LIVE PROCESSING AND FEEDBACK ON A COMBINED LASERSCANNING AND PHOTOGRAMMETRIC DOCUMENTATION WORKFLOW

L. Stampfer

FOB Baugeschichte Bauforschung, TU Wien, Vienna, Austria – lukas.stampfer@tuwien.ac.at

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ABSTRACT:

The use of a combined terrestrial laserscanning (TLS) and structure-from-motion (SFM) surveying approach has proved to be able to deliver advantageous benefits in terms of coverage and surface rendition. The elaboration of such approaches entails a succession of processes and are without many options for on-site feedback largely dependent on the experience of the surveyor. In support of this approach a combined automated processing workflow with augmented reality feedback is introduced, allowing operators to get a better understanding of their progress and project success during surveying. To do so native TLS and SFM software is connected to a shared network and data storage environment and controlled within an active framework. Within this, scans and images are aligned within RealityCapture and resulting registration is visualised to the operator using augmented reality (AR). To achieve complete independence of pre-scanned environments, the augmented reality application presented within this research uses a GNSS supported visual SLAM algorithm. With this the application is able to position virtual objects – such as markers representing the positions of registered cameras – within a physical space using only their geoposition as reference. The workflow presented here should be understood as a proof of concept to determine possible improvements that would enable such interactive means of surveying and would allow deeper integration of components into a combined AR supported documentation workflow.

1. INTRODUCTION

Today, Terrestrial laserscanning (TLS) has found wide use and large-scale application within field surveys in archaeology and documentation of tangible cultural heritage. Not only is it possible to cover large areas with ever faster devices in a brief time, but further, their increased accuracy and resolution allow a more comprehensive documentation of all accessible surfaces of a structure. Through metadata stored with each scan or within the scan project, they provide the surveyor and later users with traceable information about the accuracy of each point and the capabilities of the device in use through a well-defined specification within its technical data. Still, while laser scanning provides adequate on-the-fly feedback on data registration today, coverage and point sampling distance still largely depend on the surveyor's experience.

Photogrammetric Structure-from-motion (SFM), on the other hand, while being a very low threshold technique for 3D documentation, essentially defines its level of accuracy on the strategy of the surveyor taking the images later used to process them into a digital model. Admittedly, the type of sensor (camera) in use naturally also has a strong impact and usually does have the exact "well-defined specifications" as mentioned for TLS. However, the resulting 3D data still strongly depends on an adequate capturing strategy as well as the capability of the camera operator to execute this strategy. Feedback usually does not extend further than skipping through the images or running the data through the software while on site. As in photogrammetry sensor and software are generally manufacturer-independent from each other, the surveying method - with some exceptions through the use of mobile applications ("RealityCapture Node," n.d.; "RealityScan," n.d.) - provides no live feedback on the success and quality of the results while on site.

Nevertheless, SFM has proven to be a valuable tool for digital documentation, especially when combined with TLS. Besides increased texturing capabilities, limitations of coverage related to TLS can often be well compensated by applying SFM, as it is much easier to get a photographic sensor to a position of difficult accessibility by using telescopic poles or unmanned aerial vehicles (UAV). Combining the advantages of both techniques allows the assembly of a model utilising the accurate geometry rendition of TLS combined with increased coverage and high-quality texturing of SFM.

To utilise the full potential of this combined application of sensors, it is believed that providing inclusive feedback on the coverage of various sensors and expectable usability of data captured while being on site can be a powerful addition to this heritage documentation methodology.

2. RESEARCH PROPOSAL

A recent paper described a proposal of a combined data environment and processing workflow to synchronise methods as early in the process as possible (L. Stampfer, 2023). This aims to provide what De Luca describes as a "dynamic digital representation of a tangible cultural asset" (De Luca, 2023, p. 2). While it was proposed in beforementioned paper by the author that this should include semantic information about the object collected on site and this is undoubtedly a key motivation for setting up this interactive data environment, this current paper will mainly focus on exploring the aspect of giving the surveyor feedback on his data collection campaign. Nevertheless, a solid live processing workflow is believed to provide a robust framework for the interactive and possibly interdisciplinary inclusion of semantic information.

