metrology

Editorial

Editorial for Special Issue: "Advances in Portable 3D Measurement"

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1. Introduction to the Special Issue

In the context of the journal *Metrology*, portable 3D measurement is focused on manufacturing applications where there are typically demands for high-accuracy 3D data, with uncertainties in the range of a few 10s of micrometres to a few tenths of millimetres. Applications are commonly carried out directly on shop floors or production lines, rather than in separate, environmentally controlled laboratories. This enables the measurement of large objects such as cars and aircraft to be performed as part of the manufacturing process. Solutions to these application tasks mostly involve optical data acquisition integrated with data processing algorithms and communication systems, extracting and delivering the required metrology information into a digital factory data system.

However, it is worth remarking that the 3D application spectrum is wide, with micro surface 3D metrology and sub-surface metrology at one end, and large 3D applications such as city models at the other. It is also interesting that 3D techniques are now familiar to many of us as part of our daily lives. Satellite systems such as GPS (Global Positioning System) provide our in-car navigation, using the 3D technique of multilateration (distances from the car to instantaneously known satellite locations). Mobile phone apps use the cameras on our phones enabling us to create, for example, 3D models of everyday objects using photogrammetry (3D data from conventional 2D images).

Photogrammetry has a strong presence in the tools used for 3D data acquisition. It has long been integral to map making, which often starts with an aerial camera (aircraft or drone-mounted) imaging an area to be mapped in a series of sequentially acquired overlapping images. A development of the technique enables the use of a single hand-held camera to take multiple photographs all around an object, which provides most of the data to generate an accurate 3D model of the object. In another implementation, two synchronously operating video cameras, mounted in a rigid housing, create a real-time stereo camera which can track a touch probe or line scanner used to measure the features and surfaces of an object of interest. Alternatively, the stereo camera can dynamically track and guide the motion of a robot. By adding more cameras, the accuracy can be increased and reliability improved. Adding a pattern projector allows the system to function as a fully non-contact area surface scanner. Here, the pattern projected onto the object's surface is measured in 3D by the two cameras.

Many other tools have been added to the portable 3D toolbox. A common one is the laser tracker, which directs a laser beam at a moving retroreflector. The reflector returns the beam back to the tracker, which can then correct the pointing of the laser to stay on target. The tracker measures the distance and the horizontal and vertical angle to the reflector, hence the reflector's use as a touch probe to measure object points of interest. A similar-looking device is the polar laser scanner which can detect the return of its projected laser beam and hence measure the range directly from an object's surface. Rapid horizontal and vertical movement of the beam generates dense 3D point clouds from which the surface of an object can be modelled in detail.

This short overview presents just a few key elements in portable 3D measurement in order to place into context the four papers in the current Special Issue entitled "Advances in Portable 3D measurement". The editors welcome further contributions to this Special Issue, where readers will find the following.

3D Model-Based Large-Volume Metrology Supporting Smart 2 Manufacturing and Digital Twin Concepts

Lindquist et al. show how automated airframe assembly at Saab Aeronautics, using laser radar (similar to the polar laser scanner described above), can be optimized by applying digital twin concepts which simulate this metrology concept.

Methodology to Evaluate the Performance of Portable Photogrammetry for Large-Volume Metrology

Puerto et al. show how the Basque company IDEKO and Germany's PTB (Physikalisch-Technische Bundesanstalt) successfully evaluated the performance measurement of large-volume photogrammetric systems. Issues which need to be addressed include large working ranges of 3 m to 64 m and the use of mass-market digital cameras.

Development of a Toolchain for Automated Optical 3D Metrology Tasks

Jamakatel, Eberhardt and Kerber, at the Technische Hochschule Augsburg and the Fraunhofer IGCV, consider the issue of optimizing automated manufacturing processes involving optical 3D metrology and where diverse products are manufactured in small batches. In essence, the task is to optimize the inspection of a varied range of products. For this, they present an adaptive toolchain (linked software development tools) for vision-guided robotic processes. As with Saab Aeronautics above, digital twins again have a place here.

Multilateration with Self-Calibration: Uncertainty Assessment, Two Experimental Measurements and Monte-Carlo Simulations

Guillory, Truong and Wallerand at Cnam (Conservatoire National des Arts et Métiers) in France are developing a high-accuracy 3D measurement system based on multilateration. As indicated earlier, multilateration is an extended form of trilateration in which a point is located in 3D by three distance measurements, one from each of three known points. Having previously determined the uncertainty of individual distance measurements, the group at Cnam here evaluate the uncertainty in spatial location.

