Publishable Summary for 15SIP06 ValTraC
Validation of software development and analysis tools using TraCIM

Overview

The aim of the project was to maximise uptake, by software developers and users, of the outputs of EMRP JRP NEW06 TraCIM. This aim was achieved by working with the project's primary supporter, National Instruments, to develop demonstration software verification services for calculations implemented within its products, and then to use the verification services to assess the numerical performance of the implementations. The verification services are being made more widely available, while training undertaken during the project has facilitated the development of further verification services by the partners.

Need

Developers of software and programming tools need to have their products validated, i.e. to ensure that the products undertake the tasks for which they are intended and that they perform as expected. Increasingly, there is a requirement or desire for the validation of (components of) products to be undertaken by an independent organisation such as a National Measurement Institute (NMI). For software developers, independent validation will ensure the reputation of their products is maintained, and for software users, independent validation will provide greater reassurance on the quality of their applications.

A common approach when validating software that implements mathematical computations involves the use of reference pairs, comprising reference data and reference results. The software under test is applied to multiple reference data sets and for each reference pair, the test results are compared, in an appropriate way, with the corresponding reference results. The results of the comparison obtained for each reference pair can then be combined to provide the overall assessment of the software that is needed.

EMRP JRP NEW06 TraCIM developed a complete ICT infrastructure – the "TraCIM system" – which allows software to be validated online using reference pairs. The approach that underpins the TraCIM system is applicable to any mathematical software for which the use of reference pairs is appropriate. In order to validate software for implementing a particular computational aim, three steps need to be completed:

1. Reference data pairs need to be generated for the computational aim.
2. A software module (referred to as a "TraCIM client") needs to be written that allows the software under test to communicate with the TraCIM server using the internet, e.g., to request reference data, to send test results, etc.
3. A software module, referred to as an "expert extension" to the TraCIM server, needs to be written that implements the comparison of the test results with the reference results.

During EMRP JRP NEW06 TraCIM, as part of step 1, the partners developed reference pairs for specific calculations from the Length and Chemistry metrology domains as well as some common, more generic, calculations that occur within several metrology domains. Within EMRP JRP NEW06 TraCIM, the main focus was on the validation of software developed by manufacturers of coordinate measuring machines, such as for the fitting of geometric elements, e.g., spheres, cones, to data. For these calculations, the partners developed TraCIM clients and expert extensions, and a fully-operational validation system, along with extensive guidance on its use, was put in place.

National Instruments recognises the benefits to its own products, as well as to its customers who develop software using these products, that can be achieved through the use of the TraCIM system as a means of providing independent validation of mathematical software. Therefore, National Instruments is keen to adopt the TraCIM system.

The requirement for implementations of mathematical calculations to be validated applies to all developers of software and tools that undertake such calculations. The applicability of the TraCIM approach is therefore widespread and the TraCIM system is potentially of great use to many software companies.

The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

Objectives

The overall aim of this project was to allow both developers and users of software development and analysis tools to benefit from the outputs of the previous project, EMRP JRP NEW06 TraCIM, irrespective of the domain at which the tools are aimed.

In order to do this, two distinct types of TraCIM client need to be considered. The first type is referred to as a "standalone" client. A standalone client enables communication with the TraCIM server for software development and analysis tools that cannot connect to the server directly. Standalone clients are generally appropriate for developers of software development and analysis tools, who may be interested in undertaking validation of a function throughout the software development process. The second type of TraCIM client is referred to as an "integrated" client. An integrated client enables communication with the TraCIM server directly from within a software development and analysis tool. Integrated clients are generally appropriate for users of software development and analysis tools, including third-party software developers.

To meet the overall aim of the project, the specific objectives were:

1. To provide guidelines for developers of mathematical software development and analysis tools on how to use the TraCIM system to undertake independent validation of their mathematical functions by using standalone TraCIM clients. This mechanism will be demonstrated for a number of calculations implemented by "built-in" mathematical functions within products developed by National Instruments.
2. To provide guidelines for users of software development and analysis tools on how to use the TraCIM system to undertake independent validation of their mathematical functions by using integrated TraCIM clients. This mechanism will be demonstrated for a number of calculations implemented by "user-generated" mathematical functions developed using National Instruments products.

