and techniques from standard surveying, computer vision, photogrammetry, mechatronics, software engineering, and geological sciences, well covered by the academic and research partners. The Project mainly dealt with the **definition, implementation, adaptation, delivery and test**, **and preparations for system integration** at the SMEs' systems and frameworks, using software parts from the different RTD (Research & Technology Development) partners.

De-Montes reached its objectives by compilation of a modular sensor and processing suite for data capture and processing, targeting remote geo-monitoring applications - **Software** was developed and adapted to the SMEs' needs in terms of 3D vision processing for vision data from IATS, TLS, and photogrammetry. The system that was developed by the RTD partners incorporate the **sensors, their control & data processing, and a framework that enables an expert user (geodesist / geologist) to operate the software:**

- **IATS calibration** was described for the respective SME to be able to repeat such a process for further IATS devices
- **The IATS Hardware** (IATS devices) including a **long-range component** for communication between two IATS apart from each other established in the field for long-range monitoring was described and prepared for field tests.
- Data acquisition automation was implemented to provide **a generic data generation framework during geo-risk monitoring** or other terrestrial long-range sensor services provided by the SMEs. In addition, a **photogrammetric processing chain** containing a matching and 3D reconstruction pipeline was developed, adapted and delivered.
- A **processing scheme, based on various levels of invocation and embedding** (Python bindings on library and source-code level, the ability for each executable file to be called in batch or with a GUI (Graphical User Interface) containing Helper modules, Python batch modules on single-executable, workflow element, and workflow level, as well as dedicated GUIs for semi-automatic or manual data interaction such as 2D & 3D control point specification & edit, determination of deformation areas, and calibration) was realized to

ensure maximum flexibility and adaptation to the heterogeneous application and IT environment.

- The functional software components include the **entire processing chain as required for long-range geohazard monitoring based on IATS, TLS and photogrammetry**, and serve additional needs of the SMEs such as monument 3D reconstruction and monitoring, tunnel laser scanning and aerial image-based mapping: Bundle adjustment, 3D reconstruction from IATS stereo, multi-view stereo, single stereo, and TLS, and the ability to texture the respective data and maintain it in a unified 3D data structure was developed and/or adapted. Means for deformation and volume measurement as well as volumetric change detection between different data acquisition epochs were made available. Point detection and tracking particularly for the IATS case (but useable also for photogrammetric solutions, due to the versatile 3D data structure maintaining all used sensors) was developed as a specific processing workflow. The long-range aspects (atmospheric correction) were covered by a specific library available as Software plug-in for measurements data correction.
- Various data import and export as well as data editing facilities were made available to the SMEs.
- A **spatial data base** including access mechanisms on Software library basis with the ability to be extended in a temporal sense was provided by one of the SMEs.
- A unified **sequence planning of processing elements** was implemented in order to allow rapid prototyping and finalization of efficient processing chains.
- The same way as processing sequence planning / scheduling a **monitoring task maintenance framework** was implemented.
- Three **field tests** took place with IATS, one long-term **field test installation** at one of the SMEs' application areas at a Norwegian ford using a fixed stereo camera set-up was maintained. In addition, TLS application was tested in an **installation at an Austrian winter resort site aiming at snow height monitoring**. Data processing for the mentioned cases partly already used the delivered software components, which showed an expected short period until time-to-market of the solutions.
- The respective **delivery schemes were developed and unified,** consisting of use cases, unit test data, click-and-go demonstrations and tutorial documents.

Applications, test environments and verification procedures were provided by the SME partners. The Project results were exploited externally by dissemination activities and Demo actions. Dedicated training inside the Consortium consolidated the use of the system.

A plan for the use and dissemination of the knowledge was elaborated in two stages, to show how the results developed and delivered by the RTDs can most efficiently be used in near future by the SMEs partners. A **joint business plan** was discussed as an agreed roadmap for further cooperation between SMEs and RTDs, as well as the SMEs' own plans to exploit the delivered results and elements in their best commercially sustainable way – this was already underlined during the De-Montes duration with some fair contributions by De-Montes SMEs.

Parallel to the technical developments, more than 10 **publications** and presentations as well as posters in scientific conferences were released in cooperation between RTDs and SMEs, and parts of a book chapter were supported by contents of the De-Montes project. Two diploma theses were finished. Further dissemination activities (about 10 are the most relevant ones) include various appearances in newspapers and web announcements, With the help of its three RTD Partners, **the De-Montes Project built and tested a productive prototype system** for short-term exploitation by the SMEs involved in the Project, such that after project termination they **can immediately identify and quantify its potential for enhancing** their service portfolio, and gaining new business fields by exporting the system and its components to related application areas such as tunneling and construction, documentation of cultural heritage objects, industrial inspection, or geo-monitoring.

4.1.2. Project Context and Main Objectives

Rock falls and Landslides are major types of natural hazard world-wide that kills or injures a large number of individuals and causes very high costs every year. Such events cannot be avoided, however, it is known that knowledge about the dynamics of unstable areas (i.e. the determination and measurements of surface deformations in cm-accuracy range) in many cases allows the prediction of hazardous events, therefore **such information may be crucial in order to allow live saving reactions**. This implies an **urgent need for highly effective and reliable tools for monitoring** potential rock fall areas at an operational level, in order to obtain better knowledge on the expected dynamics, and the spatial distribution of the event.
In Europe today **mainly SMEs are running case-by-case services** in the area of geo-risk monitoring and management. Most projects are based on conventional techniques, like tacheometry, photogrammetry, laser scanning, Global Navigation Satellite Systems (GNSS), or/and geotechnical methods. A major disadvantage of most of these techniques is that **sensors have to be placed on-site** (on the object) – GNNS sensor have to be installed on the endangered region or geotechnical sensors have to be implemented on/in the object. Some optical remote measurement systems are able to monitor without being installed in a precarious regions, namely laser scanning and total stations.

De-Montes SMEs (Table 1) urgently need a monitoring system that is able to obtain long distance high-resolution 3D measurements as they are more and more confronted with requests in the field of geo hazard monitoring which cannot be fulfilled with current technology. De-Montes developed a modular monitoring system able to cope with these challenges.

The Norwegian SME participant of De-Montes **Cautus Geo** is currently involved in the **monitoring of several geo-hazard sites**, like the Åknes rock slide[1] area. In this case Cautus is responsible for the whole ground movement monitoring by means of a network of GNSS antennas in combination with a robotic total station, laser scanning and traditional photogrammetry and a complete data management system for all sensors.

GeoImaging Ltd. from Cyprus own various professional 3rd party software tools in the field of Geodesy, photogrammetry, GIS and 3D reconstruction. Having collected hundreds of representative data sets from cadastral surveying, archaeological sites and monuments documentation, GeoImaging targets to open a new market of monitoring; i.e. the monitoring of cultural heritage monuments.

Dibit Messtechnik, the Austrian SME participant, was **involved in the monitoring of the Eiblschrofen Rockfall**. In June 1999 close to the Tyrolean city Schwaz a rock face unexpectedly lost about 20.000 cubic meters of debris. With the help of the RTD performer Joanneum Research (JR) a terrestrial laser scanner (TLS) for continuous round-the-clock full-frame measurements of the rock slide area was embedded in the monitoring sensor framework, established immediately after

[1] Åknes is known as the most hazardous rockslide area in Norway at present, with an estimated volume of 35–40 million m^3 area, which endangers a ford in western Norway

the first slide within a few days. Following the dynamics of the remaining rock structure, the evacuation of about 270 inhabitants was executed and, after a thorough analysis of involved volumes, remaining rock dynamics and the 3D shape of the area underneath, protection structures were installed during the following months.

NeoVision from the Czech Republic do not run services in the area of long-range monitoring, but they are experts in computer vision systems engineering / assembly and maintenance, and as such want to support the other three SMEs as Hardware (HW) integration and system setup partner.

http://www.De-Montes.eu © De-Montes	▪ Joanneum Research (JR), Austria ▪ Czech Technical Unviversity (CTU), Czech Republic ▪ Technical University Munich (TUM), Germany ▪ Neovision (NEO), Chech Republic ▪ GeoImaging (GEO), Cyprus ▪ Dibit Messtechnik (DMG), Austria ▪ Cautus Geo (CAU), Norway

Table 1: De-Montes Beneficiaries.

The main De-Montes objectives are summarized as follows:

- Define **system requirements and test specifications** and create the according RTSD (Requirements and Test Specification Document)
- Develop **sensor control** software for IATS and TLS, as well as calibration for IATS
- Develop a **calibration procedure** for IATS
- Finalize the **De-Montes IATS Hardware system**, and its **long-range scanning and processing** abilities
- Develop an **IATS Interest Point Detection and Tracking Module**
- Develop a **Surface Texturing Module**
- Adapt a **Spatio-Temporal Data Base**
- Develop a **Bundle Adjustment Module**
- Develop a **Deformation & Volume Measurement Module**
- Develop a **Volumetric Change Detection Module**
- Develop an **Image & 3D Structure import module**
- Develop a **Data Acquisition Module**
- Develop a **Processing & Monitoring Overlay**
- Conduct various **testing** and compile a **Report on Acceptance Test Campaigns and Results**
- **Publish** the scientific work of the project, participate to **fairs**, **conferences** and other dissemination events, and compile the **Report on fairs and conferences participation and used materials** as well as the **Report on Publications and Dissemination Activities**
- Compile the **Final Plan for the Use and Dissemination of the Knowledge as well as a Joint Business Plan**
- Establish and maintain an **official web site** for education, public outreach, and information sharing (such as updating project status, disseminating results, and advertising events)

4.1.3. Main Science & Technology Results / Foregrounds

4.1.3.1 Summary of Foreground

In the following the main results as available for De-Montes SMEs are listed:

1) The Data Acquisition Module and Monitoring Overlay (Section 4.1.3.2) handles geo-monitoring data acquisition tasks in a generic way. A Task Server (Section 4.1.3.3) manages the scheduling and execution of data acquisition and data processing tasks, interfacing HW and SW (Software) components in a generic and configurable fashion
2) The IATS Control Module (Section 4.1.3.4) handles device control and data capture for the operational use of two synchronised Image Assisted Total stations.
3) An IATS Calibration process (Section 4.1.3.5) has been adapted / developed and described.
4) A long-range extension consisting of methods and software parts (Section 4.1.3.6) has been provided.
5) The TLS Control Module (Section 4.1.3.7) implements various layers of software for TLS control and data readout.
6) A workflow for TLS data capture, global registration, fusion with TLS and camera, and low-level analysis (Section 4.1.3.8) was delivered.
7) A workflow for the generation of DEM (Digital Elevation Model) / Ortho images from oriented IATS captures (including image mosaicking) (Section 4.1.3.9) was delivered.
8) Workflows for the generation of point clouds and DEM (Digital Elevation Model) / Ortho images from single and multiple stereo images (Section 4.1.3.10) as well as unoriented images (Section 4.1.3.11) were provided.
9) Modules for the detection and tracking of interest points on the TLS / IATS and photogrammetry reconstruction results were delivered (Section 4.1.3.12).
10) The tracking of interest points is complemented by a following generation of deformation vectors (Section 4.1.3.13)
11) An automatic 3D deformation evaluation and volume measurement chain (Section 4.1.3.14) was provided.
12) Semi-automatic 3D volumetric change detection software supported by a GUI (Section 4.1.3.15) was delivered.
13) A Bundle Adjustment Module was provided (Section 4.1.3.16).
14) Various stand-alone utilities were provided such as GUIs for identification of signalized targets used for camera exterior orientation (Section 4.1.3.17).
15) A spatio-temporal data-base (Section 4.1.3.18) has been made available designed to be the central spatial storage for acquired and processed data.
16) Hardware (HW) know-how and components emphasize on the IATS, TLS and DSLR (Digital Single Lens Reflex) Cameras HW configurations and the communication HW for long-range scanning (Section 4.1.3.19).

In addition, various auxiliary components, features, files, methods and know-how was adapted, elaborated and delivered:

a) Most components are available as Python bindings (library functions), allowing quick insertion into C++ frameworks and as standalone executables without further maintenance – see Figure 1 for the De-Montes Software architecture paradigm.

b) For most components both GUI-based and batch access are available for fast prototyping on the one hand, and insertion into fully automatic chains on the other hand.
c) Logging and debugging allows different levels.
d) Installation frameworks were established for various levels of detail, including use cases with demo data and one-click verification ability.
e) License file-based protection was integrated to the most crucial components.
f) Data schemes and file formats were adapted and described, such as the GPC (Generic Point Cloud) as being used for data exchange between De-Montes modules.
g) To export data from the native GPC format, export modules are available.

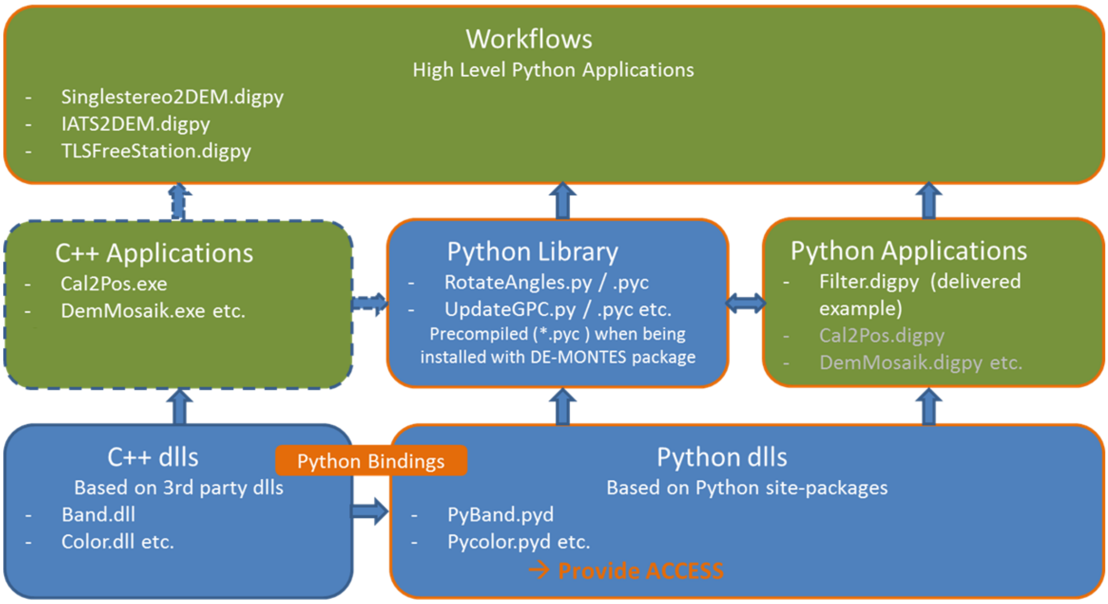


Figure 1: De-Montes software architecture.

4.1.3.2 Data Acquisition and Monitoring Overlay Module

The Data Acquisition Module executable is a command line tool called *DMAcq Server* which tries to carry out the tasks it receives via a telnet interface with the help of one of the available sensors and stores the results at a configurable location in the native GPC format for further use of De-Montes modules. The same way, via network communication interface, tasks for processing can be enqueued, updated and executed. An overall scheme of the DMAcq and its environment / clients is shown in Figure 2.