Based on setting up the proposed common data environment, it was possible to explore live processing options, which include terrestrial laserscanning and photographic data into a combined on-site processing that allows surveyors to review their progress and gather feedback on the quality of their results. It is believed that the ability to visualise this data captured with an augmented reality (AR) interface - provided through a tablet PC with
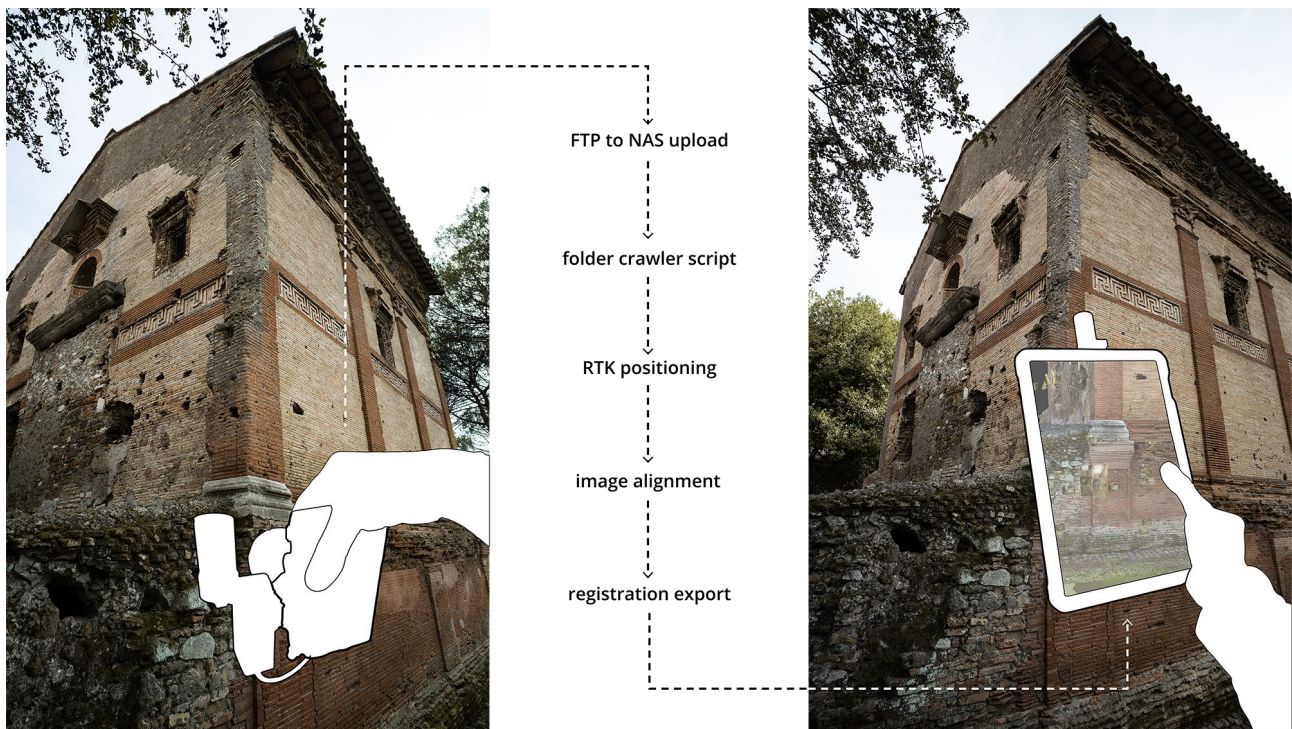
Figure 1 - Concept graphic of image alignment and feedback workflow from capture to AR visualisation (by author)

enhanced GNSS (Global Navigation Satellite System) capabilities – increases the surveying process's reliability and efficiency. Further, it can help achieve a targeted and more homogenous accuracy and coverage of the documentation effort by highlighting faulty or neglected areas and allowing them to react on the fly. Beyond contributing to a digital model or streamlining into a digital shadow, this research aims to provide a bidirectional interaction with a real digital twin (Juarez et al., 2021, pp. 030802–2 f.).

The research proposed in this paper explores the possibility of implementability and practicability of such feedback channels. It explores how augmented reality can be applied to provide on-site information about the progress and quality of the campaign by augmenting a "knowledge layer" (Minerva et al., 2020, p. 1792) to the physical environment. In a surveying context, this knowledge layer can include raw data – such as sensor positions already covered – and processed data – such as number of neighbours within a pointcloud or images covering a particular area. Further, this centralised data environment is believed to provide a platform for a more consistent and comprehensive documentation of paradata. With metadata reflecting information about the origin of the individual raw data, a paradata set could be describing the processing operations applied to the datasets, their correlation and provide contextual information about the whole process (Denard, 2012, p. 66; Hugh Denard and King's College London, 2009, p. 8).

3. METHODOLOGY

To explore the full potential of on-site feedback, an automated workflow will be introduced to process survey data automatically and provide information to an AR application for live feedback. While manufacturers already automate parts of the process, a customised framework will be established to achieve a more comprehensive process automation. The hardware in use will be a set of devices and software available to the author.