Results

Objective 1: To provide guidelines for developers of mathematical software development and analysis tools on how to use the TraCIM system to undertake independent validation of their mathematical functions by using standalone TraCIM clients. This mechanism will be demonstrated for a number of calculations implemented by "built-in" mathematical functions within products developed by National Instruments.

The partners, in conjunction with the primary supporter, selected three calculations for which demonstration software verification services would be made available:

1. Least squares fitting to data of the sum of an exponential decay function and a constant (short name "LSEXP").
2. Weighted least squares polynomial regression ("WLSPR").
3. Principal component analysis ("PCA").

These three calculations were selected for the following reasons:

- The calculations map directly to (built-in) calculations implemented within National Instruments software tools. All three are implemented within National Instruments product LabVIEW while calculations LSEXP and WLSPR can be implemented within National Instruments product DIAdem.
- The calculations are from different metrology areas. LSEXP is from chemical metrology, while both WLSPR and PCA can be classed as interdisciplinary, i.e. these two calculations are encountered in more than one metrology area.
- The input and output parameters of the calculations involve combinations of scalars, vectors and matrices.

For each calculation:

- Data generation software, developed within the EMRP JRP NEW06 TraCIM, was employed to generate twenty-five reference pairs to be used within a demonstration software verification service by the partners and the primary supporter. The reference pairs have different properties, e.g. they involve different numbers of data points, different levels of noise in the data, etc.

- An expert extension, a software component that allows reference results to be compared with results returned by the software under test, was developed.
- The expert extension was incorporated into the TraCIM server at NPL and the demonstration software verification service was made available to the partners and the primary supporter.
- A standalone TraCIM client, that allows the user of a software verification service to communicate with the TraCIM server using the internet, was developed. Although service users are free to develop clients for themselves in the language of their choice, this TraCIM client allows those who are unfamiliar with web communication and/or eXtensible Markup Language (XML) parsing to use the services without the need to undertake significant software development themselves.
- The standalone TraCIM client was successfully used to undertake verification of the implementation of the calculation in LabVIEW and, where appropriate, DIAdem (see below for more details).
- A user manual for the corresponding demonstration software verification service was written. The user manual is available to registered users of NPL TraCIM services and can be obtained by logging into the NPL TraCIM webshop (https://tracim.npl.co.uk).

The partners developed guidance material on the use of the TraCIM software verification services using standalone TraCIM clients and disseminated it to the primary supporter.

For calculations LSEXP and WLSPR, verification was undertaken for both LabVIEW and DIAdem implementations of those calculations. The process was repeated a number of times, varying (a) options (e.g. the tolerance value used when solving the fitting problem, the values of initial estimates assigned to a subset of the output parameters, etc.) that can be selected when using the implementations, and (b) the criteria used to compare test and reference results. For calculation PCA, verification was undertaken for the LabVIEW implementation of the calculation, with the process being repeated a number of times using different criteria to compare the test and reference results.

Objective 2: To provide guidelines for users of software development and analysis tools on how to use the TraCIM system to undertake independent validation of their mathematical functions by using integrated TraCIM clients. This mechanism will be demonstrated for a number of calculations implemented by "user-generated" mathematical functions developed using National Instruments products.

The partners selected a further three calculations for which demonstration software verification services would be made available:

- Least squares plane fitting (short name "LSPLANE").
- Generalised distance polynomial regression ("GDPR").
- Least squares 3D line fitting ("LS3DLINE").

The calculations were selected as they could be implemented by combining built-in VIs within National Instruments product LabVIEW.

- Data generation software, developed within the EMRP JRP NEW06 TraCIM, was employed to generate twenty-five sets of reference pairs to be used within a demonstration software verification service by the partners and the primary supporter. The reference pairs have different properties, e.g. they involve different numbers of data points, different levels of noise in the data, etc.
- An expert extension, a software component that allows reference results to be compared with results returned by the software under test, was developed.
- The expert extension was incorporated into the TraCIM server at NPL and the demonstration software verification service was made available to the partners and the primary supporter.
- A LabVIEW implementation of the calculation was developed.
- An integrated (into LabVIEW) TraCIM client, that allows the user of a software verification service to communicate with the TraCIM server using the internet, was developed. Although service users are free to develop clients for themselves, this TraCIM client allows those who are unfamiliar with web

communication and/or XML parsing in LabVIEW to use the services without the need to undertake significant software development themselves.