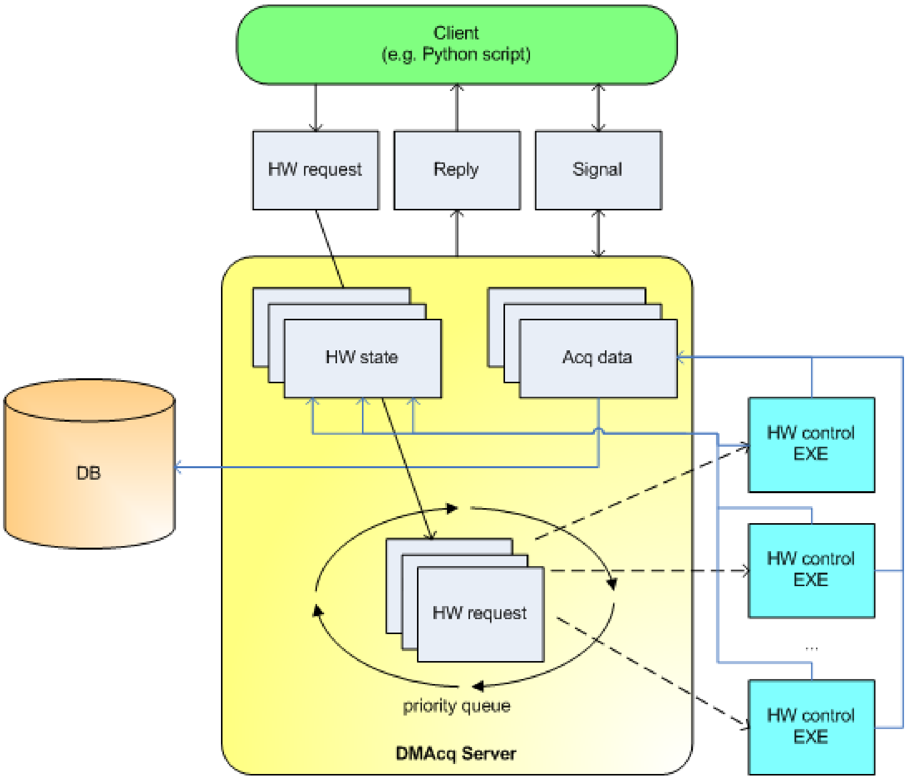


Figure 2: DMAcq (De-Montes Data Acquisition and Monitoring) Server

4.1.3.3 Task Server

The De-Montes Task Server manages the scheduling and execution of data acquisition and data processing tasks, interfacing HW and SW components in a generic and configurable fashion. A user manual gives information about the following points:

- Installation and configuration
- Starting/stopping the server
- Connecting a client and sending commands
- Task definition & group tasks feature

The main purpose of the Task Server is the management, scheduling, and execution of tasks. To define a task, the user has to create an XML (Extensible Markup Language) file describing various generic properties of the task, such as start and finish time, as well as properties dependent on the specific type of task (e.g. ROI – Region-of-interest for acquisition tasks). Group tasks allow the grouping of a sequence of related tasks to a logical unit, executed in the defined order. Often, certain usage patterns (in terms of devices and workflow functions) emerge from given requirements of a project or setup. Being able to repeat such patterns is often convenient and desirable.

4.1.3.4 IATS Control Module

The IATS Control Module handles device control and data capture for two IATS devices. Central software module is the library “Control.dll”. This part includes all algorithms and functions for the operational use of two synchronised Image Assisted Total stations. The software is written in C++ and available as DLL (Dynamic Link Library). It serves also as high level driver (generalized set of functionalities for IATS devices).

An overlaid GUI (Figure 3) is responsible for user interaction. It is also available in Batch mode for ensuring remote control in an automatic environment.

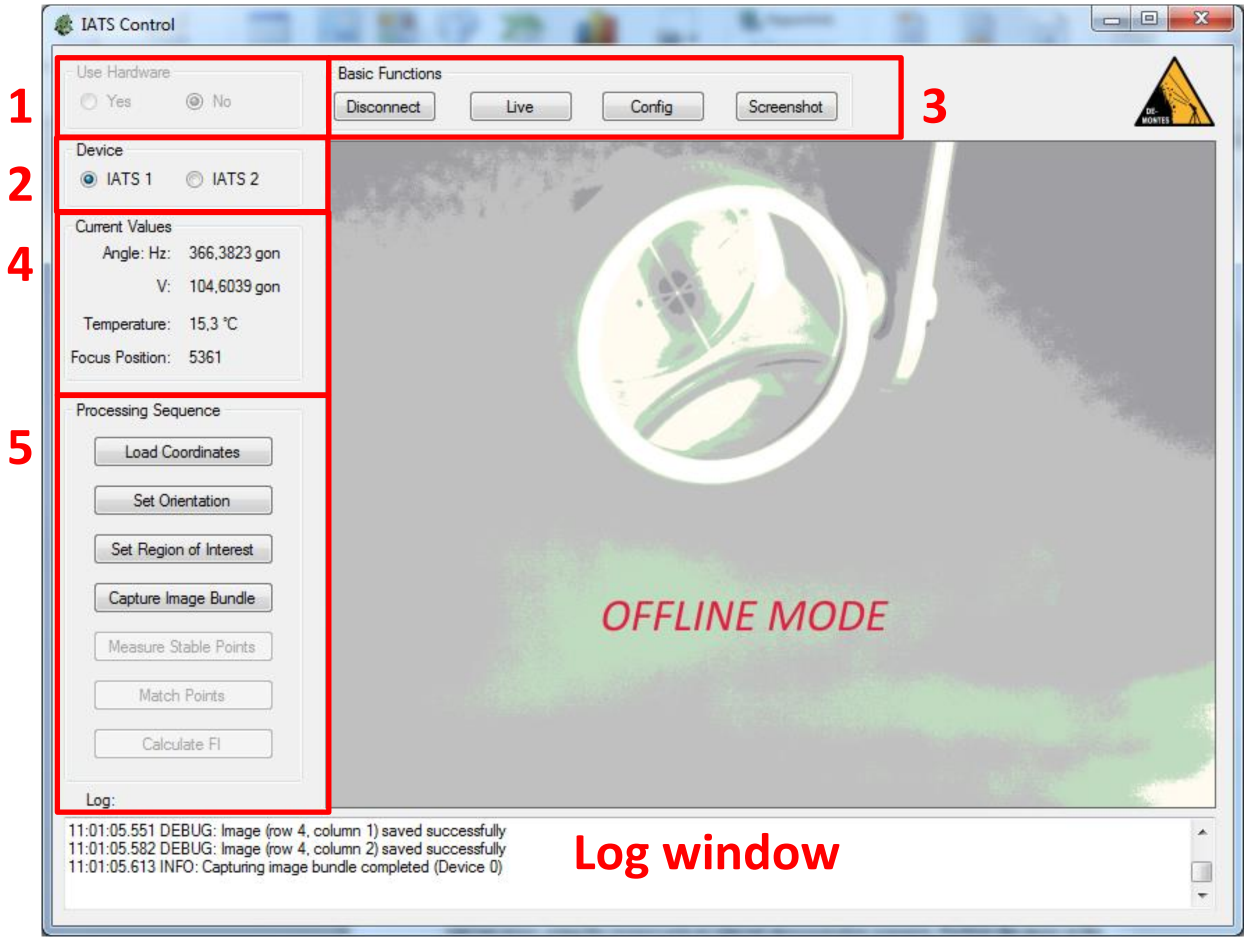


Figure 3: IATS control user interface with sub functionalities

4.1.3.5 IATS Calibration

When using an Image Assisted Total Station (IATS) or any other pan-and-tilt camera system, the act of targeting at a specific point to obtain its corresponding spatial vector information is shifted from a human operator to the image analysis operation of the control software. As a result, the target no longer has to be centred by means of a crosshair, but it may appear at an arbitrary position within the field of view (FoV). As this will lead to a misalignment of the optical telescope and the spatial vector from the theodolite reference point (axis intersection point) to the destination point, it is essential to know about the relation between the position of an object in the image and the corresponding angular corrections with respect to a reference pixel (crosshair direction). This relation needs to be found performing a calibration of the camera with respect to the actual readings of the basic theodolite, resulting in a mathematical description to transform pixel information to angular values and vice versa. As the telescope system usually is focusable, the calibration has to be done at different focus positions as the optical path will vary when focusing. For fix-focus cameras, one single set of calibration parameters is sufficient.

The basics of the calibration process were derived and the necessary instrumentation is described. An easy to create algorithm for the entire workflow (Table 2) has been shown to be programmed in an arbitrary computer language.

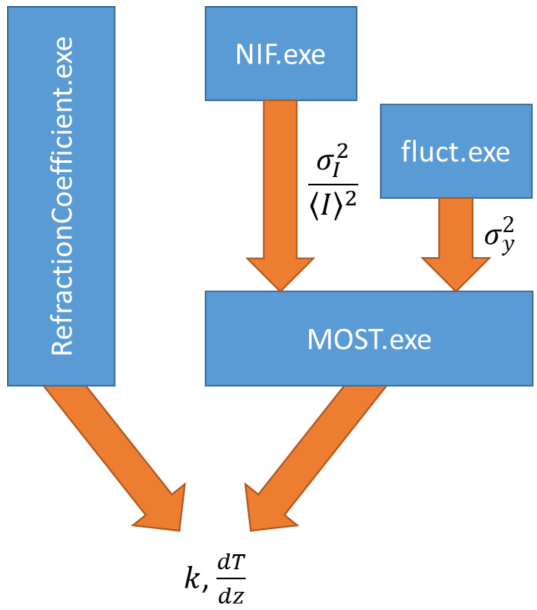
Parameter Definition	• Definition of focus motor position to be calibrated • Setup of camera (exposure, contrast etc.) • Definition of the number of target images to be observed and the position range to move the tacheometer
Calibration with horizontal view I	• Setup of collimator to show a sharp image at one end of the field of depth of the camera focus setting • Tacheometer vertical viewing angle is about 100 gon (horizontal view) • Automatic measurement of defined number of target images in both faces
Calibration with horizontal view II	• Change collimator setting to show a sharp image at the other end of the field of depth of the camera focus setting • Again horizontal view and automatic measurement in both faces
Calibration with steep view I	• Tilt collimator and tacheometer setup until vertical vieweing angle is rather steep (50 gon) • Automatic measurement of defined number of target images in both faces
Calibration with steep view II	• Again change collimator setting back to the first end of the field of depth of the camera focus setting • Again steep view and automatic measurement in both faces
Evaluation & Processing	• Combine all four sets of measurement to derive camera and tacheometer calibration parameters for the according focus position

Table 2: IATS Calibration Workflow

4.1.3.6 Long-Range Software Extension

To achieve high accurate measurements over long distances it is essential to consider some corrections respectively reductions which may be neglected for short distances. Software plug-ins for atmospheric correction and Earth curvature compensation as well as refraction were compiled and delivered.

To be as flexible as possible the delivery part *LongRangeIATS* is split in two parts, see Figure 4:



1) The main function *RefractionCoefficient.exe* executes all necessary steps to calculate the refraction coefficient k and the temperature gradient $\frac{\sigma_I^2}{\langle I \rangle^2}$ of the recorded images as described above.

2) To enable the SME to use other image processing methods/software, e.g. to use other target structures or to speed up the process, all image pre-processing steps used in 1) can be replaced. The calculation of k and $\frac{\sigma_I^2}{\langle I \rangle^2}$ is than possible with the executable *MOST.exe*.

Figure 4: Components of package *LongRangeIATS*

4.1.3.7 TLS Control Module

The TLS Control Module implements various layers of software for TLS control and data readout, based on a generic & modular hardware driver concept.

4.1.3.8 Stop-and-go TLS Data Capture, global registration & Texturing

The main TLS workflow includes the following modules as illustrated in Figure 5 and Figure 6. It consists of an import module to store data in a native format (GPC: Generic Point Cloud), a global registration module and a DSM (Digital Surface Model) and ortho image generation module.

The TLS geometry workflow provides DSM texturing using laser reflectivity (Figure 7). To provide more realistic texture additional camera images can be used. Assuming to be able to estimate a predicted camera pose, a laser reflectivity texture image can be rendered for this camera geometry. This allows co-registration using similarity in texture by feature based matching. Direct linear transformation provides exterior camera orientation based on automatically tie points generation and RANSAC (random sample consensus) iterations. The resulting improved camera pose allows to directly mapping camera texture onto the model surface providing intelligent blending between single image overlaps.

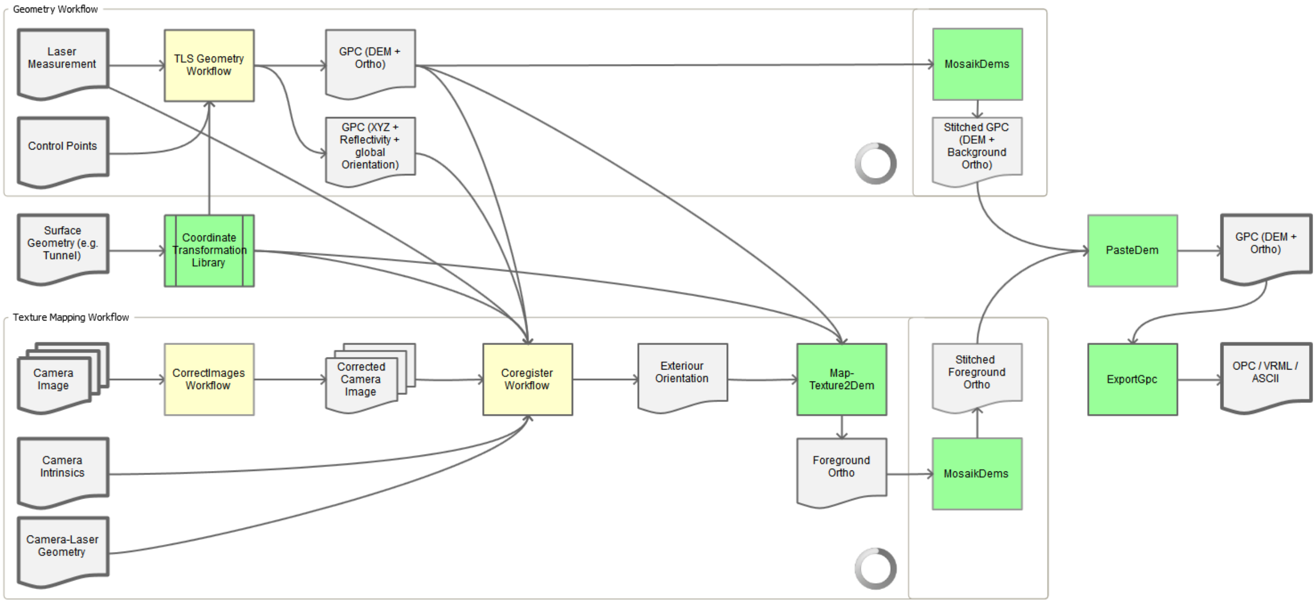


Figure 5: Overall Stop and Go TLS workflow. Above: TLS geometry pipeline for generating DEM and ortho image from laser reflectivity. Below: Texture mapping pipeline to get realistic ortho image using camera images registered and projected onto DEM/DSM. Right: Combine laser reflectivity and camera texture and export DSM / ortho to different formats.

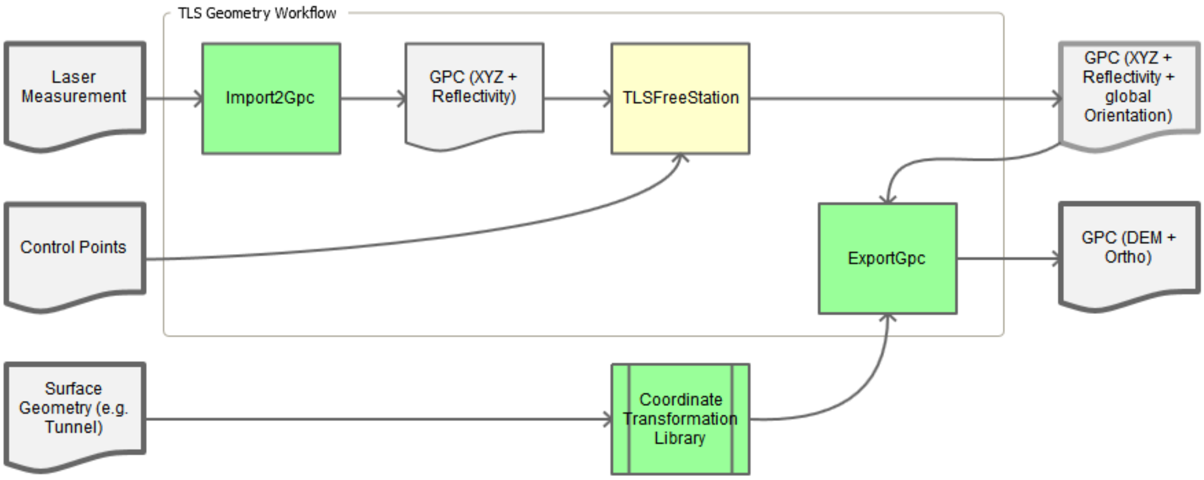


Figure 6: TLS geometry workflow.