While there are other ways to create such an automated workflow and other devices with possibly different capabilities to be implemented, the current research will not analyse the entire spectrum but focus on a case study implementing the devices at hand.

First, the components to be implemented will be analysed for their key features and possible means for implementation into the workflow. This will be done to understand better how surveying methods can complement each other instead of being used in parallel. Further, this helps establish prerequisites and possibilities for automating the necessary portion of all features available to provide the data needed for workflow integration and automated feedback.

Further, a controller framework, set up using command line handles of TLS and SFM software, will be introduced, and its capability to incorporate functionalities of surveying hardware and software will be evaluated. Actively controlling the common data environment (CDE), the controller framework aims to keep track of all the information available, trigger the right processes at the right moment, and provide the individual components with the information required to do their job.

Finally, a specifically designed AR app using a tracking algorithm with a combination of GNSS positioning and surface tracking will be applied to receive information about the survey progress by the controller framework and visualise it as feedback for the operator. Once tracking is established, feedback layers that can be visualised could be extensive, including information on sampling density, quality, deviation to earlier datasets, etc.; the implementation within this paper will be limited to the mere positioning of sensors (= position of TLS and individual images for SFM).

4. ANALYSIS

4.1 Analysis TLS Riegl VZ-600i with RiScan Pro

Brought to market in 2023, the VZ-600i terrestrial laserscanner by the Austrian company Riegl Laser Measurement Systems (1) is designed to deliver high accuracy scans in record time. With 26 seconds for a scan with a point distance of 6mm in 10m distance, quick progress with surveying can be achieved, which is particularly helpful with extensive objects.

Like all terrestrial scanners by Riegl, the VZ-600i has a limited vertical scan angle of 105 degrees (+65° / -40°) that allows placement of additional sensors, such as RGB camera and GNSS Antenna, in the rotation axis of the scanner. The absence of overhead-scanning capability with Riegl Scanners might be a disadvantage, especially within confined spaces with a high height-to-horizontal extent ratio. This is justified by increased scan speed using two deflecting mirrors within the laserscanner and a rotating unit with four facets, which is otherwise impossible (Studnicka, 2023, p. 109). In most cases, this can be compensated by additional scan positions or even the use of an additional tilt mount unit, giving the possibility of a tilted setup.

The crown jewel of Riegl seems to be the robust real-time registration handled by a secondary processor within the device. Despite the short scanning time, the registration progress can keep up with aligning the scans at the same speed as the surveying progress. Combined with the on-the-flight exchange of batteries for quasi-non-stop scanning, this allows capturing approximately one scan position per minute, including scan time with simultaneous image capture plus repositioning of the device. The experiences of projects within the department coincide with the presented case studies by Studnicka (Studnicka, 2023). Although being very refined and delivers the promised speed within this "One-touch (registration)" workflow of 26 seconds scan time for a 34mdeg resolution scan (= 6mm point distance at 10m) at 2200 kHz Pulse-Repetition-Rate (Riegl LMS, 2023a, p. 45), using the so-called "high precision mode" increases scan time significantly to 152 seconds. Further, image acquisition during scan time requires a maximum exposure time. Using the mirrorless camera with a predefined aperture of 8 and a maximum exposure time of 1/400 second (Riegl LMS, 2023b, p. 25) - pre-determined by the rotational movement of the laserscanner – this can lead to high ISO values of sensitivity and possibly unwanted grain within the scan pictures. While not of high impact on the RGB colouration of the point cloud, this certainly reduces the usability of scan images for panorama generation or inspection purposes.

A terrestrial laser scanner is a solid base geometry for many surveying efforts. With adequate resolution, precision, and accuracy, the VZ-600i is a valid tool to deliver just that. While previously presented as especially useful for extensive objects needing more significant numbers of scan positions, the application for smaller objects with higher expectations regarding surface rendition also provides excellent quality results. With a certain expectation of image quality and controllability of such, only the mirrorless camera planted on top of the device was used within projects by the author. This allows the simultaneous capture of pre-developed jpg-filetype images and/or raw arw-filetype images allowing greater possibilities of colour calibration and whitebalance within the post-processing phase. This can be particularly helpful when combined with other cameras for image documentation or photogrammetry or when highly accurate colour reproduction is demanded. Additionally, a set of integrated cameras is built into the device for a more compact scanner rig and the possibility of facial blurring before image storage for privacy protection.

Through RTK-enhanced GNSS positioning the VZ-600i can establish a georeferenced base geometry of an object to be surveyed and supersedes the necessity of fixed-point linking and position for a specific range of applications. Nevertheless, when possible, some fixed control points are recommended to reduce the positional error of the GNSS antennas and provide feedback on the registration and refinement algorithms' accuracy within the post-processing phase.

