Title:
Integrated Computer-aided Verification of Turbine Blade

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Introduction:
Computer-aided verification plays an important role in turbine blade quality control as it provides a valid means to quantify the blade geometry and thereby governs the engine performance. However, this dependency on measurement accuracy could raise significant problems and present a major drawback if the computer-aided verification results were inaccurate. Makem et al. (2012) presents an simulation approach to assess the dimensional accuracy and shape quality of aerodynamic turbine blades formed from hot-forging. They proposed a virtual inspection system using essentially the 3–2–1 approach and Iterative Closest Point (ICP) localisation algorithms to provide a virtual error assessment framework.

As shown in Fig. 1a, the 3–2–1 approach relies on six (=3+2+1) distinct points for point clouds captured from different perspectives to be merged into one. However, a minimal of three instead of six corresponding points can be used for coordinate frame registration. Moreover, feature point is difficult to be identified among the point cloud whether manually or automatically. The ICP approach employed by the inspection system uses a binary search tree based nearest neighbour algorithm to locate corresponding points between the forged model and the nominal model, Fig 1b. For processing the point cloud with the ICP algorithm, the computation is demanding and local minima may exist that leads to non-global convergence. In practice, deviation between the measured profile and the nominal one still exists.

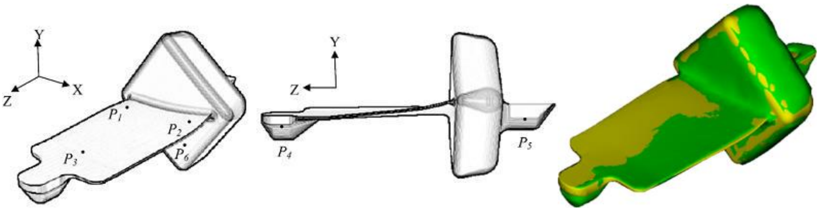

Fig. 1: Point Clouds registration (a) 3–2–1 approach, (b) ICP localisation.

Therefore, a new system is proposed by integrating inexpensive opto-mechatronic hardware as well as intelligent algorithms to simplify the turbine blade reverse engineering for downstream quality evaluation.

Main Idea:
The new integrated system (Fig. 2a) consists of a new mechanical rig design, a motorized position controlling mechanism, a non-contact 3D data acquisition system, and three software modules. The first module is a user interface for positioning control of the mechanical rig. The second module incorporates regression and transformation algorithms as well as k-d binary space partitioning tree to automatically register the multi-view scans into one point cloud. Essentially, a least square error cylindrical surface fitting is worked out for an arbitrary axis $(\vec{P}_c, \hat{a})$, i.e.,

$$\|(\vec{P}_i - \vec{P}_c) - (\vec{P}_i - \vec{P}_c) \cdot \hat{a}\hat{a}\| = r$$

This is followed by inverse arbitrary axis rotation of controlled angular increments, i.e.,

$$R_{arb} = T(\vec{P}_c)R_x(\vec{P}_c, \hat{a})R_x(\vec{P}_c, \hat{a})R_y(\vec{P}_c, \hat{a})R_z(\Delta\theta_j)R_y^{-1}(\vec{P}_c, \hat{a})R_x^{-1}(\vec{P}_c, \hat{a})T^{-1}(\vec{P}_c)$$

Point clouds for different views are stored in k-d tree (k=3) to facilitate further processing. The third module is blade quality evaluation for validating the accuracy of the blade surface by analyzing 3D error and comparing cross-sectional data between the measured and the nominal solid model. Sample result is given in Fig. 2b.

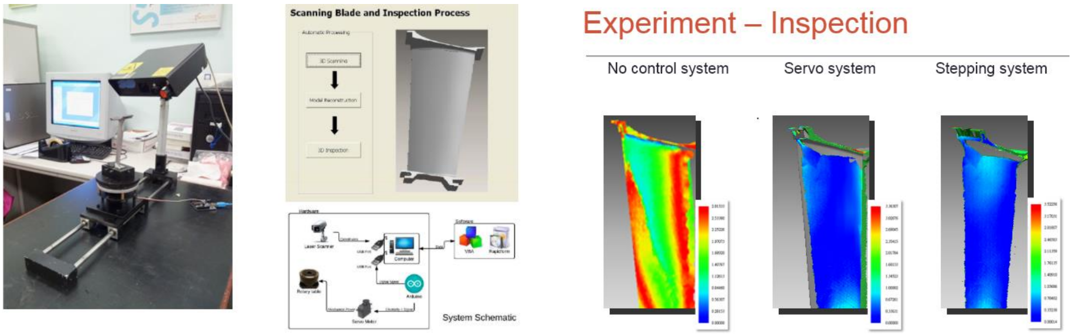

Fig. 2: (a) Integrated turbine blade inspection system, (b) Experiment results - analyzing 3D error.

Conclusions:
A low cost turbine blade inspection system has been developed and tested. The blade being mounted on the rig allows full coverage capture in multiple positions and attitudes by the 3D laser scanner. The integrated implementation of regression for arbitrary axis calibration, arbitrary axis rotation for auto-registration and k-d tree for sorted point cloud storage free us from the shortcoming of the traditional method which requires time-consuming nonlinear optimization routines.

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