NISTIR 5374

A Process for Selecting Standard Reference Algorithms for Evaluating Coordinate Measurement Software

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1 Introduction

NIST is continuing efforts to standardize the evaluation of coordinate measuring systems (CMS) software by developing the Algorithm Testing and Evaluation Program (ATEP) [1]. This program will be the first calibration service in the United States for dimensional metrology software. To test and evaluate CMS software, ATEP will rely on three components: NIST's Algorithm Testing System (ATS), test procedures based on national standards [2], and reference algorithms. This document focuses on a description of a selection process for standard reference algorithms. The ATS and the test procedures are briefly described in Section 2.

Reference algorithms provide a baseline of performance for testing and assessing the data analysis software found in CMSs. Presently, NIST-developed geometric fitting algorithms are incorporated in the ATS. These algorithms are used as default reference algorithms to provide a performance baseline. Moreover, since many geometric fitting algorithms could serve as reference algorithms, the ATS allows the use of external algorithms as reference algorithms. NIST will address mechanisms for selecting new and replacing existing standard reference algorithms (SRAs) with ones that provide an improved performance baseline. There will exist SRAs for different objective functions. The SRAs will then be the current baseline for CMS data analysis software performance evaluation.

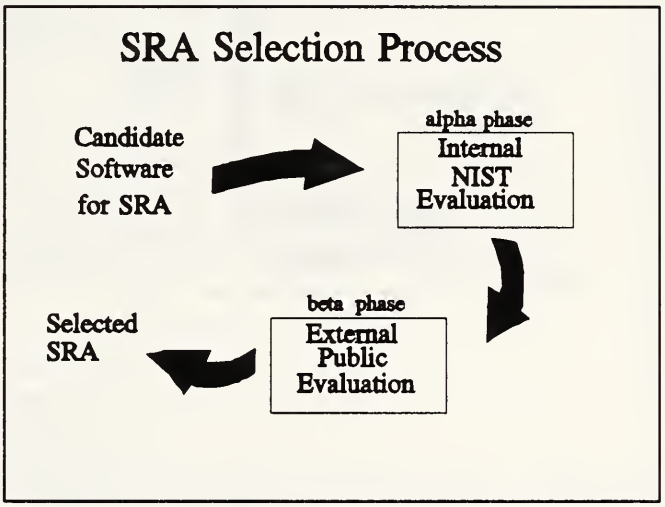

Figure 1 Candidate software goes through an alpha test phase and a beta test phase before it can be selected as a standard reference algorithm.

This report is directed towards the dimensional metrology community interested in standardizing geometric fitting algorithms used in CMSs and is intended to stimulate suggestions for establishing an SRA selection process. This report describes a procedure for selecting reference algorithms as new SRAs or as replacements for existing SRAs. An acceptance procedure for evaluating and selecting the SRAs will be identified. The acceptance procedure assures that evolving objectives for software and algorithm technologies are not overlooked. The SRA selection process provides control of variation among national reference algorithms and ensures addressing the needs of industry.

Section 2 provides a brief description of existing problems with CMS software and NIST's involvement in providing solutions. Section 3 is an overview of the SRA selection procedure. The selection procedure is envisioned as a two-stage process: an *alpha* phase conducted by NIST and a *beta* phase of public review. Figure 1 illustrates the overall picture of the SRA selection process. In Sections 4 and 5 the details of the alpha and beta phases are described, respectively. Section 6 provides a summary of related activities.

2 Background

CMSs are widely used by the dimensional metrology community during the inspection of manufactured parts. The data analysis software within the CMSs (the software that evaluates coordinate data and produces dimensional measurements) is becoming increasingly important because of the significant effects such software has on the reported measurements. For example, software computations used to convert raw data to reported results can be a major source of error in a measurement system [3]. There are no standards or available methods for testing and evaluating the effects of data analysis software on the overall uncertainty of measurements [4]. How to test coordinate measuring system software and how the measurement uncertainty is affected is currently being researched in the United States [5], in Great Britain [6], and in Germany [7].

