

Publishable Summary for 24DIT04 ScanClouDT Traceability for industrial 3D digitalisation by advanced scanning systems

Overview

3D laser scanning systems are vital for the digital transformation of geometric measurements. However, the current metrological tool kit cannot keep up with state-of-the-art 3D laser scanning systems. In addition, assessing the measurement uncertainty of such 3D laser scanning systems requires unrealistic computation efforts. This project will address these metrological issues by developing new approaches for the entire data capture and point cloud processing chain. New, validated digital metrological twins (D-MTs) will be developed which will be used to assess the complete physical measurement. A holistic quality metric will also be derived to handle the typical, excessively large point clouds. Further to this, verification strategies will be developed to validate dedicated software packages, as well as case studies in aerospace manufacturing, logistics, and geodesy which will be used to demonstrate the potential of the project's developed methods.

Need

3D laser scanning systems capture surface data rapidly without physical contact, avoiding the need for special probes and can thus be easily integrated into almost any production workflow to create digital representations of objects of interest. They considerably simplify and significantly speed up the capture of complex geometries or features that are difficult to access with point probes. However, problems arise when the adoption of such solutions go beyond quick 3D modelling and visualisation, and into tasks where quantitative and trustworthy measurement of geometric features is necessary. Examples include quality assurance in manufacturing, cargo storage optimisation in logistics, and deformation monitoring in civil engineering. In addition, assessing the quality of the final measurement product, e.g. geometric features or defects, requires a comprehensive understanding of the whole processing chain: the physical scanning process with the 3D laser scanning system, data processing (including registering multiple scans and data fusion to combine surface point samples from disparate scanning locations) as well as feature detection and analysis.

Traditional forward uncertainty modelling is reaching its limits for 3D laser scanning process, especially as the process is highly complex and suffers from mechanical errors from the dynamic laser beam positioning system, environmental influences on the system and probing beam, systematic errors from the distance measurement technique and, above all, strong material-dependent laser spot-surface interactions. A digital twin – recently identified by the EC's Directorate-General for Research and Innovation as one of six enabling technologies supporting Industry 5.0 – of this process can be a more promising modelling approach. Further to this, the resultant measurement from 3D laser scanning systems often consists of a point cloud of millions of coordinate entries, and fusion or registration of multiple scans introduces new error sources. Moreover, the individual points in the point cloud are rarely the quantity of interest. Instead geometric characteristics, such as inclination, volume, or manufacturing defects, must be derived, often using complex and proprietary software tools. These software tools are however often inadequate for critical accurate measurements, as they are usually optimised for large data volume performance rather than numerical robustness, and there is a lack of recognised independent tools and methods for the verification of the corresponding algorithms and software packages.

Report Status:
PU – Public, fully open

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European Partnership  Co-funded by the European Union

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METROLOGY PARTNERSHIP



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Objectives

The overall objective of the project is to foster the current digital transformation in 3D measurement technology based on 3D laser scanning systems by improving traceability to the SI definition of the metre. Holistic, systematic, and generalisable methods and procedures shall be developed for the entire processing chain.

The specific objectives of the project are:

1. **To develop measurement models for use with D-MTs of 3D scanning systems** including instrumental, environmental and target influences on the measurement result. A modular approach will be followed to allow model refinement and adjustment to different measurement scenarios and different scanner configurations. The generated large point clouds of the models or D-MTs will be in a format compatible with existing commercial 3D analysis software. The measurement uncertainty of the point clouds will be determined following the GUM (Guide to the Expression of Uncertainty in Measurement) and its supplements.
2. **To assess the quality of point clouds in dimensional metrology** through comparisons using a variety of measurement standards with typical (i) dimensions, (ii) features and (iii) materials generated with 3D scanning systems, and D-MTs of those instruments. Based on these results and the measurement uncertainty, a metric will be determined for the metrological quality of point cloud(s) generated by 3D scanning systems.
3. **To develop and establish reference datasets for the assessment and verification of software tools** deriving geometric or radiometric features from point clouds. The reference datasets will be suitable for deriving the achievable measurement uncertainty, and data fusion of multiple scans, will be part of the verification scenarios (where appropriate). Datasets will comprise (i) classical geometries such as spheres, planes, cylinders and (ii) more complex geometries typical for two or more applications from industrial metrology, aerospace and geodesy.
4. Using the outcomes of Objectives 1-3, to (i) develop **guidelines for the uncertainty assessment** and object classification of geometric and radiometric features derived from large coordinate point clouds, (ii) to determine the measurement uncertainty of target measurement features, using **case studies from industrial metrology, aerospace, or geodesy**, and (iii) to design and establish novel **calibration or verification services** for scanning systems.
5. To facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain (e.g. manufacturers of 3D scanners, developers of data processing and analysis software), standards developing organisations (ISO/TC 172/SC 6, ISO/TC 28/SC 2, ISO/TC 213/WG 10) and end users from aerospace industry, logistics, and geodesy.