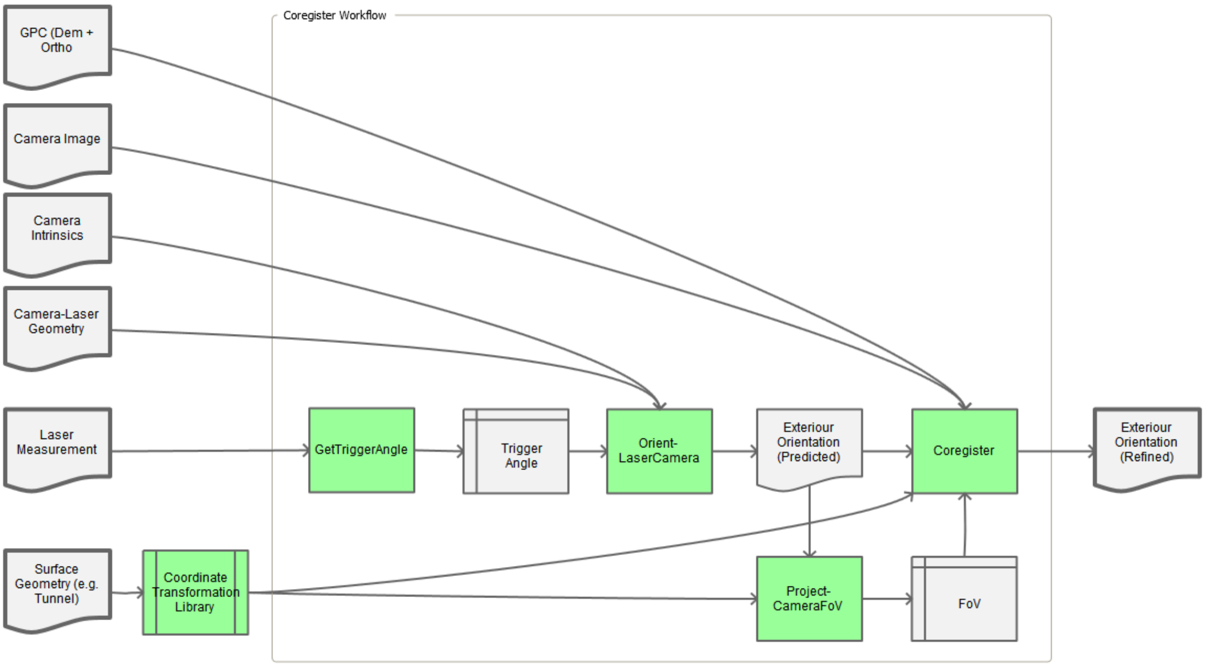


Figure 7: Co-registration pipeline to get refined camera pose using TLS geometry and laser reflectivity.

4.1.3.9 IATS DSM / Ortho Image Processing

The generation of DSMs and ortho images from mosaicked stereo IATS data is sketched in Figure 8.

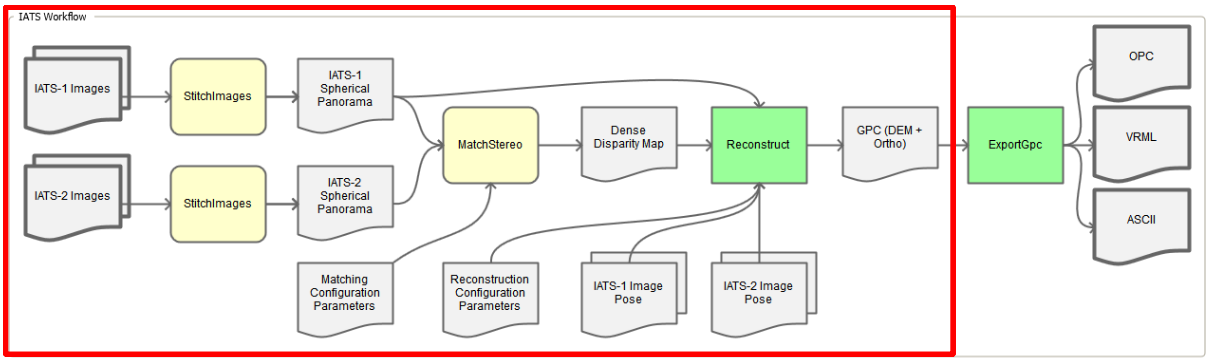


Figure 8: IATS workflow

4.1.3.10 (Multiple) Stereo Image Modules

This module contains functions for data import from digital consumer cameras, GUI-based image orientation using signalized targets, and single or multiple stereo workflows (Figure 9) using dense stereo matching and 3D reconstruction on spherical or Cartesian DEMs (Digital Elevation Models) & ortho images. The functions are available in different layers (Python bindings, and executables that allow both batch and GUI-based execution, see Figure 10 for an example). Various enhancements are available as well, such as single point matching for robust matching prediction combined with pre-warping, outlier detections, or intermediate data export to vrml (Virtual Reality Modeling Language).

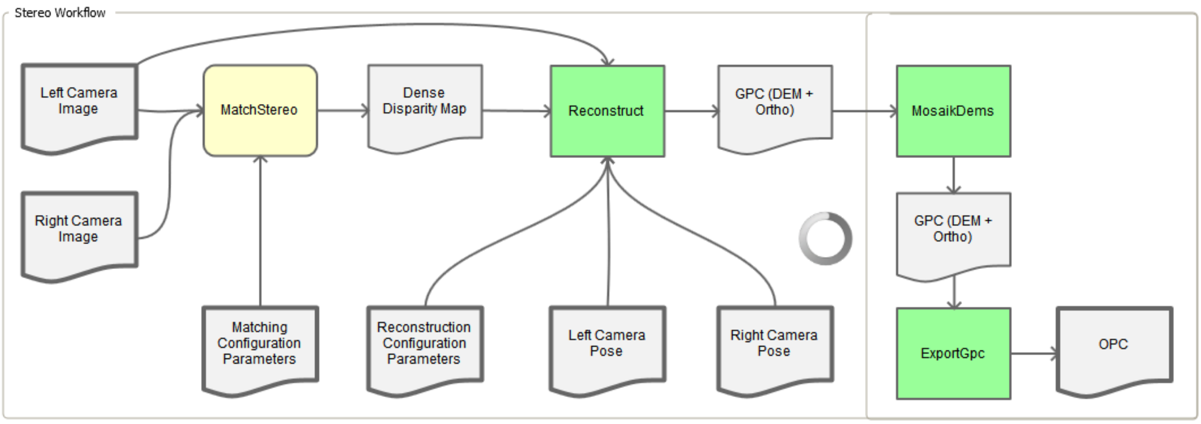


Figure 9: (Multiple) Stereo Workflow. Within the Multiple Stereo Workflow a number of dems resulting from the Single Stereo Workflow, respectively, are merged to a mosaic-dem.

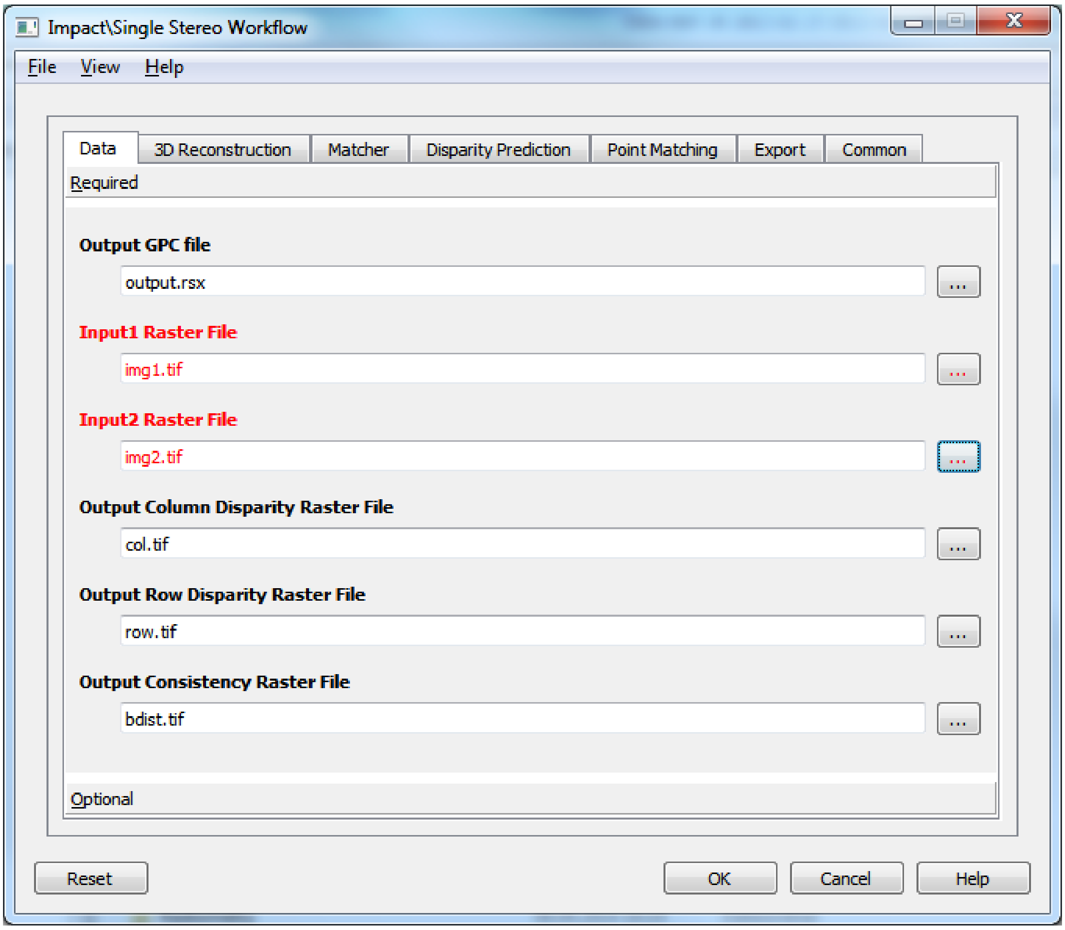


Figure 10: Part of single stereo workflow GUI

4.1.3.11 Reconstruction Workflow from Unoriented Images

The use case of generating a globally oriented DEM plus ortho image from a set of unoriented images is covered by the ReconstructUnorientedImages workflow as introduced in the following (Figure 11). It consists of an overall GUI (GeoMapper, see Figure 12), Geo-Registration with optional bundle adjustment, dense reconstruction, 3D bounding box of interest extraction, and DEM projection. The workflow is supported by visualization and 3D data manipulation as available in the Volumetric Change Detection Module (Section 4.1.3.15).

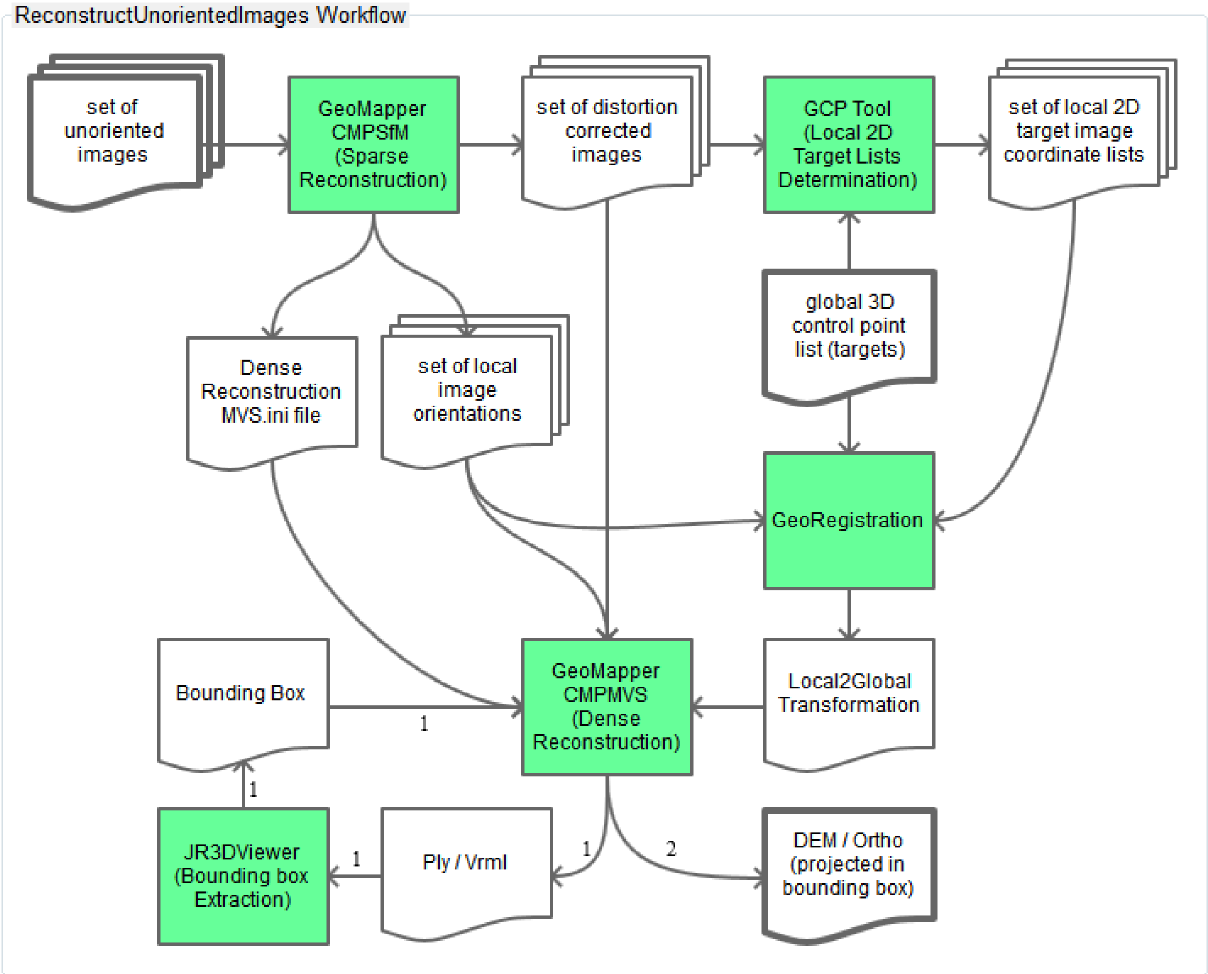


Figure 11: ReconstUnorientedImages Workflow for realization of use case 2 (green: SW modules, white bold border: in- and outputs, white normal border: intermediate results).