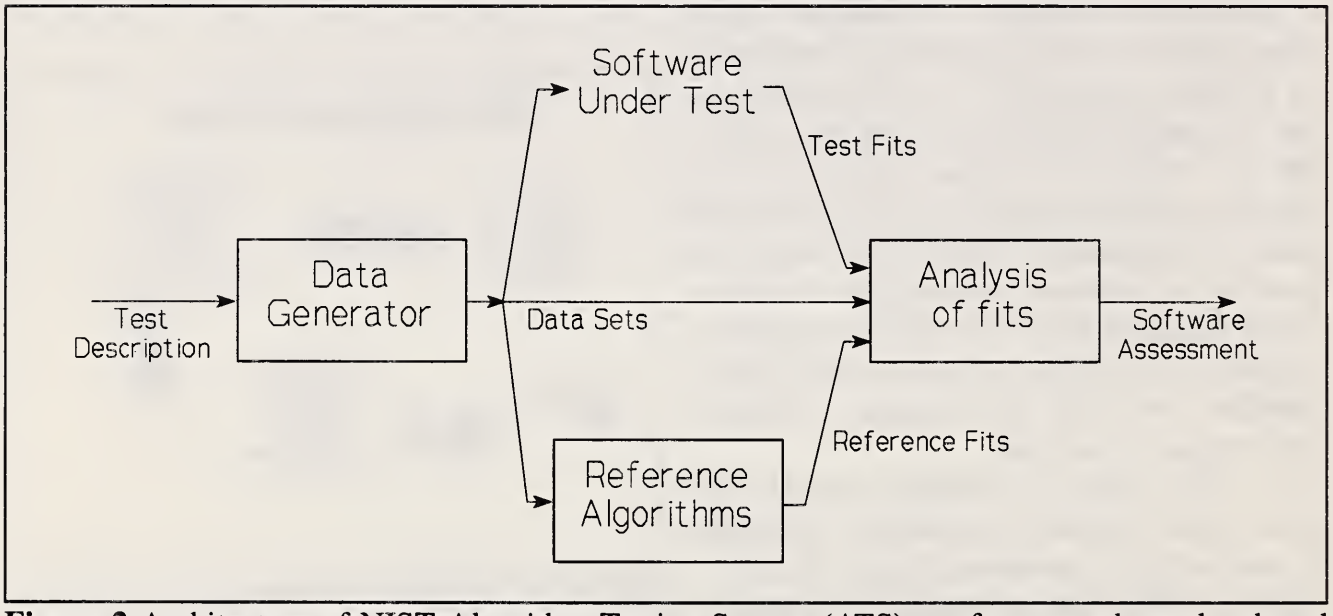

Figure 2 Architecture of NIST Algorithm Testing System (ATS)—software package developed for testing the performance of data analysis software used in CMSs.

As part of NIST's contribution to an ongoing effort by industry standard groups to establish standards for testing software used in inspection systems, NIST developed the ATS. The ATS is a software package for evaluating the performance of data analysis software. The architecture of the ATS is shown in Figure 2. The ATS provides capabilities for comparing the results of different fitting routines to a set of reference algorithms. The ATS allows the user to generate test data for various geometries with simulated form errors and simulated measurement

errors; run test data through the reference algorithms; import fits computed by other algorithms; and compare the results of algorithms.

The NIST ATS is being used as the basis for developing a new national standard, ASME B89.4.10, *Methods for Performance Evaluation of Coordinate Measuring System Software*. This standard will provide guidelines for evaluating CMS software. In addition this standard will provide the test procedures to be used in the proposed NIST ATEP.

ATEP will be a NIST service that combines the ATS, test procedures based on national standards, and control over the ATS reference algorithms. NIST will use these components to evaluate the data analysis software. Figure 3 illustrates the basic idea for the proposed NIST program to test and evaluate CMS data analysis software. The customer receives NIST-generated data sets and generates fit results with the data analysis software to be tested. NIST generates