The software that comes with the VZ-600i is called RiScan Pro and can be used for all post-processing steps, such as registration refinement, the colouration of scans, and the export of point clouds. While implementing a so-called "one-touch processing wizard" some years back, the graphical user interface (GUI) is still persuaded by a hierarchical tree structure that inhabits all information and sensor data. The published data structure, as well as the text-based XML (Extensible Markup Language) project description file, is aimed to "enable post-processing software packages to make full use of the RiScan PRO data" and "allow independent software developers to make full use of the data" (Ullrich et al., 2003, p. 299). Much like the controller framework proposed in this research, RiScan Pro works like an overarching instance controlling data processing. In contrast, the individual processing steps are done mainly by secondary programs installed with RiScan Pro. As one of them, the Geosys manager handles all coordinate systems and transformations within the project. While within the project structure, all information is referenced within a Project Coordinate System (PRCS), linked into a GNSS-informed Global Coordinate System (GLCS), the Geosys manager provides the necessary information to display and export data within a wide range of predefined or user-defined coordinate systems. Connecting to the EPSG database offers a reasonable basis for importing and exporting data from various sources and applications. While the Geosys manager provides a solid framework for handling all geospatial transformations within the project, only project transformations are accessible and exportable to the user in a 4x4 matrix representation. In contrast, global transformations can only be applied within an export process or elicited from RiScan Pro through some workarounds.

Much like most processing software of TLS data, RiScan Pro is set out to refine scan registration within a so-called Multi Station Adjustment, taking GNSS, IMU (Inertial Measurement Unit), external control points and laser distance sensor information into account for an iterative bundle adjustment of all scan positions. After all post-processing steps like fine adjustment, the colouration of scans, filtering, etc. RiScan Pro is used to export point cloud data into various open file formats like las, e57 or ascii. While Riegl's point cloud file format, rbdx, can be accessed through a published library called RDBLib (Riegl LMS, 2021), implementations could, at this point, only be found within the open-source software package CloudCompare (2). Still, they would generally allow access to pointcloud information from within the project structure by external software packages even without an additional export process. Additionally, it is possible to import external point

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(1) http://www.riegl.com/

(2) https://www.danielgm.net/cc/

clouds into RiScan Pro and the native rdbx format and process these together with Riegl scans with most of the same features.

For integration and automation purposes, the onboard registration, implemented within the VZ-line scanners, provides real-time registration of scans with a very high success rate and remarkable accuracy. In an additive process, scans are spatially rasterised to "Voxels" within a cell size of 0.05m to 0.5m – depending on the characteristics of the surveyed environment. The so-called reflectance, calculated from the distance of the surveyed point and the amplitude of the laser beam returning and digitised by the scanner, is then translated within these raster cells into a sort of "spatial signal" that allows determination of first rotation and then translation using Fourier-transformation. After pre-alignment using GNSS information (when available), IMU data and Voxel registration, alignment is refined by matching corresponding planes, increasing the registration accuracy (Ullrich and Fürst, 2017). The secondary CPU within the VZ-line scanners ensures the processing power to complete all these steps within the same time as one scan position is captured (26 sec) and the scanner is repositioned.

Having pre-registered scan positions right after capture would allow the use of scan data immediately within further processes. Nevertheless, the implemented cloud upload using wired or wireless network connection appears to be mainly designed for storage purposes, as point cloud data is only provided within a closed rxp format. Used by Riegl during the scan process, it is optimised for use during the scan process but needs to be converted into rdbx manually within RiScan Pro for external access and export. While this is done on-board to resolve ambiguities of multiple laser signals "in the air" at the same time and voxel generation, in contrary to the older VZ-400i, the VZ-600i discards the rdbx after registration – as it is of reduced information only serving registration purposes.

Fortunately, the program structure of RiScan Pro facilitates access to individual processes via a command-line interface (CLI), much like the overarching software package itself. While no sample files are available, these can be reverse engineered using rdbx files already processed within RiScan PRO, as their incorporated transaction log provides the applied configurations in full. Nevertheless, while all information needed within the configuration files, like scan pose after registration, camera mounting information or lens distortion parameters, etc., are available in readable text within the project structure, they are quite fragmented before import into RiScan and need to be accessed through a range of files.

