Publishable Summary for 17IND02 SmartCom
Communication and validation of smart data in IoT-networks

Overview

The goal of this project was to develop the basis for a secure, unambiguous and unified exchange of data in communication networks, where metrological data is used. To address this ambitious goal the SmartCom project developed a formal framework for the transmission of metrology data based on the SI (International System of Units), which is applicable to all metrology domains in the Internet of Things (IoT). The project also developed for the first time ever a concept that summarises the minimum requirements for the use of digital calibration certificates (DCCs). Further to this the project developed online validation services for the measurement data formats involved in the DCC concept as well as a secure online conformity assessment procedure for cloud system applications for legal metrology (UniTerm). The project then demonstrated the use of its outputs via 2 demonstrators; one on the use of DCCs and the other on the use of UniTerm in order to promote their uptake by end users.

Need

The Internet of Things (IoT) network provides the capability to communicate data within a network and data hubs. However, the value of that data depends on its ability to be interpreted correctly. For metrological data, the effective use of the data is only possible, if the unit of measurement and uncertainty associated with the numerical value, expressed in a standard format, are also available.

Cloud storage and services provide state-of-the-art capabilities to store data, but on their own provide little or no information on the origin of the data or how to interpret it correctly. Therefore, an essential component of a digitally-enabled metrology landscape for the IoT must be one that can meet the requirements of (i) calibration, (ii) traceability and (iii) legal metrology. Hence it needs the automatic and secure communication of all relevant elements of the data and metadata, in order to enable it's unambiguous and correct interpretation. However, the interoperability of metrology data is severely impaired if essential information is lost or corrupted and prior to the start of this protocols that addressed this did not exist.

The confusion, ambiguity and incorrect interpretation caused by missing metadata, diversity of units, etc., represents a significant risk for future investments in IoT technologies. If the IoT is to bring benefits to society, it must be based on well-engineered principles, including those derived from the metrological concepts of traceability, uncertainty and interoperability. Therefore, in order to avoid future losses of information and the consequential negative impact on decision-making, the exchange of metrological information (measurement results and associated information) must be securely and unambiguous defined for all measurement tasks.

Objectives

The overall goal of the project was to provide the methodological and technical foundation for an unambiguous, universal, safe and uniform communication of metrological data in the IoT. The specific objectives of the project were:

1. To define the requirements for a uniform, unambiguous and safe exchange format for measurement data and metrological information in an IoT network. The exchange format shall be based on the definition of SI units and meet central requirements from standards, guidelines and legal metrology.
2. To develop and establish secure DCC. This should include exchange formats for administrative information, data transfer, cryptographic requirements, authentication and digital signatures.

3. To develop an online validation for services system for the types of data format as addressed under objectives 1 and 2.
4. To develop a reliable, easy to use, validated and secure online conformity assessment procedure designed for cloud system applications for legal metrology. The online conformity assessment procedure should also be applicable for calibration services and provide compliance with current international and European standards.
5. To build and validate demonstrators involving running applications from industrial stakeholders, to facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain, standards developing organisations and end users, and to work towards a European platform for metrological calibration services.

Progress beyond the state of the art

The SmartCom project has gone beyond the state of the art by defining the requirements for a uniform, unambiguous and safe exchange format for measurement data and metrological information in an IoT network. The requirements are based on the definition of a metrological domain-independent exchange format which is founded on the internationally agreed SI. The project has made these requirements publicly available in a brochure describing a new machine-readable data representation based on such metrological standards and regulations.

Measurement results are communicated not only using SI units, but also using domain-specific units of measurement such as feet, rad, inch, weber, gallon, etc. While a BIPM brochure gives advice on how to specify derived units in the SI, this system is not sufficient for the automated data processing required in IoT, where information must be understood unambiguously and worldwide. Therefore, the SmartCom project defined a data exchange format where the expression of measurement results using SI units is mandatory, and optional information such as domain specific or derived units are included as additional information.