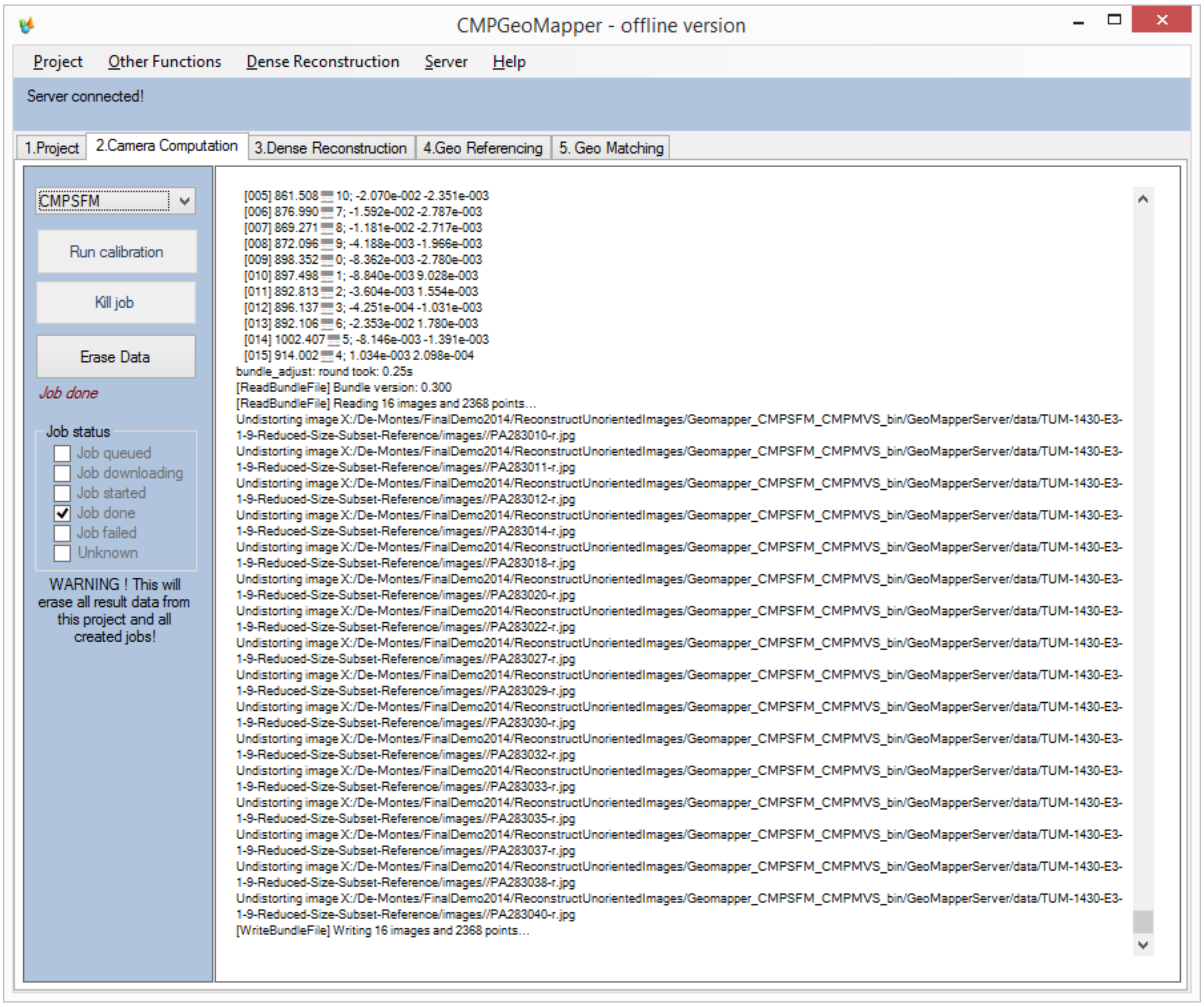


Figure 12: GeoMapper GUI: sparse reconstruction is running

4.1.3.12 (IATS) Interest Point Detection & Tracking Module

One essential De-Montes component is the interest points detection & tracking module which consists of a SIFT-based extraction part, a verification part (epipolar and/or homography), and a tracking part across multiple images. Two options are available from CTU and JR (Figure 13), respectively.

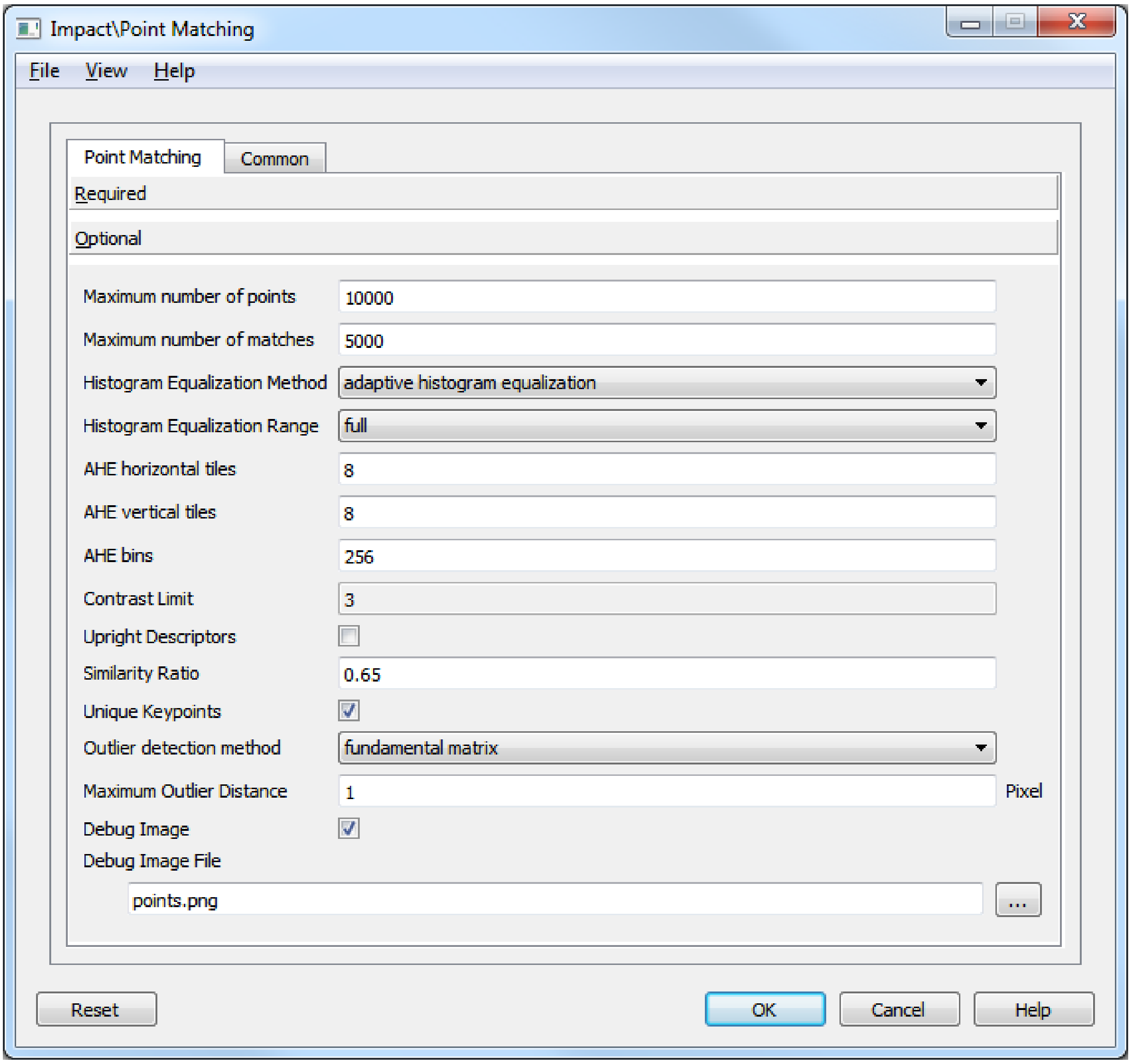


Figure 13: Pointmatching Tool optional parameters

4.1.3.13 Generation of 3D Deformation Vectors

The IATS based measurements and experiments to compare them to different sensors represent the more scientific part of the project. A point matching workflow was developed to evaluate the experiments conducted at the Field Trial in Pellheim (see Section 4.1.3.20).

It consists of the following elements:

- Calculate Stereo Point-matches between images of first measurement epoch
- Load matches as input points
- Calculate Point matches between stereo matches of first epoch and left image of second epoch
- Load matches as input points
- Calculate stereo matches within second epoch
- Use forward intersection to calculate 3D coordinates of points in first epoch
- Use forward intersection to calculate 3D coordinates of points in second epoch
- Save 3D deformation vectors for connected points of both epochs.

This processing method was evaluated by an experiment at the Pellheim field trial. An artificial deformation carried out on an artificial rock was measured via IATS, TLS and Theodolite. Further the results of the different sensors were compared.

4.1.3.14 Deformation and Volume Measurement Module

An essential component for measuring the different state of a deforming surface is the **ability to detect corresponding points & to derive deformation vector fields.** The workflow delivered for this purpose (Figure 14) is based on two different 3D model reconstructions in the form of DEM and Ortho images which were generated using the same underlying geometry. The input can be generated via the Single Stereo Workflow (section 4.1.3.10) or for IATS image bundles (Section 4.1.3.9).

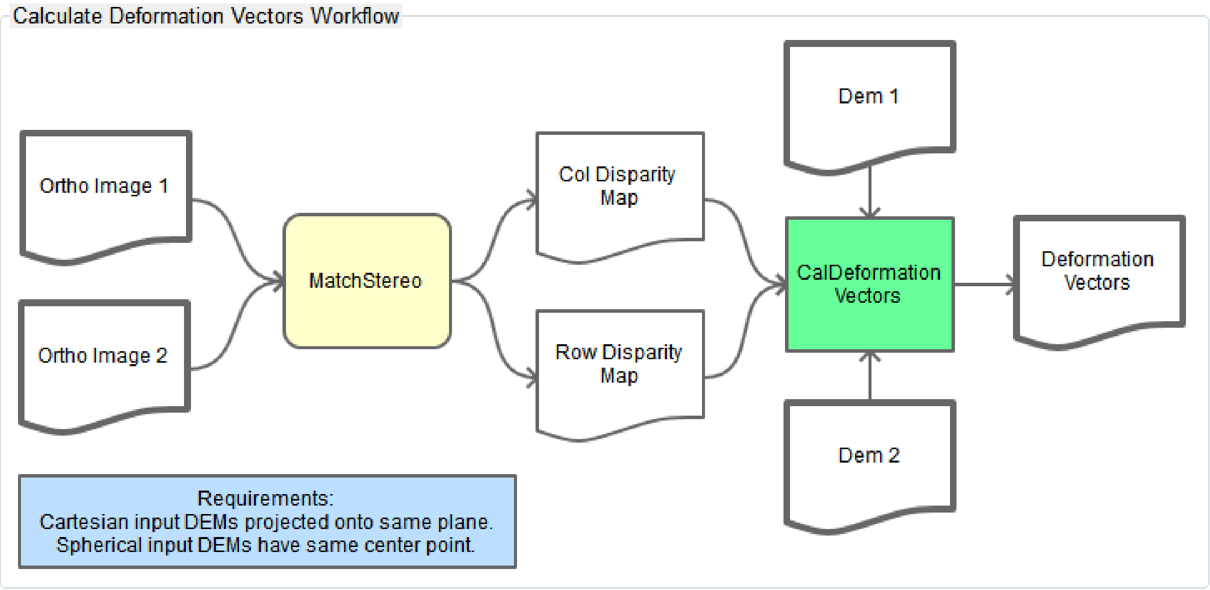


Figure 14: Flowchart of Deformation Vectors Workflow with inputs, intermediate results and outputs.

The pre-requisites for this workflow are two DEM and Ortho models in the same geometry but from different measurement epochs[2]. The workflow takes the ortho images and matches them. The resulting dense disparity maps can be used to generate a dense temporal deformation vector field from the corresponding DEMs (See Figure 15 for the results on an artificially deformed surface).

[2] For cartesian DEMs: projected onto the same regression plane. For spherical DEMs: same projection center.

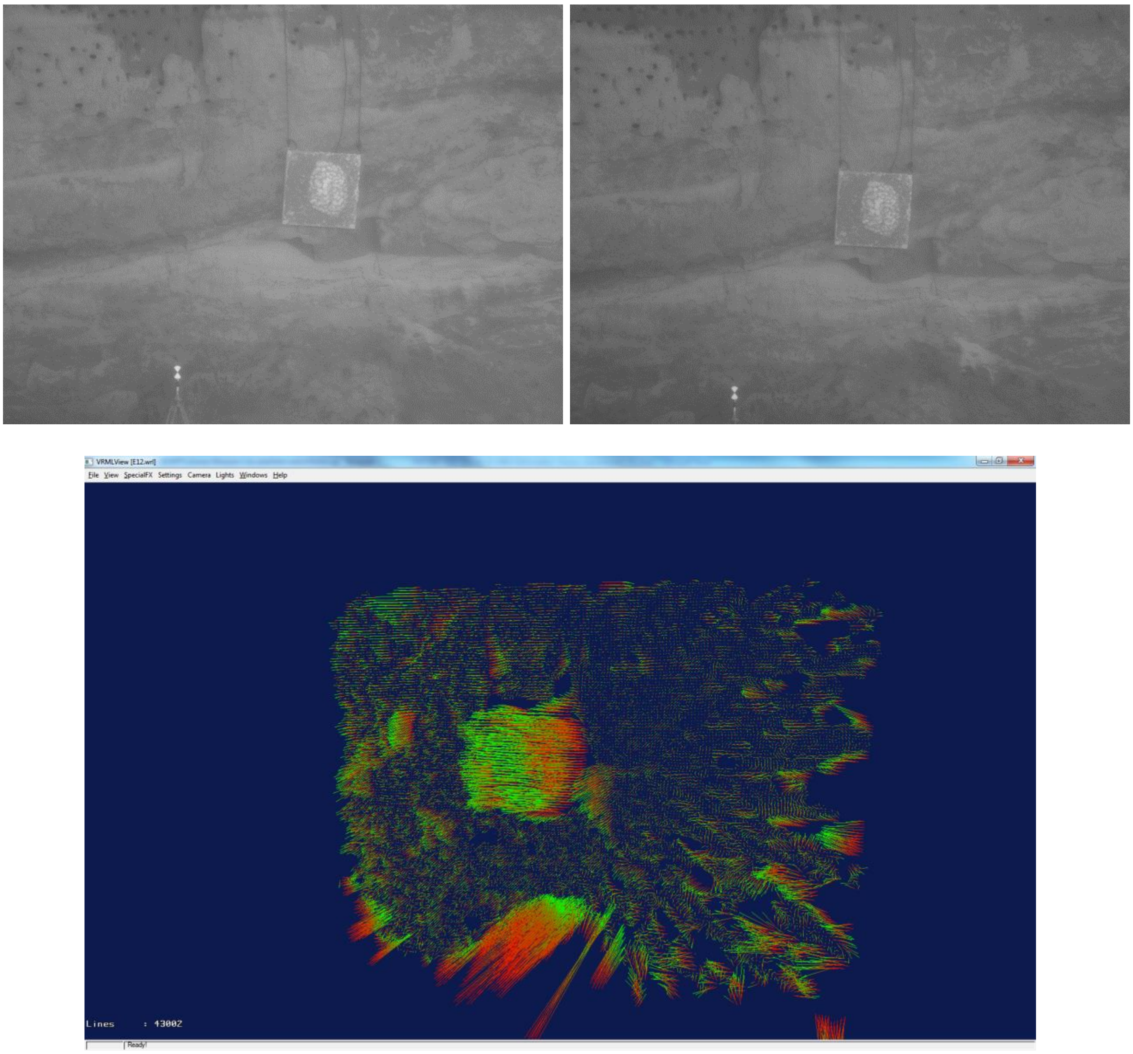


Figure 15: Example of artificial deformation, left images of stereo pairs in two different epochs (top), VRML representation of 3D deformation vector field with a grid width of 10 (every 10th vector displayed) as a result of Calculate Deformation Vectors workflow (bottom)

4.1.3.15 Volumetric Change Detection Module

One major aim of the De-Montes project was to provide deformation information for the geo-risk monitoring. This includes the detection and tracking of a deformation region in a 3D data representation of the monitored area over time as well as the determination of a measure for the degree of deformation, e.g. the volumetric change. Similar to other De-Montes components, it builds upon 3D reconstruction results of the processing components for surface measurement and reconstruction (namely "generic point cloud" - gpcx data), hence the data exchanged is compatible with the De-Montes processing suite.

The Volumetric Change Detection workflow is the only full De-Montes workflow that requires user interaction, when segmenting and selecting the deformed region of interest. Thus, the functionality of this workflow has been implemented as plugins for the VTK ParaView based JR3DViewer, an upgradable, interactive 3D viewer supporting a variety of proprietary 3D formats.

Figure 16 summarizes the semi-automatic Volumetric Change Detection workflow.