Despite the complexity of information access, the use of these command-line handles proved promising in automating the processing of laser scans - providing a controller framework able to access and collect all necessary information and generating necessary configuration files for individual processing steps. While this is possible, it appears that using Riegl's one-touch processing wizard would be much easier as it is designed to access all information and control all processes by default. Unfortunately, at this point, it can only be accessed manually via RiScan Pro and, therefore, does not allow automated triggering of processes. As even all configurations necessary can be stored and recovered using a specific text-based ini file, great potential can be seen in allowing one-touch processing to be triggered in the same way as many other processes within RiScan Pro, using a command-line handle and configuration file – hopefully, to be implemented by Riegl in future releases.

As scanner control is already accessible via a specific ROS (robot operating system) driver (Riegl LMS, 2023c) and a published library of functions for V-line scanners called RiVLib (Riegl LMS, 2022), it appears only reasonable to hope that Riegl further provides access to following processing steps at some point. For now, CLI interfaces of individual processes appear to have the best chance of automating a surveying workflow using the Riegl VZ-600i.

4.2 Analysis SFM RealityCapture with Sony ILCE7-RM3A and REDCatch HotshoeRTK

To complement terrestrial data covered by a laser scanner, capturing photos to be processed as a photogrammetric model proved to be a valid addition to a surveying effort. While earlier approaches saw processing photos into a 3D model as a low-cost and easily accessible alternative, today, the combined processing of TLS and SFM has become much more of a standard approach. It allows the utilisation of the benefits of both. Therefore, this research aims to provide an automated workflow for using one and introduce a combined sensor methodology.

A central element of every SFM approach is naturally the processing software. Different software packages are available, each providing advantages and limitations. In recent projects at the department, the software Reality Capture has proven to deliver high-quality results from a combined TLS and SFM processing approach while incorporating complete CLI controllability of all software features. It will, therefore, be the package in use within this research ("RealityCapture CLI," n.d.). Reality Capture presents itself with a more complex user interface than some of its peers, with less of a focus on black-box presets and one-touch processes, but high controllability of individual numerical and boolean parameters and incorporates the ability to import large numbers of images as well as laser scans for combined automated processing. In doing so, it is not mainly dependent on extensive hardware resources but can operate fairly well even with limited hardware capabilities.

Within a two-stage primary process, cameras (= images and laserscans) are first aligned and then processed into a triangulated model. To do so, cameras are searched for "features" that can be matched between one and another. Through overlapping coverage and a dense network of matching features, it is then possible to estimate internal camera parameters, such as lens distortion, as well as external parameters, like the camera position and orientation, as an iterative process. It is also possible to include positional data of cameras originating from pre-registration within another software or GNSS information as so-called "camera priors". The EPSG database can be implemented to select the appropriate project coordinate system for better control of coordinate reference. After alignment, the second stage of the process is the generation of a triangulated, textured model that can be exported and/or used to render orthographic views and produce digital terrain models or vector sections. Central parameters in achieving a high-quality result are coverage of all areas of interest with images of sufficient overlap (~60%) as well as the quality of images in terms of resolution and object rendition (lighting and focus). The first largely depends on the camera operator and is aimed to be supported by procedures introduced within this paper; the latter (not solely) naturally strongly depends on the sensor in use.
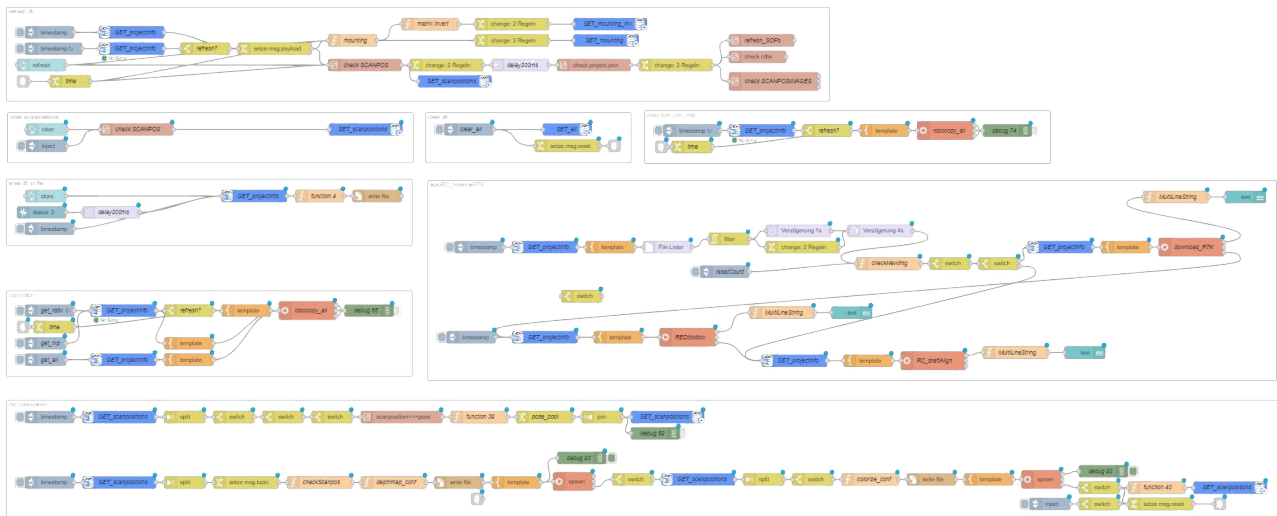
Figure 2 - Automated workflow within controller framework using browser based IoT application Node-Red (by author)