Furthermore, for the first time, the SmartCom data exchange format has provided relevant metadata for an unambiguous and comprehensive digital exchange of information on measurement uncertainty on the basis of requirements from the internationally-approved guideline GUM (Guide to the Expression of Uncertainty in Measurement). Measurement uncertainty can only be understood by machines correctly if all relevant metadata on the kind of uncertainty and its properties are stated in measurement data. Thus, the recommendations from the SmartCom data format could benefit existing data formats in the IoT where uncertainties are currently unconsidered or ambiguous. For example, the SmartCom data exchange format and state-of-the art formats such as the Semantic Sensor Network Ontology (SSN), the Request for Comments (RFC) 8428 (Sensor Measurement Lists) SenML and quantity data types in the Quantities, Units, Dimensions, and Types (QUDT) ontology have the potential to support each other with uncertainty statements.

Whilst the SmartCom project has provided the initial ideas for an unambiguous, universal and safe format for the digital exchange of metrology data based on the SI, it was clear right from the beginning of the project, that the long-term benefit needs an international initiative within the worldwide metrology community. The SmartCom project has initiated the momentum for a “Digital SI” internationally, which has led to the foundation of the International Conference on Weights and Measures (CIPM) Task Group on the “Digital-SI” in October 2019. The mission of this task group is to establish a world-wide agreed universal, reliable, unambiguous and safe format for metrological data based on the SI together with stakeholders from international quality infrastructures (e.g. ISO, IEC, Organisation Internationale de Métrologie Légale (OIML), International Laboratory Accreditation Cooperation (ILAC). In 2022 the international metrology community intends to make the joint development of a “Digital-SI” a key objective through their vote on a resolution for Digital Transformation based on the SI at the 27th General Conference on Weights and Measures, as well as Joint Statement from the organisations involved.

The exchange of printed calibration certificates or encrypted PDF/A (standardised by ISO) is still the current state of the art in metrology, but their use is not widespread in legal metrology. Automated processing of the information included is also not possible. Therefore, another important goal of the SmartCom project was to develop and provide the basis for machine-readable calibration certificates, to be used in worldwide communication of calibration information. This project addressed this by developing a guideline for (i) a

universal and flexible structure for DCCs based on ISO 17025 requirements for reporting calibration results and (ii) specifying rules for the secure use of DCCs in legal aspects of metrology.

At the European level, the Swiss NMI METAS is currently developing PDF/A based calibration certificates in line with the basic requirements defined by the SmartCom project. In addition, EURAMET TC 1448 “Development of digital calibration certificates” (in which the consortia are members) will develop interfaces between different DCC approaches (Extensible Markup Language (XML)-based, PDF/A). Internationally, the National Conference of Standards Laboratories International (NCSLI) Measurement Information Infrastructure (MII) is currently developing DCC formats based on PDF/A. However, the underlying approaches used for XML representation of the calibration data is not yet fully aligned with ISO 17025.

Validation of the usefulness of measurement data and its ability to be interpreted correctly by software is vital for DCCs as they rely on and foster extensive machine-to-machine communication. Whilst the importance of the validation and certification of evaluation algorithms with comparable standards has been recognised in the quality infrastructure for more than 20 years, the validation of the quality of the data exchange has received little consideration. Recently, projects such as GEMIMEG II “Safe and robust calibrated measurement systems for digital transformation" (the DCC main concept as well as metadata formats developed in this project was used by the GEMIMEG II project for further development) are highlighting the role of addressing the quality of data. One step towards ensuring the quality of data was made by the SmartCom project by developing an online validation service for checking the conformity of data implemented in XML with the data format developed in the SmartCom project. This means that end users can now, for the first time, upload their XML data - e.g. DCCs - and in return receive a certificate stating to what extent the requirements of the exchange format and the representation of SI units are met.