Progress beyond the state of the art and results

Development of innovative measurement models for D-MTs of 3D scanning systems

Currently there are functional models for various laser scanner architectures, as well as proposals for calibration strategies. However, they have shown limited success as they do not cover the full measurement process. This project will go beyond the state of the art by modelling 3D scanning measurements at the individual point level including all relevant error sources, i.e. instrumental sources, ambient conditions, probe beam propagation, and/or the sample influence. Instrument and physics contributions will also be separated into modules that can be combined for specific applications in aerospace, logistics, and geodesy. The project will focus on the D-MT concept and all input parameters will be determined traceably to the SI-definition of the metre together with their measurement uncertainty. Further to this the project will put emphasis on the probe beam-sample surface interaction, including dedicated experimental studies with relevant materials.

Methods to assess the quality of 3D point clouds

In metrology, the current dominant philosophy for the assessment of point cloud quality is to link point observations to a specified instrument. In contrast, this project will go beyond the state of the art by developing a holistic quality metric for point clouds that focuses on the targeted measurement product rather than the original measurement process. The project will follow the so-called Quality of X (QoX) concept, and descriptive parameters or metadata will be identified that are decisive for the measurement uncertainty of the subsequent data processing. This metric will then allow an approximative, yet metrology-grade assessment of the

measurement uncertainty of the point cloud. Which in turn should considerably simplify the uncertainty assessment of 3D laser scanner-based measurement, thus enabling this technology to be applied to critical and regulated applications.

Creation of reference datasets for software verification

Existing software tests in coordinate metrology are currently based on small datasets with simple geometric features and limited numbers of data points. The project will go beyond this by develop a numerical generator of validation reference data for the huge 3D datasets (that are typical for 3D laser scanning data). The transferability of experimental data to software performance will also be verified, i.e. the relevance of the software validation for the processing of actual measurements. Thus, the project's approach will support a service for software verification. Furthermore, procedures and a good practice guide will be developed to generate empirical reference datasets from high-quality experimental data.

Case studies, guidelines and verification services

The methods and concepts developed in the project will be applied to different use cases in aerospace industry, logistics, and geodesy, covering a broad spectrum of typical, critical scanning applications. The case studies will be used to demonstrate GUM-conformal measurement uncertainty using D-MT application, point cloud assessment and feature derivation with validated software. This work will include classification schemes for case study fields. The case studies are key for transferring the project's results to stakeholders and will be widely disseminated to the end user community.

Outcomes and impact

Key dissemination and communication activities

The primary result of the ScanCloudT project will be state-of-the-art validated, and practical tools to assess the uncertainty of 3D laser scanning-based geometric measurements.

Outcomes for industrial and other user communities

To support tangible impact, the project's concepts will be applied to case studies in two relevant industry sectors, aerospace and logistics, which will substantially benefit from the project's advancements in 3D laser scanning technology. For each of the industries, the project will create novel D-MTs and involve end users (i.e. system manufacturers) in the development process. Data acquisition and processing will also be demonstrated on artefacts with typical properties for the aerospace and logistics sectors. To support relevance to and uptake by end users, the advantages of the QoX concept will be demonstrated by the project for the envisioned digitalised quality assurance (QA) aerospace industry workflow. For the logistics sector, the project's developed procedures should allow the realisation of efficiency reserves in cargo packaging, as well as in the determination of shipping costs. Further to this, strategies for software validation will be demonstrated to both industry sectors. The aerospace sector in particular will also benefit from the metrological assessment of a new, high-performance next generation multi-channel light detection and ranging system (NGMC-LiDAR).

The results of the case studies will be presented at suitable stakeholder conferences. In addition, instrument and software manufacturers will be involved in the project as collaborators and/or in the Stakeholder Committee, through which their input will help the project's concepts and techniques like D-MTs or the QoX parameters to be more quickly implemented by end users. Further to this, the project will produce 3 good practice guides targeted at industrial end users; (i) Good practice guide on the methodological approach for the acquisition of appropriate, high quality verification datasets with laser scanning systems, (ii) Good practice guide for a novel rigorous metrological framework in cargo logistics, and (iii) Good practice guide for the uncertainty assessment and object classification of geometric and radiometric features derived from point clouds.