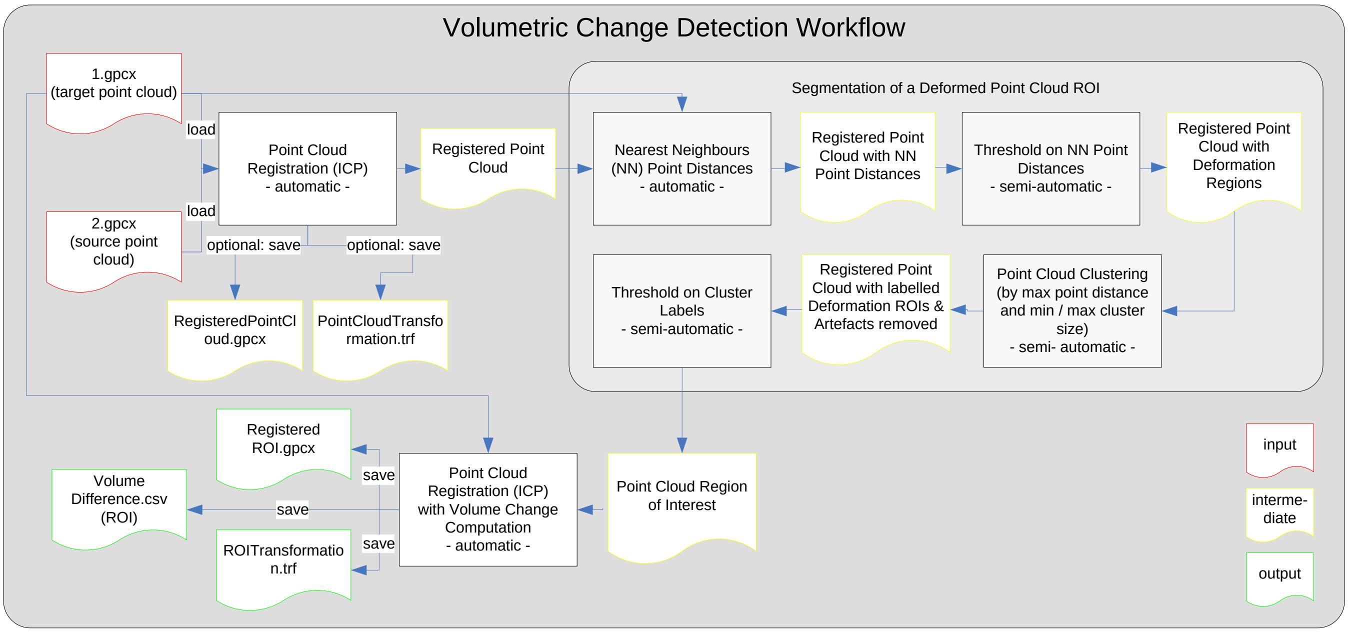


Figure 16: Volumetric Change Detection Workflow.

The JR3DViewer is an interactive tool, however it allows to store (user-selected) workflows and recall them on demand on single mouse-click. It therefore follows the paradigm of batch processing as preferred user pattern within De-Montes. The workflow is able to read two generic point clouds (1.gpcx and 2.gpcx, respectively), allows an ICP (Iterative Closest Point) registration between them, and calculates remaining point distances between the original 1.gpcx and the registered 2.gpcx. A semiautomatic threshold can be applied, leading to a clustering on the registered 2.gpcx. The largest (or in fact any) cluster can be evaluated in terms of volume difference and for moving parts segmentation. Several statistics (including the resulting volume between the selected 2.gcpx cluster and the 1.gcpx) can be reported on a csv file.
At any stage intermediate files can be saved.
Figure 17 shows an example appearance of the GUI.

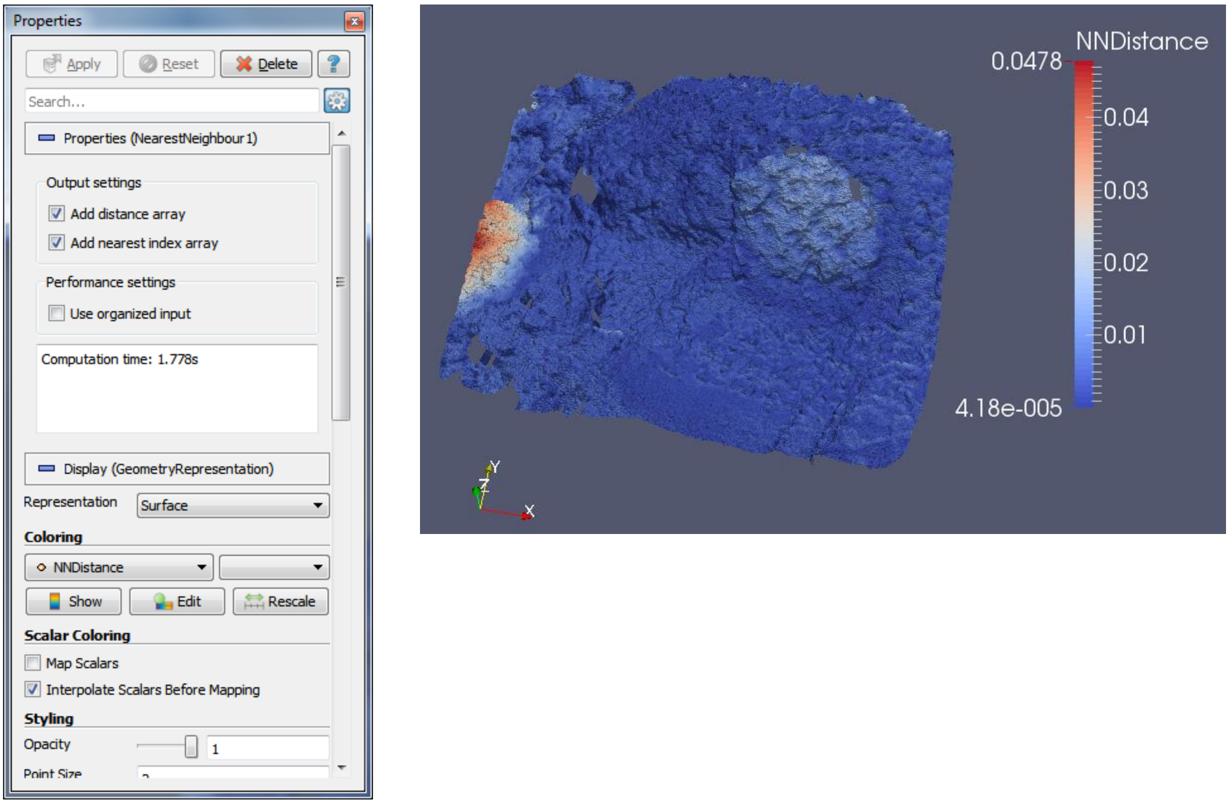


Figure 17: JR3DViewer GUI as used for the semi-automatic evaluation and segmentation of deformation between different epochs

4.1.3.16 Bundle Adjustment Module

The Bundle Adjustment (BA) module is based on the Google CERES non-linear least square solver. It utilizes State of the Art Bundle Adjustment methods. The core of the optimization is the Levenberg-Marquardt method for non-linear least squares. Other key methods are the Schur Complementation, Approximate Minimum Degree ordering, Conjugate Gradients and Cholesky factorization. The module can be incorporated into an existing Python GUI using the Python wrapper or any GUI application developed using Microsoft Visual Studio 2008 SP1 (Service Pack 1) and supporting loading of DLLs. It contains a Visual Studio solution with 5 projects corresponding to 5 different use cases. The use cases provide examples of basic and advanced functionality of the BA module and require certain input data.

4.1.3.17 CalWin, GCPTool Georegistration

The GUI based JR software CalWin can be used to identify signalized targets with known 3D coordinates within images and calculate intrinsic as well as extrinsic camera parameters. The 2D image positions targets signalized as round black or white circles are automatically refined to high sub-pixel precision.

The GUI based JR software GCPTool (see Figure 18 for parts of its GUI elements) can be used to manually identify signalized or unsignalized targets or general distinctive image features. The clicked points can be manually tracked over multiple images via an intuitive user interface.

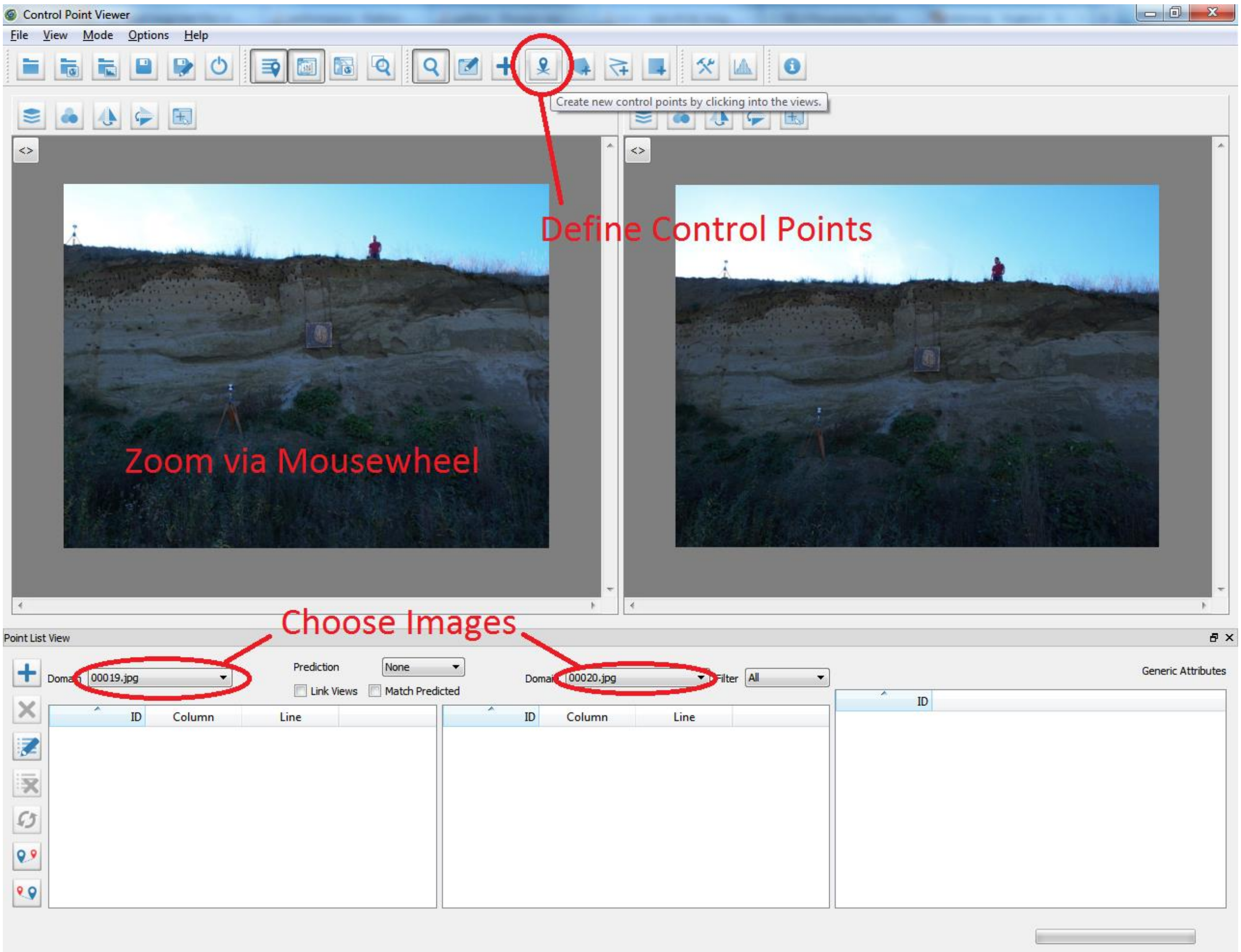


Figure 18: GCPTool main elements

4.1.3.18 Spatio - Temporal Data Base

The Spatio-Temporal Data Base (DB) is divided into several software layers with clearly defined interfaces between them (Figure 19).

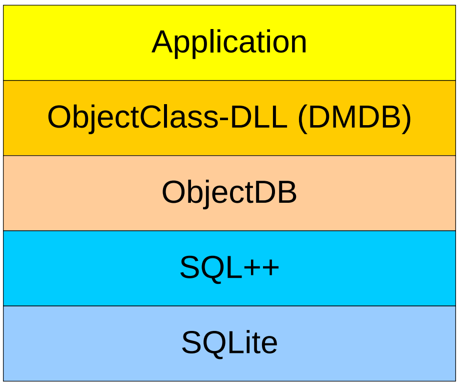


Figure 19: Spatio-Temporal DB Software Layers

1) **ObjectClass-DLL (DMDB)**: This DLL provides high-level object class-specific functions for managing and accessing data objects in the data base and in the file system. This is the Spatio-Temporal Data Base C++ overlay which provides functions for storing and retrieving Generic Pointclouds (GPC). Additional ObjectClass dlls could be implemented if other objects are to be stored in the data base.
2) **ObjectDB**: The ObjectDB provides low-level functions for managing and accessing data objects in the data base and in the file system. These functions perform the translation to SQL commands. The ObjectDB has been provided by DMG.
3) **SQL++**: This is a 3rd party C++ wrapper around SQL. It provides a transparent interface to different relational data base systems like SQLite, Oracle …
4) **SQLite**: This is the underlying relational data base used in the frame of De-Montes.

4.1.3.19 De-Montes HW-Related items

The De-Montes hardware system consists mainly of three measurement devices designed for the data acquisition. There are the Image Assisted Total Stations (IATS), the Terrestrial Laser Scanner (TLS) and the Remote DSLR module for image capturing on the remote sites.

The IATS and the TLS devices are off the shelf products which are integrated into the De-Montes system. The control of the devices implemented in the De-Montes project has been described in the deliverable D3.1 “Image Assisted Total Station (IATS) Control” and in the deliverable D3.2. “Terrestrial Laser Scanner (TLS) Control”. The IATS calibration procedure has been described in the deliverable D3.4 “Image Assisted Total Station (IATS) Calibration”.

The Remote DSLR module (Figure 20) has been developed by Neovision constructed for Cautus Geo based on a side agreement. It is designed for a long term regular image capturing on the remote sites. The image data captured by the modules are processed by the De-Montes system, where the Image and 3D Structure Import Module is used for the data importing. The image importing module is described in deliverable D3.3 “Image and 3D Structure Import Module”.

This component consists mainly of the description of the IATS Hardware setup to be able to re-build a system as being used within the De-Montes project. It describes connections between IATS and PC, and emphasizes on the long-range communication as required for the standard De-Montes use-case of long range remote geomonitoring. TLS principles as relevant for De-Montes are described as well as relevant features are given. A generic control environment (Figure 21) is further described for all devices used in the De-Montes context.