Results

Objective 1: To define the requirements for a uniform, unambiguous and safe exchange format for measurement data and metrological information in an IoT network. The exchange format shall be based on the definition of SI units and meet central requirements from standards, guidelines and legal metrology

The project defined the requirements for a uniform, unambiguous and safe exchange format for measurement data and metrological information in an IoT network and used them to produce a brochure entitled “SmartCom Digital System of Units (D-SI) Guide for the use of the metadata-format used in metrology for the easy-to-use, safe, harmonised and unambiguous digital transfer of metrological data”. The brochure describes a new machine-readable data representation based on metrological standards and regulations such as the GUM, International vocabulary of basic and general terms in metrology (VIM) and BIPM SI-brochure and has been made publicly available in English https://doi.org/10.5281/zenodo.3816686 and Chinese https://doi.org/10.5281/zenodo.4003413.

The brochure covers real, complex and vector quantities as well as formats for fundamental constants, and was optimised and updated during the course of the project. The description of the data format (in the brochure) is accompanied by a realisation of it in XML, making it more useable for stakeholders. Further to this, a shorter and more end user focussed ‘catchy’ version of the digital SI format was developed as a digital brochure.

Using the XML realisations of the data format, fundamental physical constants from the Committee on Data of the International Science Council (CODATA) have been implemented in a machine-readable format and have been made available to end users online by partner PTB (https://doi.org/10.5281/zenodo.3689263). This dataset has been downloaded more than 49 times already and provides end users in the scientific and technological communities with a self-consistent set of internationally recommended values of the basic constants and conversion factors of physics and chemistry.

Objective 2: To develop and establish secure DCC. This should include exchange formats for administrative information, data transfer, cryptographic requirements, authentication and digital signatures.

The SmartCom project developed a concept for a DCC based on the requirements in ISO 17025 Testing and Calibration Laboratories for reporting calibration results. The DCC concept is available for stakeholders and can be accessed via a GitLab repository at https://gitlab1.ptb.de/dcc-working-group/xsd-dcc

The structure for the DCC concept consists of (i) administrative (core) data, (ii) measurement data, (iii) comments and a (vi) human readable part. The DCC structure was designed with stakeholder useability in mind. The applicability of the developed DCC concept was proven for industry by industrial project partners Sartorius and Zeiss who were able to implement their first DCCs following proposed structure. The DCC structure was summarised in a *"Document describing a universal and flexible structure for digital calibration certificates (DCC)"* available at https://doi.org/10.5281/zenodo.3696567

A second document describing the rules for the usage of the DCC, *"Document specifying rules for the secure use of DCC covering legal aspects of metrology"* is also available at https://doi.org/10.5281/zenodo.3664211. This document describing the rules for the usage of the DCC, covers cryptographic standards and software tools which fulfil the legal requirements for the trustworthy transmission of DCCs, e.g., protecting integrity or authentication the origin, as well as overall rules for issuing and the withdrawal of DCCs.

Finally, the first machine-readable DCCs in XML format based on the outcomes of the SmartCom project have been developed by PTB, Sartorius, Zeiss and Aalto (see also Objective 5).

Objective 3: To develop an online validation for services system for the types of data format as addressed under objectives 1 and 2.

Online validation is a tool currently used in metrology. For example, test data for the validation of Gaussian or Chebyshev calculations or for the determination of the comparability of measurement results already exist and are available as part of the TraCIM ("Traceability for Computationally-Intensive Metrology") platform. TraCIM is a service run at PTB based on the outcome of a previous EMRP project NEW06. The validation of software versions by use of check sums is also well established and described, for example, in WELMEC (European Cooperation in legal metrology) Guide 7.2 Measuring Instruments Directive 2004/22/EC. However, the SmartCom project has gone beyond this by developing two novel modules for the validation of SI-based data formats and DCCs. These modules were implemented and are now available to industry via an update to the established TraCIM platform at PTB.

The updated TraCIM system provides stakeholders with the ability to validate data implemented in XML and uses the requirements for the XML data determined in objectives 1 & 2: i.e., the general data exchange metadata format and the implementation of the DCC concept. The updated TraCIM system was also presented to stakeholders, such as the project GEMIMEG II and is available to interested parties at smartcom@ptb.de following confirmation by the project consortium.