2. Advances in Portable 3D Measurement and Metrology

To highlight the fact that portable 3D is a very active area of development and commercial interest, a sample of other developments, commercial and research are presented in this section.

Leica/Hexagon ATS600—combined tracker/scanner

The Leica Absolute Tracker ATS600 was introduced in 2019 [1]. It can operate as both a laser tracker, following a target retroreflector, and a polar laser scanner, directly measuring object surfaces. Note that Leica Geosystems has been part of Hexagon AB since 2005.

Axiscan deflectometry system

The South African Isak du Preeze, now based in France with his company Axiscan [2], has developed a version of deflectometry with encoded reference lines which are reflected in a smooth surface, typically a car body. He calls this recent development "Latitude Code Scanning Deflectometry", and is manufacturing prototype scanners for car bodies. A further development of the process involves the use of infrared illumination for which unfinished metal surfaces act more like reflectors, potentially enabling deflectometry to be applied at an earlier stage in the car manufacturing process. See details in an interview with "Imaging and Machine Vision Europe" [3].

INSPHERE Iona robot control system

INSPHERE, a relatively new metrology company in the UK, recently introduced their Iona system. Here, multiple stereo cameras can track, monitor and control a robot in its work cell. The system is designed to facilitate the development of smart manufacturing [4].

PolyWorks AR

The Canadian company InnovMetric manufactures the PolyWorks suite of software which is designed to support 3D metrology. The current PolyWorks AR package demonstrates how augmented reality (AR), using the Microsoft Hololens, offers metrology operators guidance for their measurement tasks and feedback, merged with their view of the measured object, regarding measurement coverage and quality of results [5].

Autonomous Measurement Robot (AuMeRo)

The multi-partner project AuMeRo, led by Zeiss, was presented at the 3D Metrology Conference 2022 [6]. The presented concept showed a gap-and-flush measurement sensor mounted on an autonomous robot which could navigate its way from a holding location to a target object and make the required measurements independently. See the full presentation by Matthias Karl "Quality control by autonomous mobile robot demonstrated for flush and gap at car body" [6].

Automated fuselage alignment

Aircraft manufacturers are constantly improving and accelerating their manufacturing processes. Here, Trabasso and Mosqueira evaluate the use of laser radar and an optical tracker (triple-line camera with three cylindrical lenses which locates a target LED on three intersecting planes). These measurement systems provide feedback control two Kuka robots which align the fuselage components. The results deliver accuracy and cost advantages [7].

Integration of laser tracker in automotive production

In this study by Altiniski and Bolova, the authors evaluate a laser-scanning solution for quality measurements on car bodies. The objective is to find faster and more flexible methods than the use of traditional coordinate measuring machines (CMMs). The scanning system tested was a Leica 6DoF laser tracker following a T-Mac, Leica's line scanning head for use with robots. The authors' results support the view that there are clear advantages in a robotic scanning solution [8].

Comparison of large-volume metrology (LVM) systems in shipbuilding

Maisano et al. evaluated three types of current LVM systems for their application in shipbuilding tasks, according to a specific set of criteria agreed by a group of academic and industrial experts. The systems were a laser tracker, a total station and a (polar) laser scanner. All deliver measurements comprising horizontal and vertical angles, and the distance to a target point. A results table gives a convenient and compact overview of how the systems compared, with no one system being an obvious single solution [9].

Drone photogrammetry for metrology inspection

Unmanned aircraft systems (UASs also called drones) have established a strong presence in geospatial and heritage measurement, but they can also be effective in metrology applications. This paper by Menna et al. evaluates the concept in detail by simulating the use of a multicopter with an attached, high-end photogrammetric system for measuring a large parabolic antenna. An on-board satellite location system enables accurate positioning of the drone within a planned and optimized photogrammetric network to achieve maximum accuracy. The simulation gives valuable insights into the relevant network design and operation of the system, and further future work in real-case scenarios is proposed [10].

3. Conclusions

Portable 3D measurement continues to attract development interest from research groups and end users. The appearance of new and improved products and analytical solutions highlight the commercial advantages offered.

These development and commercial interests follow the drive towards more automation and robotic measurement. Yet more flexibility will be offered by the incorporation of drones and autonomous platforms in general. Analytical and AI methods are developing in parallel to improve the modelling of systematic and random error whilst enhancing automation, reliability and utility of the upcoming generation of portable 3D measurement systems.

Portable 3D measurement is a vibrant field for both development and innovation. It is driven by the industrial challenge for validated spatial measurement, which is a key input for the data-driven manufacture of large assemblies of components that typify the automotive, aeronautic and energy production sectors.

Conflicts of Interest: The authors declare no conflict of interest.

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