Final Publishable JRP Summary for NEW06 TraCIM
Traceability for computationally-intensive metrology

Overview

Many areas of metrology rely significantly on software that implements mathematical calculations and it is vital that such software is shown to be operating correctly. The project identified calculations relating to a number of priority metrology applications and developed approaches and associated test data to assess the performance of software implementations of those calculations. An information and communications technology (ICT) system was developed that allows mathematical software to be tested using the internet. A testing service for three of the priority metrology applications is now commercially available.

Need for the project

Developers of software that implements mathematical calculations increasingly require or desire that testing of their software be carried out by an independent organisation such as a National Metrology Institute (NMI). There are many benefits of such testing to a software developer. The risks and costs associated with bringing software containing errors to market are reduced. The developer is more easily able to demonstrate that the software meets the requirements of users. The reputation of the developer may be enhanced, providing commercial advantage over rivals operating within the same field.

Problems can arise because the specifications of calculations undertaken by software are often expressed in ambiguous language or are missing altogether. The lack of unambiguous specifications of calculations hinders the process of testing metrology software.

Several national and international initiatives have attempted to address the issue of metrology software testing but progress, though useful, has been sporadic. The software testing process involves a number of steps in which data is passed back and forward between the testing organisation and the developer. While the development of communication via the internet has simplified and speeded up the data exchange process, concerns around commercial sensitivity and the security of data must be addressed.

The project therefore sought to implement a novel approach to testing that includes: the provision of specifications of calculations; the generation of reference data (numerical artefacts) to be used to test software; the design of performance metrics to assess the performance and fitness for purpose of software; and the development of a state-of-the-art ICT system that allows software testing to be implemented securely online, at the point of use.

Scientific and technical objectives

The key aims of the project were to:

1. Identify at least ten priority metrology applications (i.e., calculation or set of calculations), with particular focus on those from Length metrology and develop a general framework for testing metrology software.
2. Develop a procedure to ensure that the specification of a calculation in any metrology domain is correct and unambiguous and, for each priority metrology application, provide specifications of calculations.
3. For each calculation, undertake a mathematical analysis and develop software to generate numerical artefacts, i.e., reference input data and reference results for which quantitative statements about their accuracy have been derived (analogous to calibrating a physical artefact).
4. For each calculation, develop performance metrics that allow test results, i.e., results obtained by applying software under test to the reference input data, to be compared with reference results.

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5. Develop the framework of an ICT system for the online assessment of software implementing mathematical calculations, and make available testing services for calculations identified as significant in coordinate metrology.

Results

Objective 1: Identification of priority metrology applications

Project partners, including four industrial partners, all manufacturers of coordinate measuring machines, identified the following priority metrology applications for which testing services would be made available:

- least squares geometric element (LSGE) fitting; and
- minimum zone geometric element (MZGE) fitting.

The priority metrology applications from the Length metrology area identified by project partners were:

- evaluation of surface roughness parameters; and
- least squares fitting of data to a NURBS surface.

From the Chemistry metrology area, the priority metrology applications identified were:

- least squares fitting of a constant plus exponential decay function to data;
- least squares fitting of a sum of line profiles to data; and
- principal component analysis.

From the Electricity and Magnetism metrology area, the application of determining the error vector magnitude of a digital signal was identified.

Finally, a number of "Interdisciplinary" metrology applications were identified:

- least squares polynomial regression;
- interlaboratory comparisons; and
- uncertainty evaluation.

Objective 2: Specifications of computational aims

A procedure was developed that allows a calculation (or computational aim) to be specified in a document in which a number of sections must be completed. The sections include Title, Keywords, Mathematical area, Input parameters, Output parameters, Mathematical model, Properties, References and History (of the specification). This procedure enables the specification of any calculation in any metrology domain in a well-defined and unambiguous way. The web-based, searchable "Computational Aims Database" (www.tracim-cadb.npl.co.uk) was developed to facilitate the storage of documents containing specifications of calculations. Project partners populated the Computational Aims Database with specifications of calculations for the identified priority applications.

The Computational Aims Database is available for users to populate with additional calculations and will be an important component in future software testing activity.

Objective 3: Reference data

For each calculation, project partners have developed software to generate reference input data and corresponding reference results. Software under test is applied to the reference data and the test results obtained are compared, in an appropriate way, with the reference results to provide an assessment of the performance of the software for that reference pair. Additional information may also be provided to indicate bounds on what claims can be made by, and what can reasonably be expected from, software under test. "Benchmarking" reference pairs have been made freely available to download from the Computational Aims Database, and can be used by a software developer to test their software implementations.