The quality evaluation of an SFM model is not the focus of this paper. Therefore, image resolution or lens parameters are not the main qualities in cameras in search of this research. Instead, transferring data from the sensor to a central processor is a crucial element for automating the process of a combined TLS and SFM surveying effort. While TLS often has wireless transfer and FTP upload capabilities implemented, this is much rarer with consumer-grade cameras. Fortunately, the model used for this research, an ILCE7-RM3A by the manufacturer Sony, provides such capabilities. Although successive models would have a background transfer while shooting (ILCE7-RM4) and even improved transfer speed (ILCE7-RM5), the capabilities of the RM3A are considered sufficient for proving the concept.

As a third element within the SFM side of this research, an RTK-supported GNSS antenna planted onto the hotshoe of the camera was in use. This so-called HotshoeRTK by REDCatch (3) allows a high-accuracy positioning of individual images, beneficial to the processing workflow as well as geopositioning of the whole surveying model. In combination with an already geopositioned TLS model, the secondary antenna with the camera could be considered an unnecessary redundancy, as images aligned to the laserscan-data will already inherit a geoposition. Nevertheless, following the previously published principles of survey tool alignment, it is deemed an enrichment of data quality to have an individual GNSS position for each data element. The predecessor of HotshoeRTK, called Imagevector, was able to provide orientational information on the camera as well but is unfortunately not able to provide real-time access to position and orientation, as it is stored on a cable-connected logger device without external access while in use. In contrast, the new HotshoeRTK uses an application within an Android device to provide access to correction data and store the positional info for every image in a log file on said device.

In regular use, images and log files are manually loaded into the software RED toolbox to link images to positional information and store it within image metadata (EXIF) or text-based files that can be read into SFM and other software. Fortunately, the RED toolbox also provides CLI access, which can be combined with other processes previously introduced within this research. The camera series used for this research would allow to

(3) https://www.redcatch.at/

complement EXIF data with GNSS information provided by a Bluetooth-connected device right at the moment of triggering the shutter and could, therefore, skip this post-processing altogether. Unfortunately, this only includes positional information without altitude and is, therefore, limited to professional surveying.

5. AUTOMATED FEEDBACK

Within the previous chapter, the functionalities of hardware and software used within this research were analysed towards finding a common ground for an automated processing and providing feedback information. Early on, it became clear that using command-line handles provides the best middle ground for accessing a range of features within a given setup. While more extensive processing appears to be possible for real-time feedback and combined processing of laserscan and photogrammetry and the aim of this research, the following steps necessary to be automated were identified:

1) Pre-registration of scanpositions
   ➤ within the scanner during the scan progress
2) Upload of scan data to an external processor
   ➤ implemented within the scanner firmware
   ➤ CLI robocopy (windows integrated)
3) Conversion and resolution of signal ambiguity
   ➤ CLI rimta5.exe (RiScan Pro)
4) Colorization of scans using scan images
   ➤ CLI rdbcolorizer.exe (RiScan Pro)
5) Conversion of scans into an open file format e57
   ➤ CLI riegl2e57.exe (RiScan Pro)
6) Download of images from the camera
   ➤ Internal FTP upload or via T&T App
7) Download of HotshoeRTK log file
   ➤ CLI Android Debug Bridge (Android SDK)
8) Assigning GNSS position to images
   ➤ CLI REDtoolbox.exe
9) Processing of cameras and export registration
   ➤ CLI RealityCapture.exe

The sequence of these processes is used to import colourised laser scans with geo position in e57 format as well as images from a mirrorless camera with their geo position logged into a text file. All these cameras (= laserscans and images) are then

aligned using feature matching to refine their relative positioning and average their absolute position. The recalculated geo position is then exported into a comma-separated-value (CSV) file with the camera name plus positional and rotational information.