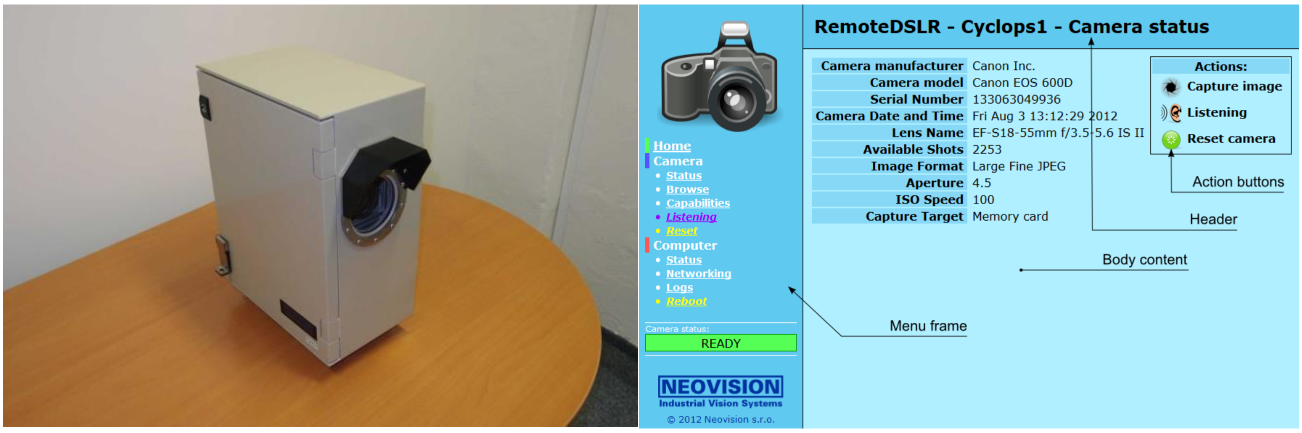


Figure 20: DSLR System as delivered to Cautus Geo by Neovision. Left: Hardware (camera inside), right: Software

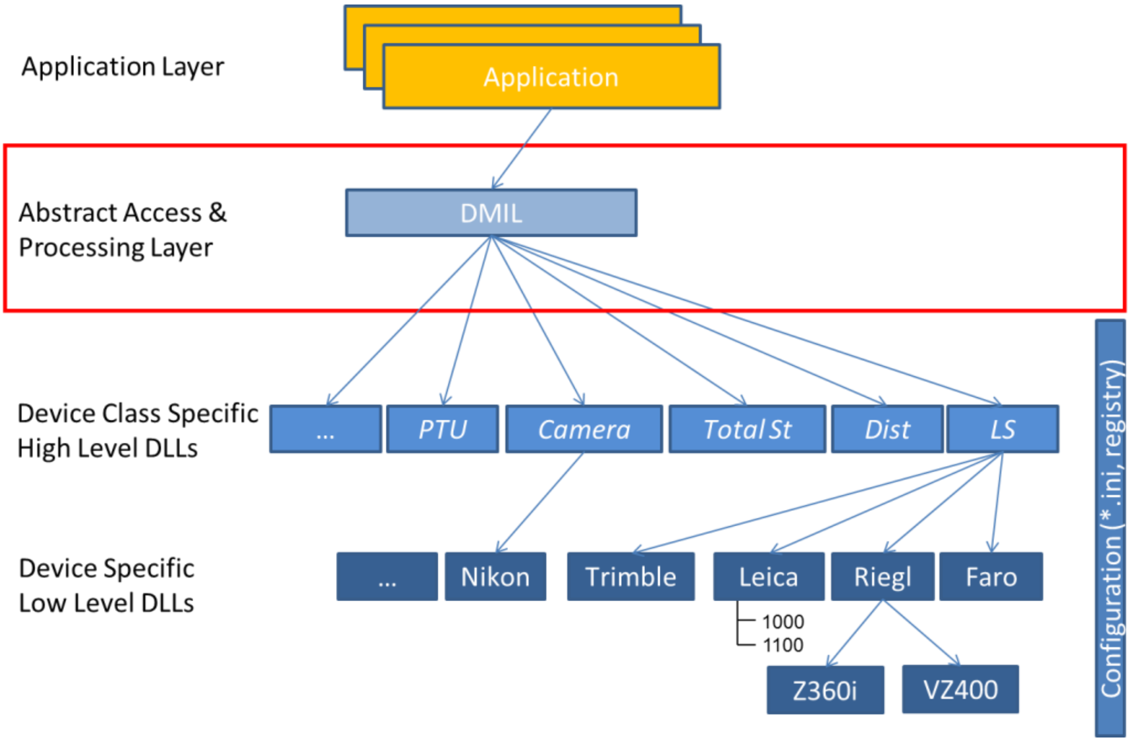


Figure 21: General Hardware Driver concept, hierarchical implementation.

4.1.3.20 Campaigns

Table 7 gives an overview of the test campaigns held in the scope of De-Montes. Further figures cited in its last column illustrate the test conditions and some major results. The campaigns are briefly described in the following.

Campaign	Participants	When	Where	Examples
IATS Control Test	TUM	20.08.12	stone quarry Untermurbach near Lenggries (DE)	Figure 22
Graz Workshop	CAU CTU DMG NEO JR TUM	25.02.13-01.03.13	Graz (AT)	Figure 23; Figure 24; Figure 25; Figure 26
Dachau Workshop	JR TUM	30.10.13-31.10.13	Dachau / clay pit Pellheim (DE)	Figure 27; Figure 28; Table 5; Figure 29; Figure 30; Figure 31
Cyprus Workshop	CTU GEO JR	20.11.13-22.11.13	Cyprus (GeoImaging)	Figure 31
Snow Height Monitoring Alpe Rauz[3]	DMG JR	From 2013; fixed installation	Alpe Rauz (Arlberg, Vorarlberg / AT)	Figure 32; Figure 33; Figure 34; Figure 35; Figure 36; Figure 37; Figure 38

Table 3: Overview of De-Montes campaigns and tested SW-modules.

[3] In cooperation with Federal Research and Training Centre for Forests, Natural Hazards and Landscape (BFW) in Innsbruck / Austria

To test the TUM software developments as well as to verify the conducted IATS calibration under real conditions an **experiment in a stone quarry in Untermurbach (near Lenggries, DE)** was done. Both IATS devices were used, set up with a baseline of approximately 75m in an object distance of ~110m, see Figure 22. A local coordinate system was defined using one additional prism as orientation point. Tested was especially the up to that point developed software modules, like the control system, coordinate handling, sensor orientation, ROI selection, image bundle acquisition or logging. Based on this experiment the data exchange to other SW modules was redefined – e.g. the format for the orientation files – and the captured images served as input data for the matching module, the data acquisition module and the long range package (SW and HW).

Figure 22: Stone quarry Untermurbach, Lenggries (DE)

As part of Task 5.5, an integrated **unit test of the overall system was performed at 25.02.2013 in Graz, Austria.** At a climbing wall a local coordinate system was realized with stations for both IATS, one TLS and a TPS (total station) sensor. Control points (round targets with reflective surface) were used around and within the target area, which is a blank rock face with a size of 40 x 20 m (Figure 23). With the help of these targets, the IATS, TLS (Figure 24) and photogrammetry data can be transformed into the same reference frame and the results compared based on coordinate differences (Figure 25, Table 4, Figure 26).

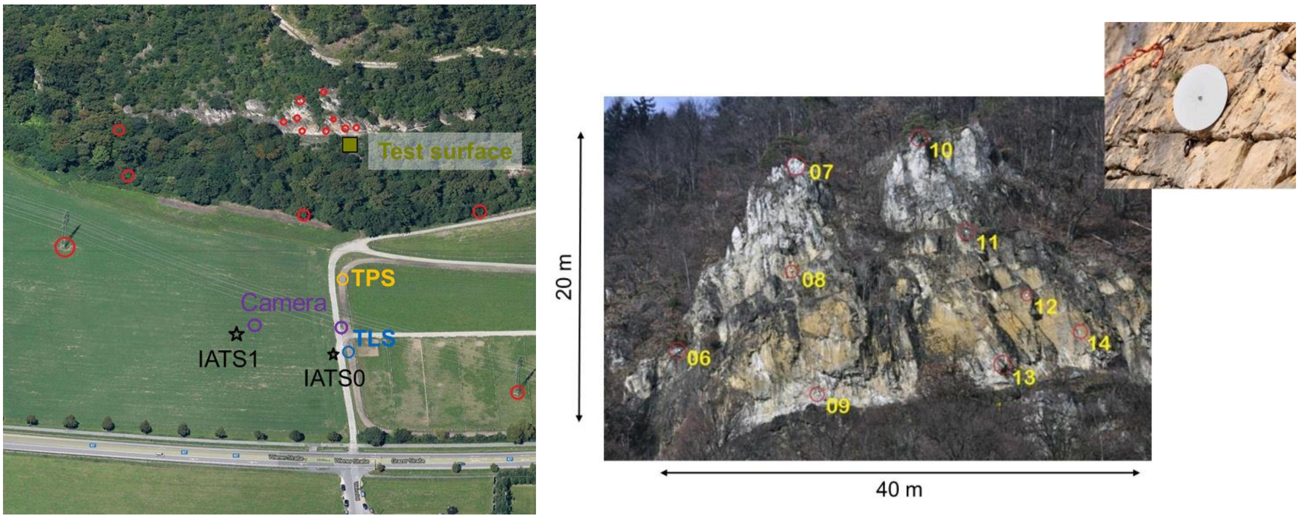


Figure 23: Graz workshop test side: Left: Overall site map showing rough reference control point positions (red circles), IATS positions (black stars), TLS position (blue circle) and theodolite position (yellow circle). Right: ROI

Figure 24: Graz Workshop TLS scan.

	TLS Result			IATS Result			Photogrammetry Result		
Point	**Δ X [m]**	**Δ Y [m]**	**Δ Z [m]**						
6	-0,002	0,003	-0,005				-0,004	0,043	0,023
7	-0,004	-0,004	-0,011				-0,019	0,015	-0,008
8	-0,001	0,007	0,022	0,000	-0,001	0,003	0,006	-0,001	0,004
9	0,011	-0,001	0,013						
10	-0,001	0,013	-0,013				-0,004	0,003	-0,022
11	0,001	-0,001	0,013	-0,008	-0,004	-0,008	0,016	-0,014	-0,009
12	-0,008	-0,016	0,013	0,000	0,006	-0,008	0,003	-0,002	-0,011
13	0,006	-0,009	-0,016	-0,004	-0,003	0,003	-0,005	-0,035	0,017
14	-0,002	0,007	-0,016	-0,002	-0,001	0,001	0,008	-0,010	0,007

Table 4: Graz Workshop result of single point evaluation (compared to Theodolite) of different sensors during Graz Workshop

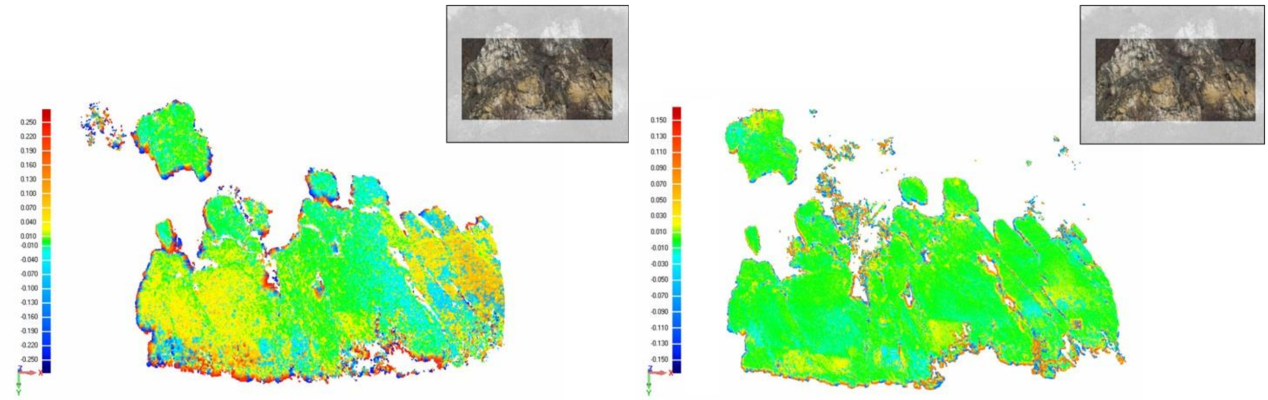
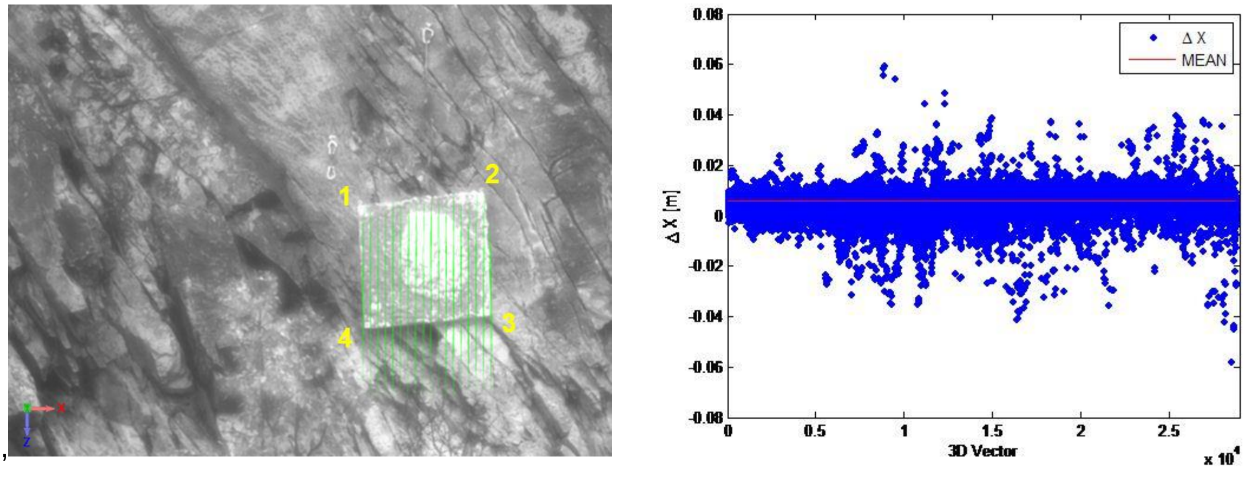


Figure 25: Graz Workshop: Left: Comparison IATS – Photogrammetry. Right: Comparison IATS – TLS



a) b)

Figure 26: Graz Workshop: Artificial deformation a) displacement vectors b)

The second major integrated test was carried out in a **clay-pit – owned by Hörl & Hartmann Ziegeltechnik GmbH & Co. KG – end October 2013 in Pellheim**, a village close to Munich. The objectives of this experiment were to obtain higher accuracies for the control points as for the first experiment as well as to get statistic information to the achieved accuracies of the IATS measurements. Figure 27 shows an aerial image of the survey area, Figure 28 a detail of the ROI. The measured epochs and applied changes are listed in Table 5. Comparisons & accuracy assessments are listed in Figure 29, Figure 30 and Figure 31.

Figure 27: Field trial Pellheim – overview

Figure 28: Region of interest with control points and artificial rock

Epoch	Time	Description	Distance[4]
E0	13:30	Artificial Target in position 0	300 m
E1	13:40	Translation of Target (1-2cm to the left)	300 m
E2	14:00	Rotation of Target (~5deg) Minor deformations next to target using shovel	300 m
E3	14:30	Translation of Target (15-20cm) More deformations next to target via shovel	300 m
E4	15:00	Removed Target	300 m

Table 5: Summary of measured epochs

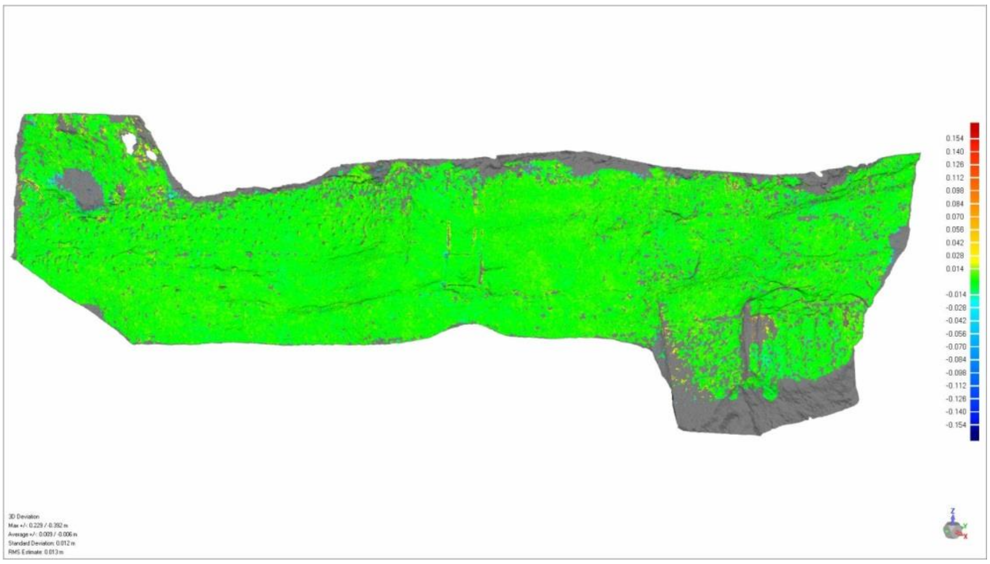


Figure 29: Comparison of the TLS and the IATS point cloud (epoch 0)