Objective 4: Performance metrics

For each calculation, project partners have developed performance metrics to assess the performance of software under test when applied to a reference pair. Where appropriate, the performance metrics take account of the numerical uncertainty and measurement uncertainty information that accompanies the reference data. Procedures to combine the performance metrics returned for multiple reference data sets to determine a single "figure of merit" figure for the software have also been developed. The performance metrics allow an assessment of the uncertainty contribution associated with the software which can be compared with other uncertainty contributions in an uncertainty budget.

Objective 5: ICT system
Project partners designed and developed the components of the "TraCIM system", an ICT system to allow testing of software to be undertaken using the internet. The TraCIM system is designed to make use of the reference data and performance metrics developed in the previous objectives and has three key constituents: the server; the expert module; and the client module. The server lies at the heart of the TraCIM system and communicates with the other two components. The client module is an interface implemented on the computer of the software developer or user, and is responsible for connecting the software under test with the server. The client module requests reference data from the server and, after processing, returns test results to the server. The expert module provides reference data to the server on demand and undertakes the comparison of reference and test results, using the performance metrics.

Expert modules have been developed for three of the identified priority metrology applications, two from the Length metrology area, LSGE fitting and MZGE fitting and the interdisciplinary application of interlaboratory comparisons. For each application, formats have been defined for XML files that contain the reference data to be provided to the software developer or user, and the test results that are subsequently returned to the server. Guidance on developing client modules for the applications has also been written and serve as a template for using the TraCIM system to test any item of metrology software.

Overall
The TraCIM server developed within the project is available to all NMI partners. Following the end of the project, each NMI partner may use the server to provide its own software testing services, for both the calculations considered within the project (for which partners have generated reference data) or for additional calculations (for which reference data needs to be generated).

Commercial testing services have been developed for three of the metrology applications considered during the project, namely LSGE fitting, MZGE fitting, and interlaboratory comparisons. The first two testing services meet the requirement of industry, in particular, the developers of coordinate measuring machines (CMMs).

Actual and potential impact

The project's outputs have been widely disseminated to the relevant metrology and industrial communities. Project partners have been involved in 13 international conferences. These conferences include ISPEMI 2014 (the 9th International Symposium on Precision Engineering Measurements and Instrumentation) in Zhangjiajie, China, August 2014, and LMPMI 2014 (the 11th IMEKO Symposium on Laser Metrology for Precision Measurement and Inspection in Industry) in Tsukuba, Japan, September 2014. A session on validation of metrology software was organised at AMCTM 2014 (Advanced Mathematical and Computational Tools in Metrology and Testing), held in St Petersburg, Russia, in September 2014. Project partners also delivered presentations at IMEKO XX World Congress, Busan, Korea, September 2012 and IMEKO XXI World Congress, Prague, Czech Republic, September 2015. In addition to published conference papers, eight articles have been submitted and published in peer-reviewed journals. Project partners have also attended two trade fairs to demonstrate and describe the TraCIM system.

During the project, the "TraCIM Association" was formed with the aim of ensuring that the outputs of the project continue to be utilised by software developers and users, and also providing a foundation for future work and international collaboration in the area of software testing. Membership of the association is open to NMIs and Designated Institutes that have particular interest in software testing.

Regular discussions with the project partners from the Length metrology area helped to ensure that the testing service being developed satisfied their expectations, and therefore those of other potential users. Towards the end of the project, workshops were held in Germany and the United Kingdom to present, and provide guidance on the use of, the TraCIM system to potential industrial users.

Three online testing services have been implemented and are now live, for LSGE fitting, MZGE fitting, and interlaboratory comparisons. The LSGE testing service has already been used by three of the project's four industrial partners, plus an additional four companies from outside the project team. The MZGE validation service has been used by three of the industrial partners, plus two additional companies.

The TraCIM system was developed with the aim of being easily extended to cover other applications from any area for which the use of reference data is appropriate for software testing. It is intended that project partners will make available additional testing services, both for some of the calculations considered within the project and for further calculations. Work is continuing in the field of coordinate metrology, with reference data currently being generated for calculations implemented by involute gear software and hole fitting software. Partners are also engaging with a leading supplier of test and measurement software development tools to make available testing services for a number of the calculations, including least squares polynomial fitting and principal component analysis, considered within the project. Both activities ensure that the outputs of the project, i.e., reference data and the ICT infrastructure, will continue to make impact following the end of the project.

The uptake of project outputs will lead to environmental and financial impacts. Environmental impact will be achieved by improvements in the quality of results returned by software products leading to fewer products being unnecessarily scrapped. Financial impact will be achieved by reducing the costs software developers are required to spend on testing their products and on dealing with the consequences of bringing software containing errors to market. Sales of software that is seen to have been tested by an independent organisation may also increase.

List of publications

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