Objective 4: To develop a reliable, easy to use, validated and secure online conformity assessment procedure designed for cloud system applications for legal metrology. The exchange format shall be based on the definition of SI units and meet central requirements from standards, guidelines and legal metrology.

The current legal requirements for technology supporting legal metrology do not cover the communication of legal instruments over an intranet or internet. With the advent of the IoT and Industry 4.0, future legal metrology activities will be able to operate within and over such networks as well as connecting to cloud-based computer services. These services could also include remote access interfaces to legal metrology instruments with the potential to calibrate and update devices without the need to physically "visit" the instrument.

Following discussions with stakeholders from the weighing industry (partners Sartorius and Mettler-Toledo), it was decided that the EU Document of Conformity (EU DoC) following the EU Non-automatic weighing instruments (NAWI) Directive 2014/31/EU was the most relevant process for conversion into an XML based, cloud service, digital form. As a first step towards the development of "online" legal metrology, the SmartCom project considered a typical example of legal metrology information that must be communicated safely and securely between relevant stakeholders before placing a new measurement instrument on the EU market i.e. the EU DoC requirements for the formal acceptance of a new product in the EU.

To enable digital online conformity assessment, a browser-based user interface, UniTerm, was developed by the project. The UniTerm interface enables the user to complete a form with required information for an object and subsequently generates an XML version of the EU DoC. The UniTerm interface is connected to a central service hub located on the service-oriented architecture (SOA) platform of the German Federal Ministry of

Education and Research (BMBF) and the European Social Fund (ESF) project AnGeWaNt (Work on calibrated scales for hybrid weighing services on commercial vehicles, https://www.angewant.de/messwesen/), where the validation, storage and distribution of the data is managed. The SOA of the AnGeWaNt project was chosen due to its modular structure, enabling a rapid service prototyping. Additionally, to increase flexibility and ease later expandability, the platform employs standardized and harmonized interfaces across all services. A more detailed description of the interface and service can be found in the project's "Guideline describing the concept of UniTerm and how to establish secure communication interfaces in legal metrology" at https://doi.org/10.5281/zenodo.5121620

Objective 5: To build and validate demonstrators involving running applications from industrial stakeholders, to facilitate the take up of the technology and measurement infrastructure developed in the project.

The project produced two demonstrators to facilitate the take up of the project's outputs (Objectives 1-4).

1. The first demonstrator showcased Objectives 1 & 2 and the use of DCC, Digital SI (D-SI) and appropriate cryptographical methods such as digital signatures and Distributed Ledger Technology (DLT), a.k.a. a blockchain, for the secure exchange of measurement data and relevant metadata. The DCC demonstrator used a system for the secure exchange of mass and position data of containers in harbours as a part of a logistics chain. The DCC demonstrator's approach for ensuring the security and trustworthiness of the data included two aspects. Firstly, the correct representation and traceability of the measurement data, and the reliability of the devices used to collect the data were ensured using the D-SI and DCCs. The validation of the metrological data was performed with the TraCIM system, from Objective 3. Secondly, the integrity and authenticity of the data was ensured using digital signatures whilst the database was protected against subsequent adding, removing, or replacing of data files by using IOTA. IOTA is the distributed ledger system developed to handle transactions between connected devices in IoT. Further details on the demonstrator on DCC use are in a "Report on the validation of a demonstrator for the exchange of dimensional measurements in an end user application, with a secure logistic data chain including DCCs" available at https://zenodo.org/record/5522855
2. The second demonstrator showcased the use of the UniTerm application developed in Objective 4. Based on a basic version of the EU DoC for the weighing industry, the UniTerm demonstrator showed how, in principle, legal metrology information can be shared and processed in a local, or wide area network environment. A graphical user interface (GUI) provided the different functionality that instrument manufacturers and their users require in order to work with the digital EU DoC. The UniTerm demonstrator software can be run locally on a computer or any other interned connected device, as the GUI is executed within a web-browser. The GUI provides the 'button' to manually create a new EU DoC which, subsequently, is converted into a machine-readable XML file. The process is supported by automated notifications to help prevent incomplete or wrong content by users. A simple Drag-and-Drop mechanism for pre-prepared XML files is provided as well. The up- and download of the digital EU DoC to the could UniTerm platform is controlled using a unique ID and uploaded XML files are validated against an XML Schema Definition (XSD). The partners from industry (Sartorius and Mettler-Toledo) tested the UniTerm platform and suggested improvements in terms of input automatisation and integration of the application with the instrument manufacturing system. The functionality of the developed UniTerm demonstrator is described in a "Report on the validation of a demonstrator for the use of UniTerm in the legal weighing industry" at https://zenodo.org/record/5527050

