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Automated assessment of object coverage in smart, optical form measurement

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Abstract

As part of a project to develop a smart 3D form measurement system for quality control of complex 3D parts, we present early work in algorithmic assessment of coverage achieved on the surfaces of a part subjected to optical measurement from a single pose. The method performs an automated detection of pose by finding the best-matching position of the measured point cloud to a reference CAD model. The point cloud is then partitioned by associating measured points to individual CAD surfaces and coverage quality indicators, such as sampling density and covered area, are computed for each surface. The method is developed as part of a smart measurement solution that will provide real-time feedback to the measurement system on the success of the measurement acquisition and autonomously adapt the measurement strategy for complex 3D geometries in real-time to achieve an optimised measurement result. As proof of concept, a prototype implementation is presented that involves the combination of commercial measurement hardware and 3D modelling software components.

Form metrology, smart optical systems, adaptive measurement, geometric alignment of point clouds and CAD geometry, geometric sampling and coverage.

1. Introduction

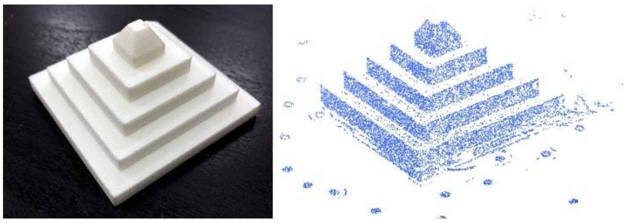
Highly customised parts fabricated in low production volumes are gaining traction, in particular due to the increasing market penetration of additive manufacturing technologies. For the specific case of high value-added parts, for example, in the biomedical sector, stringent verification requirements often need to be met and the costs of part rejection are prohibitively high. However, because of the low production volumes and frequent changes in shape and size of the parts, it is often inconvenient or even impossible to prepare and set up optimised inspection plans [1]. The involvement of digital technologies in most rapid product development and fabrication processes, in particular when additive manufacturing is involved, gives rise to numerous information sources that could be exploited to develop smarter measurement solutions. Information-rich metrology (IRM) is a recently introduced paradigm [2] which promotes the development of smart, digital measurement systems that can make use of any available source of information (a priori or from sensors) to automatically plan and optimise a measurement process, or correct it during execution. Sources of information may pertain to the object being measured, the measurement system itself and its interaction with the part materials and surfaces, or the environment where the measurement is taking place. The application of IRM to the non-contact, optical measurement of complex parts is being investigated, for example, to implement fast, self calibration of multi-sensor form measurement systems [3].

In this paper, a smart point cloud processing solution developed according to IRM principles is illustrated, dedicated to solving the pose estimation problem (i.e. automated determination of position and orientation of the measured object with respect to the measurement system) and capable of automatically assessing indicators of measurement quality, such as covered area (percent of part surfaces covered by the measurement) and sampling density (number of measured points per unit area). The automatically processed information is meant to be used by an AI-powered decisional system to assess whether the measurement is satisfactory given the current part specifications, or a new measurement should be performed, possibly from a different pose. The solution is presented as proof of concept, in a preliminary implementation form. The prototype relies on the combination of existing, commercial measurement hardware and point cloud processing software.

2. Experimental set-up

The experimental set-up consists of an optical fringe projection measurement system (NUB3D SIDIO XR), combined with the commercial point-cloud processing software Polyworks Inspector by Innovmetric (version Polyworks 2017). Automation is achieved via scripting within Polyworks (MACRO language interface). Point cloud data is transferred from the measurement instrument to the point-cloud processing software in the CSV format.

The selected test measurement part is shown in Figure 1a. The part was fabricated by selective laser sintering (SLS) in Nylon 12, with size of the rectangular enclosing envelope: (50 × 50 × 28) mm. The result of a single measurement from an unspecified direction (unknown pose) is represented by the point cloud shown in Figure 1b. As the part has four nominally identical corners, pose estimation only pertains to the accurate identification of angular orientation of the central corner in the point cloud (of the three visible). As the part has been additively manufactured, a geometric model is available in the form of triangulated dataset (STL file).



a) b)

Figure 1. Elements of the experimental set-up; a) Nylon 12 sample (50 × 50 × 28) mm fabricated by SLS; b) point cloud obtained by optical measurement from a single, unknown direction.