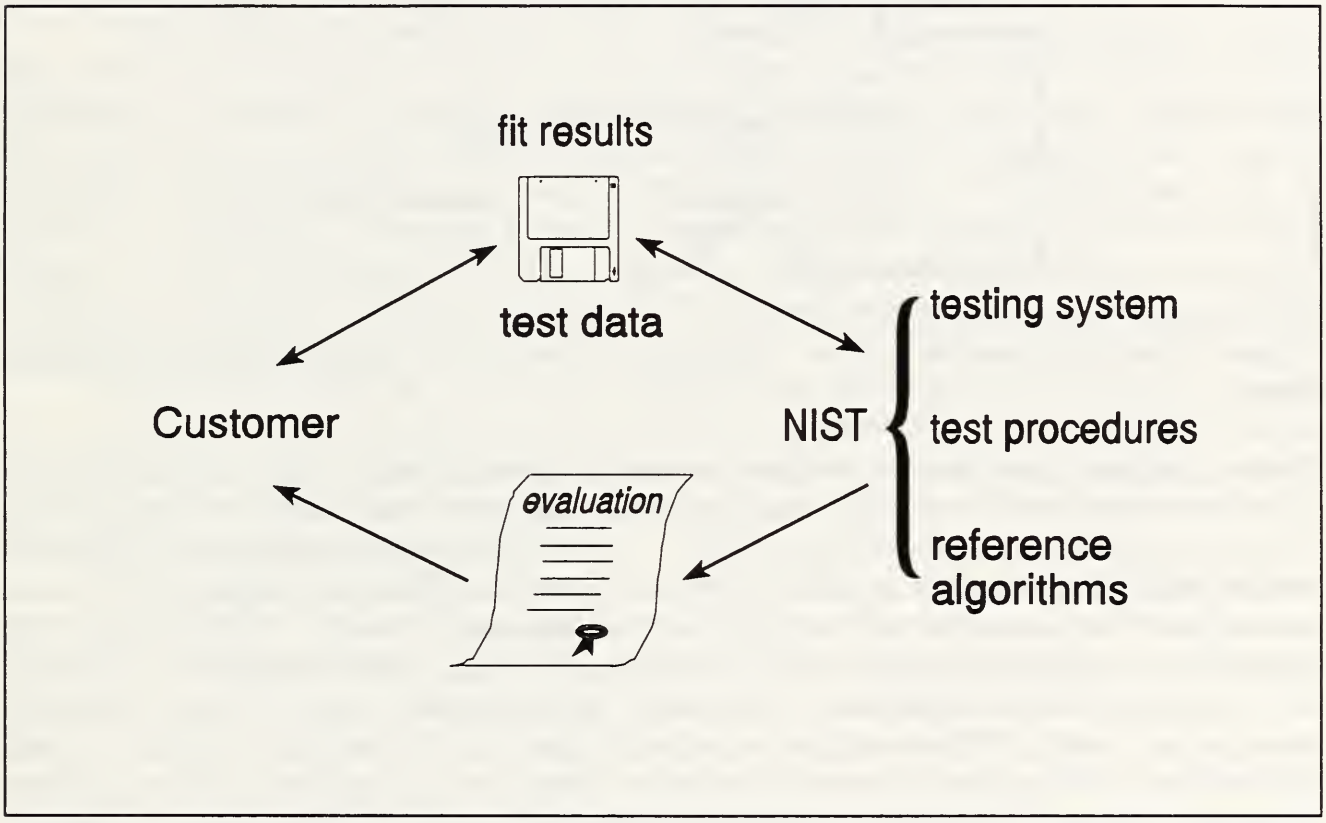

Figure 3 Proposed NIST Algorithm Testing and Evaluation Program for performance evaluation of CMS data analysis software.

fit results from the same data sets using the ATS's reference algorithms. NIST then compares the two sets of fit results. According to predefined test procedures, NIST provides the customer with an evaluation of the software.

The rest of this report describes the SRA selection process, as currently envisioned, that NIST will use to maintain and update the reference algorithms used in the ATEP.

3 Overview of SRA Selection Procedure

Figure 4 illustrates the SRA selection process. The process starts with the development of a new algorithm. The algorithm may be developed by NIST, private industry or academia.