5.1 Controller framework and automated processing

After establishing the functionality of the individual processing steps introduced before, establishing a controlling instance connected to a shared network environment is necessary. Tasks of this controller platform involve coordinating network processes, pointing the processing software to the data storage locations, initiating processes, and exchanging information between different interactors involved. In this, the exchange of information is specifically essential in providing all processes with the correct data, some of which need reformatting. Odd enough, it appears that in this, "advanced" datasets like point clouds, meshes and global coordinate references appear to be relatively easy to transfer from one process to another as they mostly follow standardised formatting. On the contrary, for example, planes, boxes, or local coordinate systems seem to be implemented with widely ranging definitions and barely any standardised interfaces, demanding specific reinterpretation for specific software packages.

A platform able to handle the tasks described above was discovered widely in use within Internet-of-things (IoT) applications. The browser-based open-source programming tool Node-Red (4) provided the necessary features to incorporate all the aforementioned CLI processes under one umbrella and work as a framework initiating and controlling their progress. Within a node-based editor, a dataflow can be set up to read information from various text-based files (XML, JSON, TXT,…) and extract the necessary information. Furthermore, through implementing javascript commandlets and native transformational nodes, it is possible to transform, delimit and compile this information into the required configurational files needed by the CLI processes. At last, it is possible to execute processes from within Node-Red using these command-line handles plus configurational files. With additional capabilities of controlling network processes and accessing files within the network using native nodes and again command-line scripts, functional necessities appear all combined within this platform. By integrating all information into the controller framework and providing complete control over processing software, it can keep track of the processing progress, check and confirm the successful completion of individual steps and trigger processes at the correct time. The sequential layout of the nodes can be understood within this as dataflows, representing a functional workflow originating from a previously published diagrammatic procedural design (Lukas Stampfer, 2023).

Within Node-Red, it was possible to set up a data processing framework that could control and execute the previously listed processes for an automated progression.

5.2 AR feedback

Based on the previously established automated processing, an augmented reality interface in the form of an Android-based tablet PC is set up to visualise data captured and processed and provide feedback to the surveyor. While this setup is chosen for its advantages in the development phase, using other interfaces

such as head-mounted-displays - i.e. Microsoft Hololens ("Microsoft HoloLens," n.d.) – or Tablet PCs with increased sensor capabilities – such as light detection and ranging (LIDAR) sensor – could be set up following very similar principles. In an operation within AR referred to as "tracking", the interface is referenced to the physical environment.

Within this research, this is done through the application of external GNSS antenna ("REDcatch SmartphoneRTK," 2021) and RTK correction data combined with a visual simultaneous localisation and mapping (SLAM) algorithm. The application is developed using the Unity game engine (5) and utilises its native "AR Foundation" engine plus the "AR+GPS Location" asset (6) available via Unity's asset store. Within this, a series of calculations are performed to determine the position of an object within a local AR tracking system by a pre-defined GNSS location and the current device GNSS location:

1) Transforming all ellipsoidal to cartesian coordinates.
2) Calculating a so-called "displacement vector" from the current device GNSS position to the position of the object to be placed in an Earth Centred Earth Fixed (ECEF) cartesian coordinate system using the Haversine Formula.
3) Establishing an East-North-Up (ENU) coordinate system with the current device position as the centre.
4) Using the transformation from the ECEF System to the ENU system to apply the previously calculated displacement vector within the ENU system to get the position of the object to be placed within the current AR tracking system.
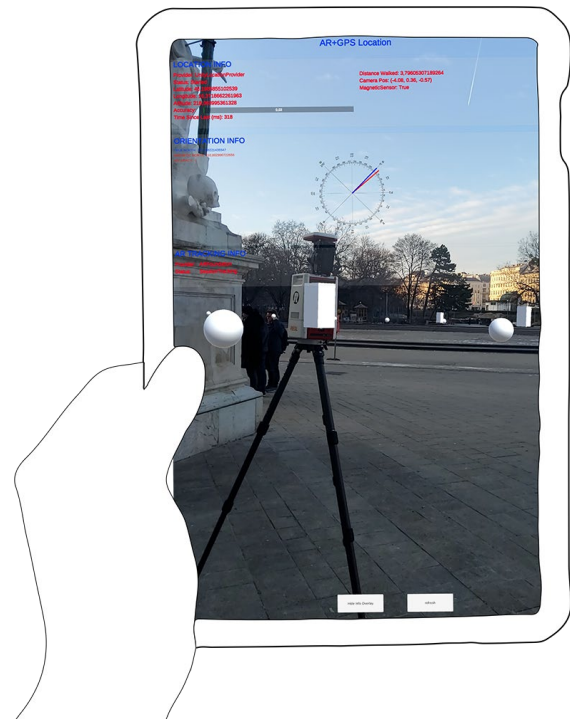
Figure 3 - Screenshot from the AR feedback application; spheres represent photos, boxes represent laserscans - comparison to original laserscanner position visible (by author)