- The integrated TraCIM client was successfully used to undertake verification of the implementation of the calculation in LabVIEW (see below for more details).
- A user manual for the corresponding demonstration software verification service was written. The user manual is available to registered users of NPL TraCIM services and can be obtained by logging into the NPL TraCIM webshop (https://tracim.npl.co.uk).

The partners developed guidance material on the use of TraCIM software verification services using integrated TraCIM clients and disseminated it to the primary supporter.

For the GDPR calculation, verification was undertaken for the LabVIEW implementation of the calculation. The process was repeated a number of times, varying (a) the tolerance value used when solving the fitting problem, and (b) the criteria used to compare test and reference results. For calculations LSPLANE and LS3DLINE, verification was undertaken for the LabVIEW implementations of the calculations, with the process being repeated a number of times using different criteria to compare test and reference results.

Impact

This project built on the outputs of EMRP JRP NEW06 TraCIM, which was primarily concerned with the verification of metrology software, through the development of software verification services for additional calculations, the majority of which are also of interest beyond the metrology community. Following the end of TraCIM, PTB hosted a number of software verification services. A key outcome of ValTraC has been that additional software verification services are now being hosted by a second TraCIM partner, NPL.

Initial impact was achieved through the use of the first three ‘demonstration’ software verification services by the primary supporter. This indicated how the TraCIM approach can be used to verify calculations implemented in both LabVIEW and DIAdem. To maximise the impact for National Instruments, the standalone TraCIM clients were specifically developed to simplify the verification of calculations implemented in DIAdem i.e. American Standard Code for Information Interchange (ASCII) files were generated from, and written to, the XML files that are used for data exchange. The expert extensions were also developed to allow a subset of the output parameters to undergo testing. This functionality reflects the fact that not all of the output parameters, listed in the specification of the calculation (developed during EMRP JRP NEW06 TraCIM), are output by the calculations when implemented in LabVIEW and DIAdem.

An oral presentation was delivered at the British Computer Society (BCS) Software Quality Management Conference in April 2017. A corresponding paper was published in the conference proceedings. A further oral presentation took place at the Metromeet International Conference on Industrial Dimensional Metrology in March 2018 following successful submission of an abstract. An article on the TraCIM approach, discussing both standalone and integrated TraCIM clients was published in The Tester, the newsletter of the BCS Specialist Group in Software Testing. A case study on the use of the clients that were integrated into LabVIEW has been submitted to National Instruments. When published, it will be visible to users of National Instruments products.

For the primary supporter, additional impact could be achieved by sharing the outputs of Objective 2. LabVIEW provides facilities for both web communication and XML parsing, therefore it provides a perfect environment to develop integrated TraCIM clients, which will allow calculations to be straightforwardly implemented in LabVIEW. For the calculations considered in Objective 1, the partners have already integrated TraCIM clients into LabVIEW.

An important aspect of the project involved making available example TraCIM clients in both executable and source code forms. In particular, the availability of source code provides a valuable starting point for users of TraCIM software verification services to develop their own TraCIM clients in their preferred programming language.

Future impact has been ensured through the delivery during the project of training among the partners. In particular, the training on the development of expert extensions will prove to be vital for the provision of future software verification services. Indeed, NPL and PTB intend to develop and make further services available in the near future. They also intend to investigate the verification of calculations implemented in alternative software environments. The guidance material developed within the project will be extended, and, where

applicable, integrated TraCIM clients will be developed for those languages and made available to registered users of the NPL TraCIM system through the NPL TraCIM Webshop (https://tracim.npl.co.uk).

While not a requirement, a project website has been created to be populated with both the outputs of the project and material developed beyond the end of the project.

Overall, through the use of a small number of software verification services, the project has demonstrated to a major developer of software development and analysis tools the benefits of employing an alternative, independent means of ensuring the reliability of its products. Moving forward, increasing uptake of the TraCIM approach to mathematical software verification will help software developers to reduce (a) software development costs (for which the testing phase is often the most expensive), and (b) costs associated with the correction of errors in software.

<table>
<tr><td colspan="2">Project start date and duration:</td><td>1 July 2016, 18 months</td></tr>
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2. PTB, Germany</td><td>External Funded Partners:
3. Ostfalia-HAW, Germany</td><td>Unfunded Partners:</td></tr>
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