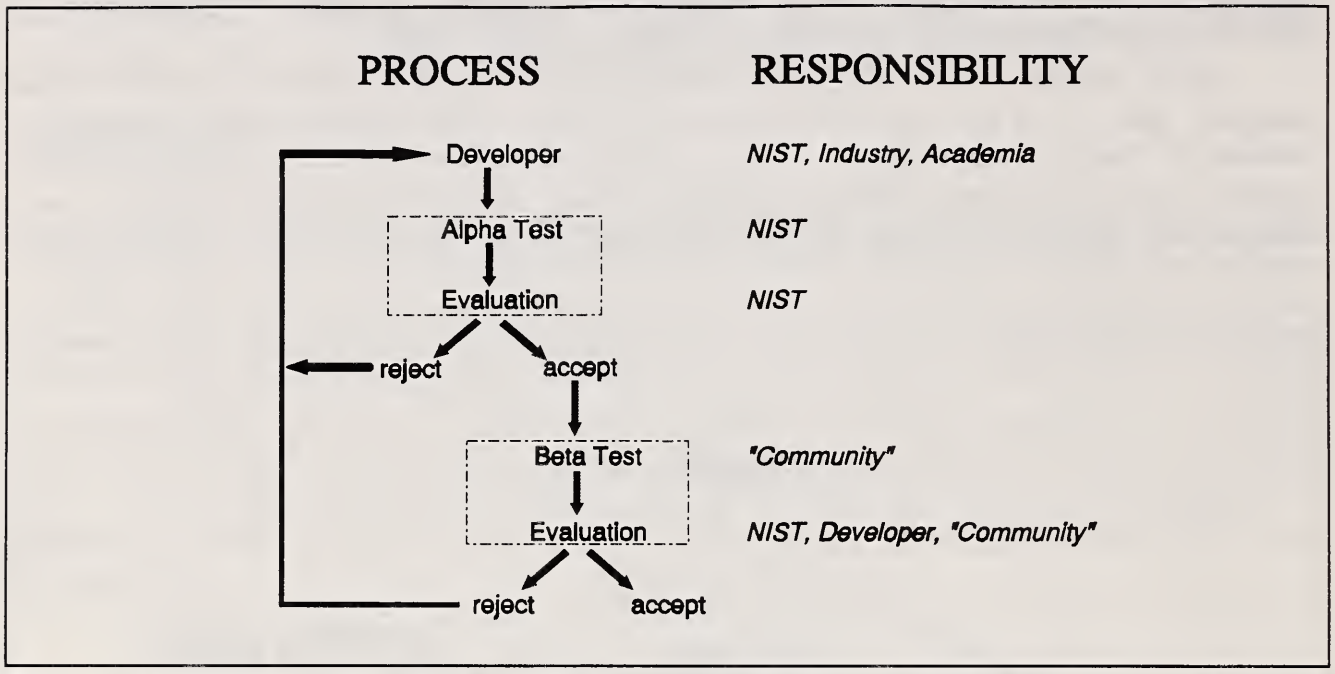

Figure 4 The SRA Selection Process. The process proceeds in two phases, shown by the dashed boxes.

Before a proposed algorithm is submitted, a developer contacts NIST. NIST and the developer agree on a statement of work. The statement of work specifies what information is required to accept the algorithm as a candidate for an SRA. The developer submits the proposed algorithm and the required information to NIST. NIST reviews the submission for completeness of information and adequacy of terms according to the statement of work. Additionally, NIST acknowledges receipt of the request. If the submission is incomplete or inadequate, it is returned to the developer with an explanation. Otherwise, NIST begins the alpha test. After evaluating the alpha test results, NIST determines whether the algorithm is suited for beta testing. If the algorithm fails the alpha test, it is returned to the developer with an explanation. If the algorithm passes the alpha test, it is distributed to the coordinate measurement community for beta testing. NIST evaluates the beta test results and tries to build a consensus for the disposition of the submitted algorithm. If the algorithm is not suitable, it is returned to the developer. Otherwise, it becomes a standard reference algorithm and can be used to improve or enhance the testing capabilities offered through the ATEP.

4 Details of Alpha Testing

Before NIST begins the alpha test, the developer is to meet certain requirements. First, the developer provides a statement of benefits and applicability of the algorithm. The developer

states why the submitted algorithm would be useful as an SRA. Additionally, if the algorithm is a replacement of an existing SRA, the developer states why the submitted algorithm is better.

Second, the developer provides technical documentation about the algorithm: a written, detailed description of what the algorithm does and how it does it. Pseudo-code and source code (preferably in ANSI standard C) are optional. Code in other programming languages are addressed in the statement of work. The documentation should specify the theoretical basis for the algorithm. An objective function, input and output considerations (restrictions, data points, parameters), and error handling should be clearly stated. The design of the abstract implementation should also be described. That is, the underlying mathematical and numerical details (e.g., minimization methods, solution methods) should be documented. The algorithms that implement the mathematical or numerical methods used, or references to these algorithms in literature, are to be included. Portions of the documentation that are proprietary should be marked as such. Documentation that is not marked is assumed to be public information.