[4] Mean distance between both IATS and ROI

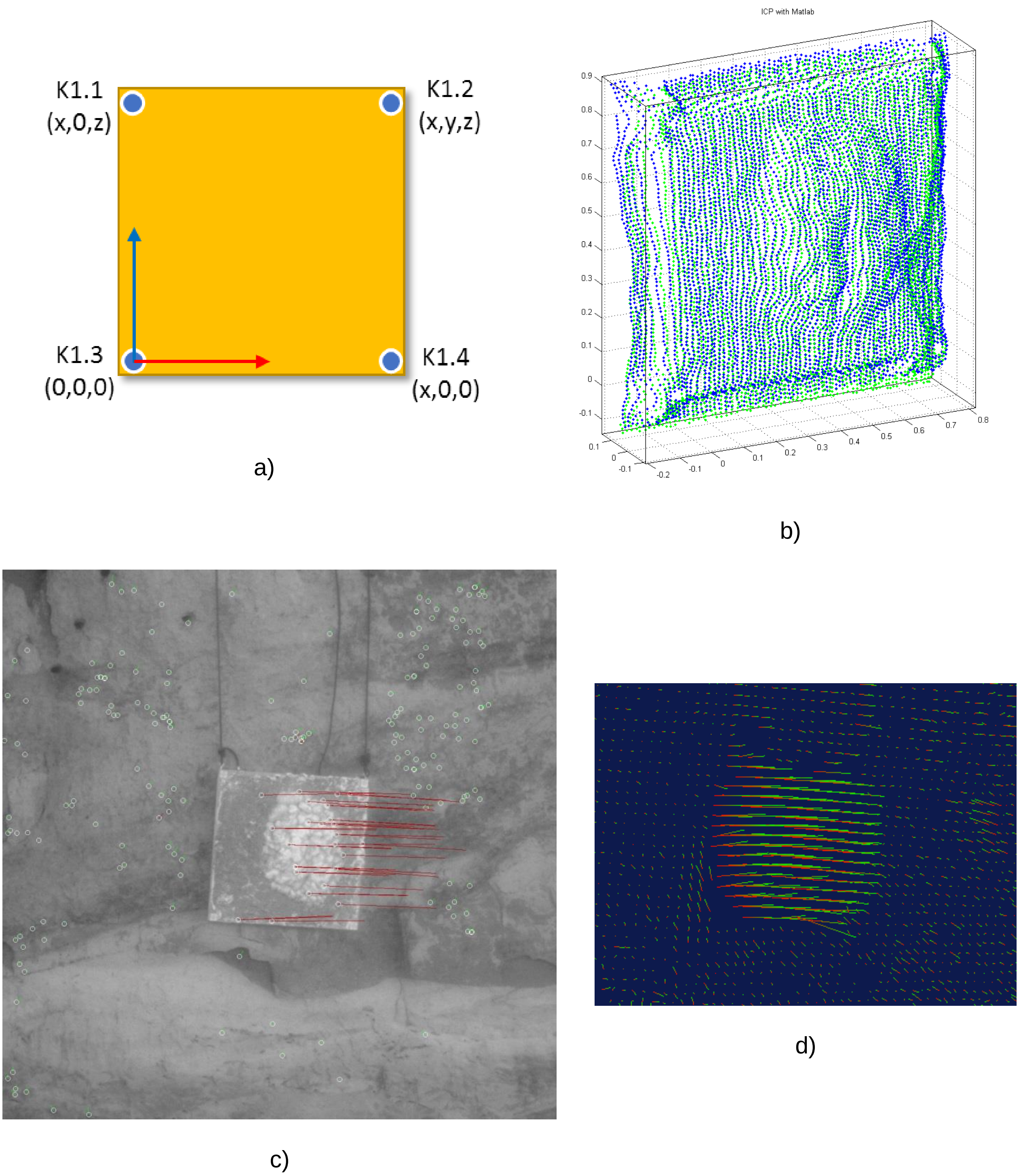


Figure 30: a) Local coordinate system of artificial rock; b) TLS data of artificial rock transformed by ICP algorithm; c) Selected deformation vectors of IATS analysis with highest matching accuracy projected into left image of Epoch 0 exaggerated by a factor of 10; d) 3D representation of a subset of the deformation vectors exaggerated by a factor of 10.

The **Cyprus workshop in Autumn 2013** was targeted at the measurement and reconstruction of cultural heritage sites and man-made objects in general. In order to demonstrate this on large scale a dataset from a cultural heritage site in the centre of Nicosia (an old university building) was captured containing over 1100 images taken with an 18 mega-pixels camera. The dataset contains details of the insight of the building, especially a courtyard and theatre as well as balustrades and repetitive balconies. The dataset is connected to the street and facades outside via three narrow passages (see Figure 22). The resulting reconstruction was able to connect more than 1000 cameras to a fully detailed and consistent model of the building including courtyard, street and outside facades.

Processing results can be seen exemplarily in Figure 31. Using the unoriented images processing chain a coherent local model registering over 1000 of the taken images was produced.

Figure 31: Adjusted camera positions and reconstructiuon for over 1000 images of old University building in Nicosia (Cyprus).

In cooperation with the Federal Research and Training Centre for Forests, Natural Hazards and Landscape (BFW) in Innsbruck / Austria, **during Winter 2013/14 a long range TLS system was installed at Alpe Rauz (Figure 32) next to the Arlberg pass road (Vorarlberg, Austria)**. A Riegl LPM-2k laser scanner in weather proof housing was tested for automated continuous scanning under high-Alpine winter conditions. At the end of winter the setup was upgraded to a faster TLS (Riegl LPM-321) and to a monitoring, geo-referencing, and data analysis framework developed within De-Montes.

The software developed within De-Montes was tested for both automated recording as well as for the evaluation of laser scanner measurements. The aim was the continuous recording of snow depth in a target area with high spatial and temporal resolution. The main focus is the collection of mass balances of avalanches in the target area in order to support decision-makers from the provincial road authority, responsible for avalanche protection.

The actual DSM can be compared with a reference DSM (Figure 33, to get the total snow height) or to a previous measurement (to get the relative snow height change). This assumes to have perfectly oriented measurements.

For georeferencing at least 4 targets (Figure 34, Figure 35) were measured both before and after each region-of-interest (ROI) scan. This allowed to determine if the system is rigid during measurement scan, which can last a long time (e.g. some hours) depending of scanning grid resolution.

The monitoring (Figure 36) and processing was verified and snow height outputs could be produced (Figure 37; Figure 38). Optionally as final part of the TLSMonitoring workflow the resulting DSM (absolute height or height difference) can be exported as (filled) contour-plot.

Figure 32: Overview of target area Alpe Rauz (VOGIS © State of Vorarlberg, 2013).

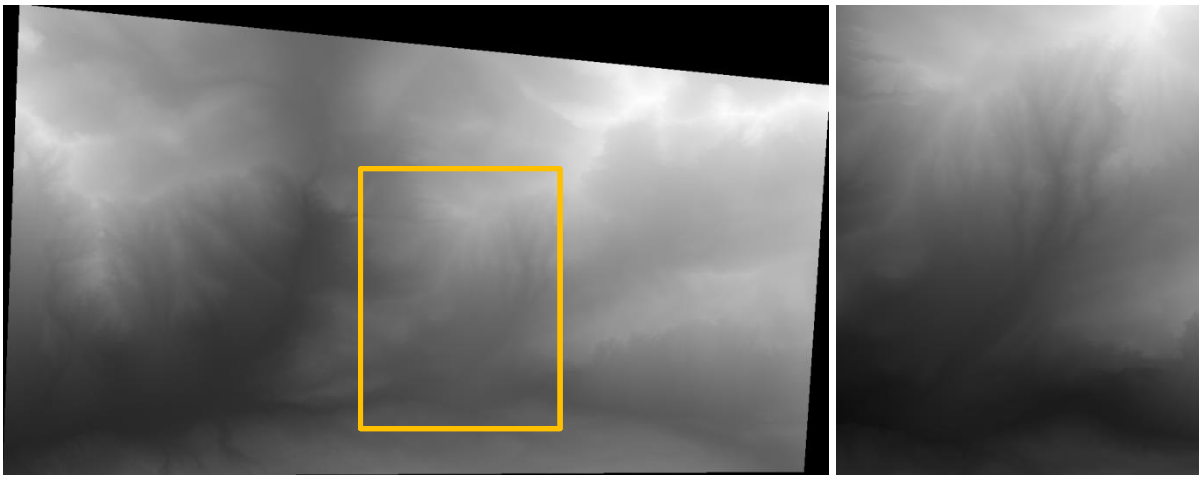


Figure 33: Alpe Rauz reference DEM (courtesy of VOGIS, © State of Vorarlberg). Left: Surrounding area [-14747.3, -9381.3; 224666.6, 221603.64]. Right: Restricted area for laser scans [-12139.8,-10850.3; 223580.14, 221910.64].

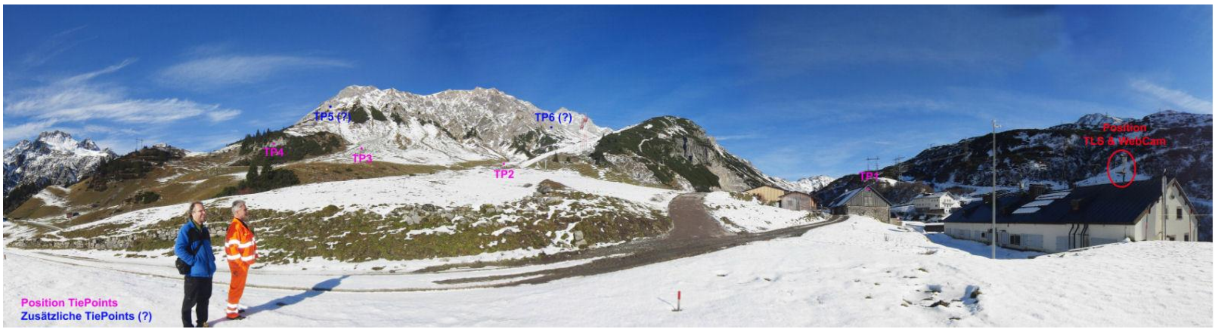


Figure 34: Alpe Rauz Position overview for TLS and targets

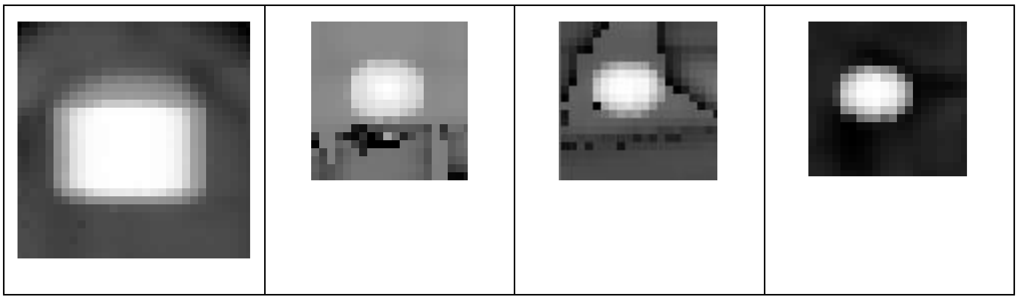


Figure 35: Alpe Rauz example for target scan performed on 01/28/2014 17:00. Reflectivity (bright: good reflectivity, dark: bad reflectivity).

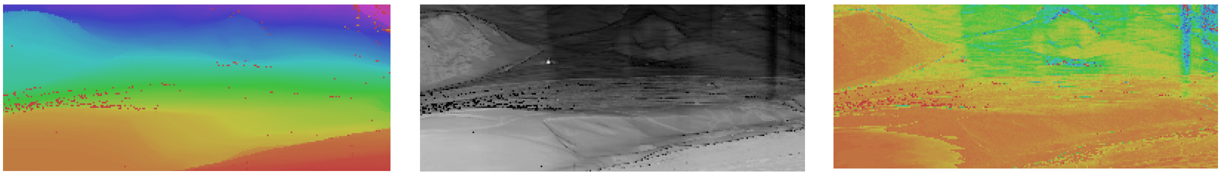


Figure 36: Alpe Rauz example for ROI scan (scfix_alperauz_bottom_2013_12_23_18_55_45.3dd) with 261x113 measurement grid. Left: distance. Middle: reflectivity. Right: standard deviation.

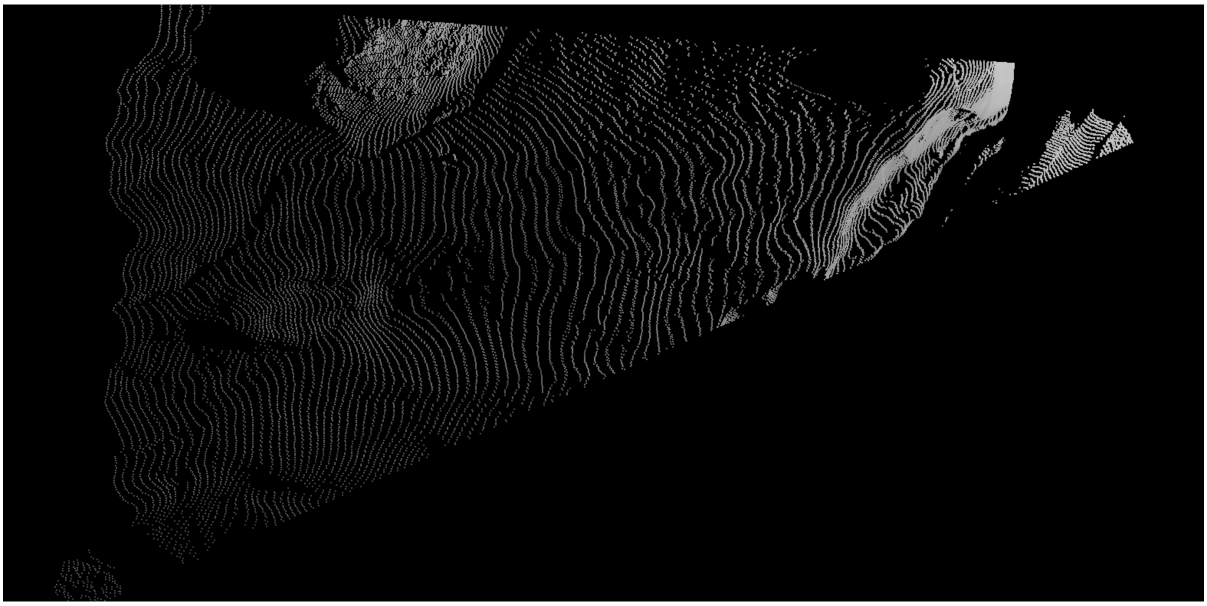


Figure 37: Alpe Rauz cartesian DSM without interpolation.

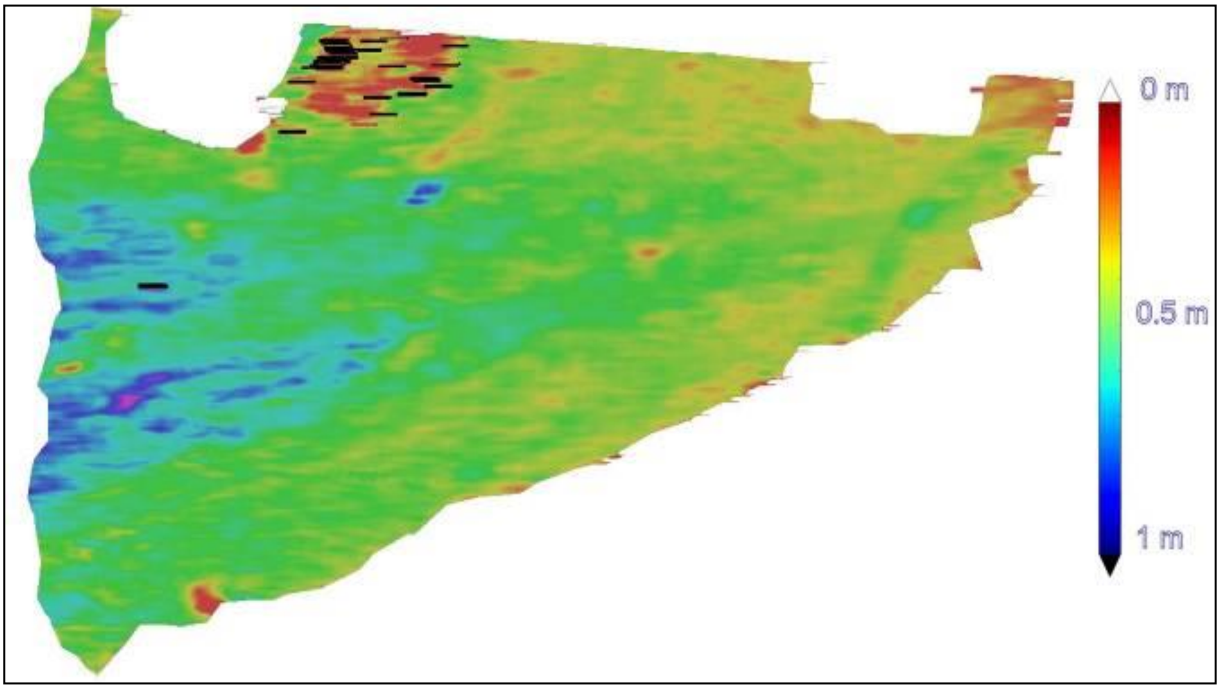


Figure 38: Alpe Rauz difference DSM between 01/28/2014 and 12/23/2013.