Outcomes for the metrology and scientific communities

Another key beneficiary of this project is the dimensional metrology community itself. The project intends to establish 3D laser scanning as a validated metrological method and provide a valuable tool kit for further collaborative research. The project's open-access/sharing of results and modular structure should also make it easier for the metrology and scientific communities to develop D-MTs specific to their applications. For example, the project's case studies and models will be able to be further refined, enabling the metrological quantification of large coordinate point clouds in other industrial sectors. The project's software validation

procedures and datasets should also help simplify the use of commercial software packages at NMIs for critical applications, thereby, helping to establish 3D laser scanning as a routine tool in large volume dimensional metrology.

The wider scientific community that uses laser scanning as a tool for digitisation and documentation will benefit from the project's metrological tools. This includes geodesy, to which the project's third case study is dedicated, as well as other communities including archaeology, earth sciences, cultural heritage preservation, forensic science and engineering surveying. Geodesists are strongly involved as participants in the project, and geodetic conferences and relevant standardisation committees will be regularly attended, and the project's progress and results will be disseminated to them. By the end of the project, the wider scientific communities should have access to practical guidelines for the uncertainty assessment of their data.

Outcomes for relevant standards

The project will develop new approaches for the uncertainty assessment of measurements made with 3D laser scanning systems. The methodology tool kit developed, will include the 'trinity' of (i) D-MT, (ii) a holistic quality metric for point clouds and (iii) independent metrological software verification. Together with the new instrument calibration and software verification protocols, these project results will be communicated and advocated to relevant standardisation committees in different stakeholder communities. These include ISO/TC 213 with several working groups for the manufacturing community, ISO/TC 172/SC 6 for the geodetic and surveying community, and ISO/IEC JTC 1/SC 41 for new insights in the D-MT concept. The project will also approach and collaborate with suitable technical committees of influential international and national professional organisations, such as the WG II/2 of the International Society for Photogrammetry and Remote Sensing (ISPRS), the International Federation of Surveyors (FIG) Commission 5 - Positioning and Measurement and the EURAMET community.

Longer-term economic, social and environmental impacts

In the longer-term the project should support an increase in the trustworthiness and manageability of 3D laser scanning data and help to promote the even wider uptake of the technology. This should in turn, support an increase in the use of 3D laser scanning systems in industrial process monitoring and digitalisation, supporting the digital transformation in the manufacturing sector. The construction industry can also use the project's technology for quality control (QC), and a quantitative capture of the 'as built' status. A reliable understanding of scan quality is also essential for a fully digital workflow in the logistics sector. Studies predict substantial efficiency gains in cargo transportation can be achieved in the future, if such measurements and associated optimisation algorithms can be implemented. Further to this, a solid metrological foundation for laser scanning data interpretation will facilitate the broader use of 3D laser scanning in legal metrology, promoting the practical digitalisation of this regulatory and economic area.

As mentioned above, an improved efficiency in cargo transportation (due to improved 3D scan data) can directly translate into carbon dioxide reduction, creating valuable environmental impact. A better quantitative understanding of laser scanning data, particularly its registration into geodetic coordinate systems, will also support the maintenance and improve the quality of global geodetic reference frames (GRF) that form the metrological backbone of global level observations. Such understanding is of particular importance in climate monitoring and change detection, which are needed to assess risks from natural hazards such as flooding.

Finally, the reliable and practicable quality assessment of laser scanning data will facilitate monitoring of Europe's ageing geographic and building infrastructure, which is a key challenge in the EU, as the demand for inspection, evaluation, and management has drastically increased over the last few years, especially for bridges. In Germany alone, maintenance activities for nearly 50 % of all bridges are overdue. Understanding data quality is a prerequisite for accurate interpretation, comparison and prioritisation of refurbishment needs, and will support efficient longer-term use of resources in this field.

List of publications

This list is also available here: <https://www.euramet.org/repository/research-publications-repository-link/>

Project start date and duration:		1 st June 2025, 36 months
Coordinator: Florian Pollinger, PTB E-mail: florian.pollinger@ptb.de		
Project website address: https://www.scancloudt.ptb.de/		
Internal Beneficiaries:	External Beneficiaries:	
1. PTB, Germany	9. AKL-tec, Germany	
2. CEM, Spain	10. ENS Paris-Saclay, France	
3. CMI, Czechia	11. Ommatidia, Netherlands	
4. GUM, Poland	12. TEKNIKER, Spain	
5. LNE, France	13. TUM, Germany	
6. NLS, Finland	14. UCL, United Kingdom	
7. RISE, Sweden	15. WUT, Poland	
8. VTT, Finland		