Last, certain non-technical issues will be addressed before the alpha test begins. Because the process of selecting an SRA requires public participation, the SRA becomes public information. In addition, the developer and NIST will coordinate the algorithm's implementation and integration into the ATS. If the two parties agree that NIST will implement the proposed algorithm, then the developer should be available for consultation. This arrangement may be informal or formal (e.g., Cooperative Research and Development Agreement). If the developer agrees to do the implementation, NIST will provide guidelines for implementing an algorithm in the ATS environment. Future maintenance of the implementation would be the responsibility of NIST.

Once these criteria are met and the conditions are agreed upon, NIST begins the alpha test. As the first step of the alpha test, the benefits and applicability of the submitted algorithm are evaluated by surveying the coordinate measurement community. If there is sufficient interest for the algorithm within the community, testing continues. This survey provides a mechanism for eliminating irrelevant algorithms.

In the second step, NIST reviews the detailed algorithm description, considering three elements: the theoretical basis for the algorithm, the abstract implementation of the algorithm, and ATS environment issues. Questions relevant to the theoretical basis include: Does the algorithm do what it says it does? Is the objective accomplished? Questions regarding the abstract implementation are: What are the strengths and weaknesses of the underlying numerical analysis methods outside of any particular computing environment? How stable, complete, and accurate are these methods? Question regarding the environment issue is : Can the algorithm be implemented in the ATS?

For the third step, NIST and/or the developer implement and integrate the proposed algorithm into the ATS, assuming problems encountered during the review are resolved.

Finally, the ATS implementation of the submitted algorithm is tested and analyzed using test data sets. These test cases are yet to be defined.

All the results from each step of the alpha test are evaluated. If any problems encountered during the alpha test cannot be resolved, then the submitted algorithm is returned to the developer.

5 Details of Beta Testing

If the submitted algorithm passes the alpha test, it is prepared for beta testing. Beta testing is done by interested members of the coordinate measurement community. The developer compiles user documentation for the submitted algorithm, while NIST prepares user documentation for the ATS as modified with the new algorithm.

The first step of the beta test is the compilation of the beta test distribution packet. The distribution packet requires an IBM/PC compatible computer. The minimum configuration is:

- 80286 or higher cpu
- DOS Version 3.3 or higher
- Hard disk with at least 2 MB free space
- EGA or VGA graphics

The distribution packet includes the following items:

- Documentation
  - Detailed algorithm description
  - ATS implementation information
  - ATS user documentation
  - Beta test guidelines
- 3 1/2" Diskette
  - ATS executable with submitted algorithm implemented
  - Source code
  - Test data sets
  - Documentation
  - Install procedure
  - Information file
  - Disclaimers
- Comment sheet/questionnaire
- Cover letter

NIST then sends the distribution packet to participating members of the coordinate measurement community. The community evaluates the submitted algorithm and returns comments to NIST. NIST reviews and summarizes community evaluations.

Based on its own findings and community input, NIST writes a position paper regarding the disposition of the submitted algorithm and tries to build a consensus among the community. For unresolved problems, the action depends on the nature of objection. Levels of problem severity will be determined at a future time.

6 Summary

The SRA selection procedure is still under development. Specific test procedures need to be identified and will be described in future reports. The completion of the ASME B89.4.10 standard for CMS software performance evaluation will provide the guidelines necessary to determine the test procedures. The B89.4.10 Working Group on Software Performance for

Coordinate Measurement Systems is currently working on completing the draft national standard. The draft standard is now scheduled to be available in 1994.

The ASME B89.4.10 standard will also provide the specifications for testing and evaluating data analysis software under NIST's Algorithm Testing and Evaluation Program. ATEP is also under development and is expected to be available for 1994.

Version 2 of NIST's ATS is scheduled to be completed by mid 1994. Version 1.1 of the ATS was distributed to members of the ASME committees for beta testing. The ATS supports testing of least-squares fitting algorithms for six common geometries found on manufactured parts. Version 2 of the ATS supports more geometries and other methods of geometric fitting (e.g. minimum circumscribed). Version 2 is also easier to use and provides greater testing and evaluation capabilities.

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