4.1.3.21 Reports

In the following, the **executive summaries of all formal deliverables** are given.

The **D1.1 Consortium Agreement** regulates the consortium-internal contractual framework.

The **D1.2 Project Handbook (PH)** contains all links to the Project master data (contracts, project organization, work description, administrative and financial planning data) and all information necessary to ensure unique management procedures, communication streams, and quality management. The PH serves as a single entry point to all information needed to manage the De-Montes project in internal cooperation, and externally in relation to EC (European Commission). In its first official version (mid April 2012) it has been compiled in agreement with the De-Montes Project Management Board, and EC Contract Managers.

The **D1.3 Project CMS and Maintenance** describes the CMS (Content Management System) of the De-Montes project. During project lifetime various types of information, mostly documents and other files (data, pictures, logos) – have to be stored and distributed between the De-Montes partners to avoid large documents to be sent via email and to have a unique and well-structured document store available. Also a well organised structure makes it easy to find information – e.g. an agenda of a meeting, minutes or presentations. In addition to a project webpage the project CMS offers the possibility to add information to a section or to internally deliver reports and maintain their versions.

The **D2.1 requirements & Test Specifications Document (RTSD)** describes the De-Montes system modules' requirements from users point of view, systems requirements derived therefrom (functional as well as parameters and error cases), and tests to verify all given requirements.

One major part of the project is the further development of terrestrial visual survey sensors, namely Image Assisted Total Stations (IATS), used to perform long-range high-resolution measurements on single points. The **D3.1 Image Assisted Total Station (IATS) Control** describes Deliverable D3.1

IATS Control compiled by the Technical University Munich (TUM) containing the IATS control software and driver concept, demo cases and documentation.

The **D3.2 Terrestrial Laser Scanner (TLS) Control** provides up to date information about the TLS (Terrestrial Laser Scanner) control software and driver concept that was developed within the De-Montes project. The software design as well as implementation details are given, as well as information on how to implement the TLS control into a common De-Montes monitoring suite or the software environment of the individual partners.

The **D3.3 Image and 3D Structure Import Module** provides up to date information about the Image & 3D Import Module that was developed within the De-Montes project. Related software components are described. Information on interfaces, configuration and user handling are given.

The **D3.4 Image Assisted Total Station (IATS) Calibration** describes Deliverable D3.4 IATS Calibration compiled by the Technical University Munich (TUM) containing information about IATS calibration routines.

The **D3.5 De-Montes Hardware System** provides up to date information about the hardware system that is developed and used within the De-Montes project.

The **D3.6 Long-Range Scanning Package (Hardware Part)** describes the necessary hardware components as required for the use of two IATS devices when they perform stereo measurement from large distances.

The **D4.1 Image Assisted Total Station (IATS) Interest Point Detection & Tracking Module** provides up to date information about the IATS Interest Point Detection and Tracking Module that was developed within the De-Montes project. Related software components are described. Information on interfaces, configuration and user handling are given. Discrepancies to definitions and specifications made in other deliverables stated close to project start are explained and reasons are given.

The **D4.2 Surface Texturing Module** provides up to date information about the Surface Texturing Module that was developed within the De-Montes project. Related software components are described: Texturing of 3D models within a multiview stereo workflow, and the texturing of terrestrial laser scans, including the related 3D vision workflow to derive spherical, tunnel and planar models, as well as co-registration between camera and laser texture. Information on interfaces, configuration and user handling are given. Discrepancies to definitions and specifications made in other deliverables stated close to project start are explained and reasons are given.

The **D4.3 Spatio-Temporal Data Base** provides up to date information about the Spatio-Temporal Data Base and related software, which is an optional component that is able to handle spatial information together with temporal information (=the Spatio-Temporal Data Base), as well as the access elements necessary to operate on this data.

The **D4.4 Bundle Adjustment Module** describes the Bundle Adjustment Module in all its respects in order to allow proper usage in industrial environment of the De-Montes SME Participants.

The **D4.5 Deformation and Volume Measurement Module** provides up to date information about D4.5 Deformation and Volume Measurement, which is realized in the Deformation Vectors Workflow. The following sections give information about the workflow structure, its handling and its integration in the De-Montes software.

The **D4.6 Volumetric Change Detection Module** provides up to date information about D4.6 Volumetric Change Detection. The following sections give information about the workflow structure and the semi-automatic workflow realization by the delivered JR3DViewer software. Instructions for the software installation, the licensing as well as information on the provided test data are given as well.

The **D4.7 Image & 3D Structure Import Module (Core)** provides up to date information about the Image & 3D Structure Import Module that was developed within the De-Montes project. The Module represents one major De-Montes use case: the generation of a 3D model in a global system based on a set of unoriented images and known global 3D target coordinates (Reconstruct Unoriented Images workflow). Related software components are described. Information on interfaces, configuration and user handling are given. Discrepancies to definitions and specifications made in other deliverables stated close to project start are explained and reasons are given.

The **D4.8 Long Range Scanning Package (SW Part)** provides up to date information about necessary corrections for long range measurements to achieve high accurate results. Information about the influences acting on the measurements, their mathematical derivation as well as the implementation are given.

The **D5.1 Data Acquisition Module** provides up to date information about the Data Acquisition Module that was developed within the De-Montes project. The software design as well as implementation details are given, as well as information on how to integrate the Data Acquisition Module into the De-Montes software environment.

The **D5.2 Processing Overlay** provides up to date information about the Processing Interface including information about the De-Montes workflows, their handling and the required software environment, as well as details about the underlying software architecture and the installation process. This document may serve as user manual for the delivered processing software as well.

The **D5.3 Monitoring Overlay** provides up to date information about the Monitoring Overlay that was developed within the De-Montes project. The software design as well as implementation details are given, as well as information on how to integrate the Monitoring Overlay into the De-Montes software environment.

The **D5.4 Data Export Module** provides up to date information about the Data Export Module that was developed within the De-Montes project. Related software components are described. Information on interfaces, configuration and user handling are given.

The **D6.1 Report on Acceptance Test Campaigns and Results** provides up to date information about Acceptance Test Campaigns and Acceptance Tests. It gives a summary of all SW components developed in the scope of De-Montes and goes through unit and application testing of the De-Montes deliverable elements (mainly software components on various levels) and lists examples and success of tests

The **D6.2 Report on Fairs and Conferences Participation and Used Materials** summarizes the activities in fairs and conferences in (pre-) commercial context within the scope of the De-Montes technical solution and applications.

The **D7.1 Website www.De-Montes.eu** is the Report on the web site for the De-Montes Project prepared under the Seventh Framework Programme (FP7-SME-2011-1) Grant agreement no: 285839.

The **D7.2 Joint Business Plan** describes how the SME partners will further exploit the De-Montes results with respect to their business cases. It gives an overview of the products and outcomes usable for business exploitation, summarizes a market analysis as from the time of project finalization, and sketches a possible business model for all SME participants. In the form of pilot applications it gives direct link to future exploitation modes.

The **D7.3 (Interim) and D7.4 (Final) Plan for the Use and Dissemination of the Knowledge** describe the project objectives w.r.t. use and dissemination of knowledge, the exploitation and dissemination goals, and the expected dissemination and exploitation: Starting with an implementation and integration plan the treatment of outcomes and deliverables at the SMEs' side are described, and the plan for the exploitation of foreground and background is sketched in terms of ownership and business plan. For each individual SME the plan for use and exploitation of specific project results is described. Dissemination goals, target groups, means and media of dissemination are described and the dissemination activities throughout the project are listed. Technical aspects of exploitation are covered. Cooperation aspects are mentioned.

The **D7.5 Report on Publications and Dissemination Activities** lists details about all De-Montes dissemination activities.

The **D7.6 Videoclip showing and explaining the De-Montes system** describes a summary video clip generated for De-Montes and being available on www.De-Montes.eu.

4.1.4. Potential Impact, Main Dissemination Activities & Exploitation Results

4.1.4.1 Potential Impact

The system that was developed by the RTD partners incorporate the **sensors, their control & data processing, and a framework that enables an expert user (geodesist / geologist) to operate the software**. Applications, test environments and verification procedures were provided by the SME partners. The Project results were exploited externally by dissemination activities and Demo actions. Dedicated training inside the Consortium consolidated the use of the system.

With the help of its three RTD Partners, **the De-Montes Project built and tested a productive prototype system** for short-term exploitation by the SMEs involved in the Project, such that after project termination they **can immediately identify and quantify its potential for enhancing** their service portfolio, and **gaining new business fields** by exporting the system and its components to related application areas such as tunneling and construction, documentation of cultural heritage objects, industrial inspection, or geo-monitoring.

De-Montes lead to **knowledge to be seen from different aspects**. The following is a list of knowledge expected to be result of De-Montes.

a) Quantifiable / verifiable
   1. Deliverables as stated in the Description of Work (DoW), including their components
   2. Technical parts (SW and HW) that are not immediate components of Deliverables, but are needed to allow easy integration of the Deliverables into the Beneficiaries' environment

3. Other documents (Material for Fairs / folders / advertisement) as immediate output from the Project
4. Data from tests, verifications and for dissemination

b) Not quantifiable / verifiable
1. Technical Know-How as collected during meetings, reading documentation, personal communication
2. Strategic Know-How about other partners, competitors and the market environment
3. Renewed Staff profiles
4. RTDs being future source of information / consulting
5. Future joint projects
6. SMEs future potential providers for other SMEs & RTDs

The SME members of the De-Montes consortium tend to use the outcome as soon as possible. The time frame is distinguishing three periods of integration:

- Immediate (for prototype development),
- mid-term (for integration, evaluation and demonstration) and
- long term (for product and service customization and market entry, as well as market expansion),

depending on the complexity of any module and its inter-dependencies with other modules.

The impetus for exploitation and dissemination is given as follows:

For SMEs mainly in:

- Economic aspects (immediately gaining turnover)
- Sustainability in background (to own knowledge that they can efficiently use over a long period of time)
- Flexibility on the market (to own and have access to knowledge of no immediate use, but that is helpful for quick reactions to new trends and requirements of their customers)
- Enhancing the ability of staff to react to new challenges on the market,

for RTDs mainly in:

- Flexibility in meeting their research customers' needs
- New prospects for publication
- Establishment & maintenance of new research staff
- New cooperation modes with other RTDs embedded in De-Montes.

4.1.4.2 Dissemination Activities

A plan for the use and dissemination of the knowledge was elaborated in two stages, to show how the results developed and delivered by the RTDs can most efficiently be used in near future by the SMEs partners.

Parallel to the technical developments, **more than 10 publications** and presentations as well as posters in scientific conferences were released in cooperation between RTDs and SMEs, and parts of a book chapter were supported by contents of the De-Montes project. Two diploma theses were finished. Further dissemination activities (about 10 are the most relevant ones) include various appearances in newspapers, web announcements, TV and press releases occurred.

The following Table 6 lists the major dissemination activities during De-Montes and thereafter. The number of dissemination elements in different categories is quantified in Table 7.

Who	Content	Media / Scope	Comment / venue / date
JR	De-Montes technology and scope	Austrian newspapers, e.g. Kleine Zeitung or Der Standard	Summer 2013 after georisk event
JR	Mobile Laser Scanning for Tunnel Inspection and As-Built Documentation	MoLAS 2014	2014-11-26
JR / TUM	De-Montes Video containing technology, Graz experiment description and possible applications	YouTube	Released 2013-07
TUM et al	Geo-Monitoring By High-Resolution Optical Sensors	Paper & presentation at Oldenburg	Oldenburg conference 2013-02
TUM et al	Image Assisted Total Stations: Prospects for Deformation Monitoring	Presentation & Abstract at Conference	JISDM 2013 Nottingham
TUM	Vision-Based Geo-Monitoring – A New Approach For An Automated System	General Assembly 2012 of the European Geosciences Union (EGU)	2012
TUM	Tutorial Videotachymetrie	17. Internationaler Ingenieurvermessungskurs, Zurich,	15.01.2014
CTU	Paper and conferences presentations.	Paper and conferences	During and after project
CTU	CTU Website	Project promotion via the company's website	On-line
NEO	Poster presentation of the De-Montes project	The International Engineering Fair (MSV)	By 2012-10
NEO	Robot live demo, Poster, Flyer. For the De-Montes project	The International Engineering Fair (MSV)	By 2013-10
NEO	Camera system for long- range georisk environment monitoring	The International Engineering Fair (MSV)	By 2014-10
NEO	Company website	Project promotion via the company's website	On-line
GEO	Company website	Project promotion via the company's website	On-line
DMG	Geomechanik Kolloquium ("Geomechanics Colloquy")	European geotechnical community geotechnics, rock- and soil mechanics and tunneling	Oct.. 2014 and continuing in following years

CAU	Presentation of Cautus Geo solution from the De-Montes project at Stikningskonferansen 2013	Survey conference towards the construction business in Norway	February 6, 2013
CAU	Innovation Norway presentation of Cautus Geo and De-Montes. Interview and presentation of Norwegian SME company in Europe	Web	December 2012

Table 6: De-Montes Dissemination activities

Category	No. of Items
Conference Papers & presentations	7
Papers in peer-reviewed journals	4
Web page	1
Web site entries & features	1
Videos	2
Exhibition	1
Posters	7
Media Briefings	1
Press Release	1
Popular Press appearances	3
TV Clips	1
Research Reports	1
Master's theses	2

Table 7: Categories of dissemination activities

4.1.4.3 Exploitation Results

Explicit exploitation by SME members of De-Montes are subject to their business and marketing plans which is confidential. Exploitation by SMEs has been analysed in the following aspects:

- Usability of the individual project outcomes (see Section 4.1.3.1 for a summary) in technical sense and from application point of view
- Required expertise (e.g. availability of development staff) to install & maintain
- Application costs (adaptation costs, sensor costs, etc.)
- Most likely application cases and their time-to-market.

De-Montes SMEs at project end have analysed their exploitation possibilities as per individual module. It was found that the IATS solution has high technical potential, however due to large investment costs it could be crucial to apply it to the standard case. The photogrammetric tools were found applicable to other applications beside the geo-risk area (such as tunnel survey, monument monitoring, road & bridge monitoring, and in particular niche solutions). Similarly, the laser scanner modules will find application beyond the geo-risk use case. The snow-height monitoring case will be further used in the season 2014-2015 with a follow-on verification phase at the same site as for De-Montes. In general it was agreed that the usage of the elaborated technology should start where it has its biggest potential, regardless of monitoring / capturing distance or scale. Simple sensor solutions (e.g. fixed 2-camera systems) are in general preferred over more complicated installations.

A **joint business plan** serves as an agreed roadmap for further cooperation between SMEs and RTDs, as well as the SMEs' own plans to exploit the delivered results and elements in their best commercially sustainable way – this was already underlined during the De-Montes duration with some fair contributions by De-Montes SMEs.

Scientific exploitation has already started with publications based on De-Montes experiments and developments, such as a publication in the Journal of Applied Geodesy.

4.1.5. Address of project public website and relevant contact details

http://www.De-Montes.eu

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