3. Geometrical computation methods and results

The alignment is performed by means of an iterative closest points (ICP) algorithm [4], assuming the availability of an initial, coarse pose estimation.

'Optimal alignment' is defined as the rigid transformation (translation and rotation) that must be applied to the point cloud so that an alignment error function is minimised. The 'alignment error function' is in this case defined as the sum of squared Euclidean distances betweeen each point in the cloud and its closest virtual neighbour located on the triangular facets.

Once the alignment problem is solved, the data is expected to be in the configuration shown in simplified form in Figure 2. After alignment, each triangle belonging to the original triangulated dataset will have a certain number of measured points associated to it. The number of points associated to each triangle is used to compute coverage for the triangle, so that triangles with zero points are classified as having zero coverage. The number of points associated with each triangle is also used to compute sampling density, using the area of the triangle to determine how many points fall on average within the unit area. To obtain information associated with the surfaces of the original part (considering that flat surfaces will be generally made of multiple triangles), information from individual triangles belonging to the same surface is aggregated.

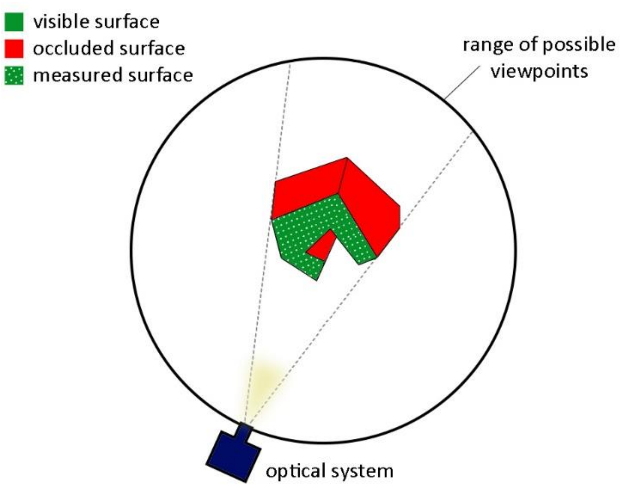
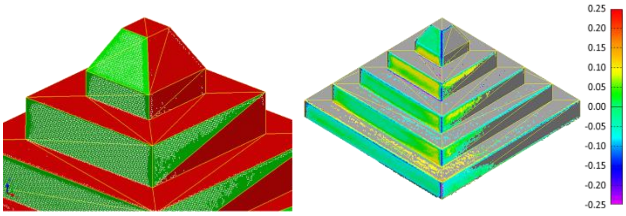


Figure 2. Data configuration at the end of the alignment step. A different number of points will be found aligned to any of the surfaces of the part. Surfaces with no associated points (marked in red) are usually outside of the viewing range, or covered by other surfaces.

Both coverage and sampling density results can be output in numerical form for further processing by other computational units implemented within the smart measurement system, or visualised on screen to provide feedback to human operators, through the use of rendering based on artificial colour-marking. A rendered example used to visualise a result of sampling coverage is shown in Figure 3a. In Figure 3b, artificial colour-marking is used to highlight the local deviation (Euclidean distance) between each measured point and its paired closest nominal neighbour located within the nearest triangle.



a) b)

Figure 3. Artificial colouring used in Polyworks to highlight some of the results of the automated processing of the measured point cloud; a) colour-marking based on surface coverage; b) colour-marking based on Euclidean distance of each measured point to the closest paired one in the nearest triangle.

4. Conclusions and future work

In this paper, preliminary results from the early stage development of a smart point cloud processing solution based on IRM principles have been illustrated. The prototype is dedicated to solving the pose estimation problem for a simple test part with four symmetric sides, and is capable of automatically assessing covered area and sampling density from a single, unidirectional optical measurement. The current implementation is realised using commercial measurement hardware and point cloud processing software, and acts as proof of concept. We demonstrate the ability to automate pose estimation and assessment of measurement quality which will contribute towards the development of an AI-powered, decisional system for automated measurement process planning and control. Future work involves the development of further measurement quality indicators to automatically compute from the point cloud, based on additional information coming from the part, the measurement instrument and the environment, in compliance with the IRM paradigm.

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