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CMM FUNCTIONAL SOFTWARE EVALUATION (ALGORITHM QUALIFICATION)

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Abstract

The mathematical algorithms for geometric features contained in proprietary coordinate measuring machine (CMM) vendor's software were tested by standardized data set applications and results were compared with known algorithm outputs. The CMM vendor's proprietary software requirements shield the user from visibility of the actual equations programmed into the coded software routines. All that is visible to the CMM inspector is the input data and the resulting output. Details of how those results were calculated from sample probing data would not typically be visible. Therefore, to gain rigorous confidence that the CMM inspection routines function as desired, independent testing was performed using sets of data with known results. Comparisons with the known results then verified functional algorithm acceptance. Agreement to the fifth and sixth decimal place was common.

Summary

The application of computer controlled coordinate measuring machines (CMMs) for product and tool inspection requires inherent confidence that the CMM software provides accurate mathematical analysis of the sample point measurements and constructed geometry. The CMM vendor's proprietary software or firmware algorithms must be mathematically correct. In this project, methods were developed to verify the accurate functioning of the CMM software or firmware geometric algorithms.

The approach used defined and correlated mathematically exact geometry data for input into CMM algorithms as pseudo data, or data that could be represented to the CMM software as if it had been generated by sample point measurements. Initially, over 30 data sets were identified as prospective examples for consideration. Several parameters such as the number of data points vary. The methodology developed involves reviewing and evaluating the present status of CMM algorithm experimental measurement results. Prior to release of CMM software,

if a measurement result looks suspect, that set of routines used should be among the first selected and analyzed.

Analysis consists of comparing the exact results previously calculated with the CMM algorithm experimental measurement resulting from applying the pseudo data and assessment of conclusions derived. No disturbing anomalies have become visible. This set of reviews was completed, but as future vendor's software updates are received, additional reviews will be conducted as required. Analysis and improvements to the methodology continue.

Discussion

Scope and Purpose

CMM software available from CMM vendors is proprietary code and therefore shields the user from visibility of the actual equations programmed into the software (or firmware) routines. All that is visible to the CMM inspector is the input data and the resulting output. The purpose of this effort was to develop methods for independent verification of the accurate functioning of the CMM software geometric algorithms.

Prior Work

As manual CMMs became popular inspection systems, replacement of the older surface plate, rotab, and height gage inspection techniques accelerated. Desktop calculators were the sustaining calculation device, and coordinate readouts provided spatial data for input to known and trusted geometry equations. Then, computers and software for CMMs were added to this calculation-intensive task. Computer numerical control (CNC) automated the sample point probing data generation and geometric calculation functions. CNC CMMs provided obvious benefits of increased speed and proficiency. Quality conscious calibration and inspection personnel were initially instructed to validate their inspection system's mechanical accuracy; for the most part, the computer software systems were assumed above reproach.

A truly proficient metrology system considers no part of measurement systems as above reproach. Awareness of the potential for error introduced by the software embedded within the computer or

CMM system and potential misapplications of measurement routines were slower in being recognized as error sources. That growing concern throughout industry formed the basis for studies and evaluations seeking to provide the same or greater level of confidence for the soft portion of the measuring system that had been routinely obtained for years from independent calibration of the hardware portions.

The need for independent evaluation of the measurement equations embedded in the vendor proprietary software/firmware of the CMM system caused metrology professionals to address several tasks that required separation of errors caused by mathematical algorithms from the mechanical sources of error always inherent in coordinate metrology. Algorithm qualification became the subject of several interested technical groups, including the ASME B89.1.12 Software Task Force.

Methods for independently verifying algorithm qualification were not solely developed by one group of individuals. Development, as progress has been achieved, was a joint and collaborative effort.

Activity

The techniques for CMM algorithm qualification had to address three specific areas:

- How is "goodness" of an algorithm determined?

- What is the proper algorithm for the measurement application?
- How can independent testing be performed?

Several sets of data for representative geometric samples were received from the German Physikalisch-Technische Bundesanstalt (referred to herein as the PTB data) through Carl Zeiss, Inc. Discussions in the B89.1.12 meetings led to the following plan of attack.

- The goodness of fit of an algorithm should be evaluated by respected and authoritative mathematicians.
- Several algorithms can be used to evaluate data gathered and, depending on the application, one can be better than another. Among these are least squares fit, maximum inscribed fitting of a cylindrical surface, or minimum circumscribed fitting of a cylindrical surface. It was agreed that the least squares fit was the most predominant algorithm used on CMMs. Results should be viewed with these potential differences in mind.
- Algorithm qualification should use the PTB data to provide a common set of results for individual study comparisons.

Plans called for techniques to be developed to permit input of PTB data with known geometric configurations and statistical deviation in such a way that the CMM software algorithms could treat this data as measured point coordinates. Then, the CMM algorithms could construct the specific geometric results (least squares fit, etc.) from the data, and the resulting constructed geometry would be comparable to independently validated results.

Care must be taken to understand the specific CMM vendor's methods for projecting measured geometry on working planes. Those working planes must be defined in the specific CMM part program to be applied. Many details of the specific CMM vendor's software data files and formats and their manipulation therein constitute proprietary information that is protected by legally binding nondisclosure agreements and shall not be revealed.

An Algorithm Testing System¹ (ATS), a software package for the IBM PC, was created by the National Institute of Standards and Technology (NIST) to address the general problem areas. The ATS can generate numerous customized sets of data for testing geometric algorithms. The basic procedures for using the ATS are as follows:

- define a test description for a given geometry,
- generate a data set for the test,
- fit the test data set using the least squares method, and
- analyze the fit results.

It is beyond the scope of this report to interpret the complex mathematics contained in the ATS documentation. Let it suffice to state that probing point errors and form errors constitute the data comparisons for evaluation. Minimized form errors indicate more nearly perfect geometry.

Accomplishments

No disturbing anomalies in qualifying CMM algorithms have become visible. This set of reviews was completed, but, as future vendor's software revisions and updates are received, additional reviews will be conducted as required. Analysis and

improvements to the methodology are still sought.

Future Work

Future work should address the difficulties encountered in dealing with firmware-embedded algorithms and the differences in hardware platforms.

Reference

¹Mary Elizabeth A. Algeo and Theodore H. Hopp, *Form Error Models Of The NIST Algorithm Testing System* (Interim Report, NISTIR 4740) Gaithersburg, MD: NISTIR 4740, January 1992.