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(4) https://nodered.org/

(5) https://unity.com
(6) https://docs.unity-ar-gps-location.com/

The finesse within this system is that the GNSS position is not used for the AR tracking, as this would incorporate a lot of jitter as even RTK-corrected GNSS readings only provide limited stability. A local AR tracking system that can incorporate any sensors or physical references – such as surfaces, images, or entire spaces – is established to provide a local system with tracking that is as stable as possible. It is then augmented with objects and their positions calculated from geolocations. The AR+GPS Location asset further incorporates a series of smoothing and averaging functions to reduce jitter by GNSS and magnetic sensors and provide a more continuous experience. Through the integration of an accuracy threshold, it is further possible to exclude GNSS data with limited accuracy to avoid "negatively affecting (wearable) AR tracking capabilities with inaccurate positional data (De Pace and Kaufmann, 2023, p. 3178).

Using the previously exported CSV file of re-calculated camera positions from RealityCapture, it was then possible to instantiate "prefab" objects within the AR system to mark the positions of already captured and processed laser scans and images. In doing so, it is possible to provide automated real-time feedback on sensor positioning within a combined terrestrial laser scanning and structure-from-motion documentation workflow.

6. CONCLUSION

By applying a command line-based controller framework using Node-Red, it was possible to introduce automated processing into a combined laser scanning and structure from motion documentation workflow. Involving manufacturers more closely in adapting their software packages could allow a deeper integration, but at this point, the CLI approach appears to deliver a working automated processing environment. It was possible to show that within this setup it is possible to connect sensors, processor and interface in a way that allows to use augmented reality to receive feedback on surveying progress. The application of a GNSS-supported visual tracking algorithm, while showing some jitter, is considered a promising basis for interaction outside predefined environments.

While it is believed a crucial element of proposed research that tracking works independently of recognition of a predefined geometry – such as tracking an object like a pre-specified building, element, or image – this undoubtedly has limitations. Especially as the GNSS position is considered unavailable in interior spaces, tracking could only rely on continuous surface recognition. Therefore, the possibility of including other tracking capabilities in the process should be considered.

As RealityCapture detects features within cameras to match images, the matched features – called "tie points" could be exported and reused within the tracking algorithm to track surface features. The higher sensor quality through high-resolution cameras and terrestrial laser scanners could introduce a higher accuracy within the mapping part of the SLAM algorithm.
Further, in exchange with Riegl LMS, it was possible for them to refine the e57-export within RiScan Pro to comply with the needs of Vuforia's Area Target Generator, allowing to convert full scans into a tracking environment for AR, possibly on the fly. As the Vuforia engine can work side-by-side with AR Foundation, an integration within the already in-use application seems possible.

At last, as control points are still widely in use within a construction and documentation environment, these could be incorporated by applying coded targets, able to serve as another source of absolute positioning within the tracking environment. Nevertheless, all these possibilities are considered to enhance the tracking algorithm in use within this research, as the absoluteness of a global navigation satellite system is unmatched.

Therefore, the next step should be evaluating GNSS tracking accuracy to understand better how jitter can be reduced through targeted averaging and systematic use of other tracking references. Furthermore, integrating interaction with the digital twin presented here is fundamental. A possible elaboration of feedback channels providing information on sensor rotation and descriptive parameters and qualitative evaluation, such as coverage and the robustness of alignment or point density, could be valuable additions.

On the process automation side, it could be of great value, and a substantial simplification of the process to have a deeper integration of command line handles into RiScan Pro instead of executing individual processes with specific configurational files would considered an invaluable improvement to be able to control the one-touch processing wizard within RiScan Pro via command line. As there is already the possibility to import / export text-based configurations, it appears to be a natural next step that can hopefully be implemented.

Lastly, having deeper capabilities for implementation within photo cameras would make a significant difference. While Sony already provides a Camera Remote SDK (Sony, n.d.), options for interweaving the camera more closely into the automated process have not yet been explored as they require more extensive coding. Further, an integration within some sort of application on the camera (not considered possible at this point) in a similar fashion as the RealityScan (7) application with feedback right within the viewfinder might be even more helpful. At last, as it is not comprehensible why an integration of GNSS positioning into the Sony camera EXIF was done without altitude information, this might be an unfavourable preset that will hopefully be fixed by the manufacturer soon.

For now, the CLI integration appears promising and can hopefully be tested in a more extensive project environment to evaluate its practicality and reliability.

7. ACKNOWLEDGEMENTS

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