Impact

The project has attracted significant interest from metrological organisations, academia and industry and its promotion to the CIPM of D-SI units for the communication of metrological data has led to the foundation of the CIPM Task Group "Digital-SI" which is pursuing the future harmonisation of SI units in digital applications.

The project has produced 5 publications which are either published or approved and waiting for publication and has been presented 17 times at national and international conferences such as CIM 2019, Euspen

International Conference 2020, the 2021 CIPM/BIPM workshop on the International System of Units in FAIR Digital Data and the 1st Internationale DCC Conference.

The consortia have also published 4 articles in professional journals from their attendance at the 2020 Global Internet of Things Summit (GIoTS), 2020 IEEE International Workshop on Metrology for Industry 4.0 & IoT and International Conference on Industry 4.0 and Smart Manufacturing.

Further to this, the project has published 4 Good Practice Guides on its developed 'Digital System of Units – D-SI Guide for the use of the metadata-format used in metrology for the easy-to-use, safe, harmonised and unambiguous digital transfer of metrological data' and 'D-SI in Short - Digital brochure on establishing the use of units in digitised communication' (both Objective 1).

Finally, the project outcomes were presented to a broad international audience at a final project workshop in association with EUROLAB on 'Metrology for Digital Transformation'. The consortia provided the main content for one of three workshop sessions 'Digital processes in the quality infrastructure: the digital calibration certificate' and chaired the subsequent Q&A session. The joint EURAMET and EUROLAB workshop was held in September 2021 and attracted over 600 participants worldwide from a wide range of organisations and institutions including: NMIs and DIs; Accreditation organisations; calibration laboratory's members organisations; OIML and WELMEC.

Impact on industrial and other user communities

The project has shown end users from industry how its DCC demonstrator can provide the secure exchange of mass and position data for containers in harbours as a part of a logistics chain. Partner, Aalto's smart overhead crane and its digital twin were used as a platform to build a secure data chain including DCCs of critical component logistics from the manufacturer to end users at harbour site and to the respective authorities. The demonstrator was then validated with support from the project's industrial partners Zeiss, Hexagon, Mettler-Toledo and Sartorius.

The Finnish company Beamax who provide smart calibration instruments for use in industry, plans to implement a commercial product based on the project's DCC with high usability for laboratories in the pharmaceuticals industry. The exploitation is progressed and supported with help from parter Aalto. Another example of impact on industrial users is the German start-up company labfolder, which plans to implement an electronic laboratory folder software product for metrology end-users that uses the metadata format (objective 1) and the DCC for representing and exchanging measurement data.

The SmartCom project's concept of a uniform and globally available communication protocol (objective 1) is highly valuable for industry and calibration services. In demonstration of this the European weighing industry invited the SmartCom project to their annual meeting in 2018 to obtain information on how it's stakeholders could benefit from the project's results. In addition, partner PTB was invited to disseminate the SmartCom concepts multiple times to the German Mechanical Engineering Industry Association (VDMA) and the Association of German Engineers (VDI), where the project's DCC concept was identified as an essential part of future metrological infrastructures.

The project has worked with stakeholders from industry and other end user communities throughout its lifetime in order to ensure that its results are applicable to end users. The project's stakeholder advisory board (which was joint with EMPIR project 17IND12) has included input from end users such as ABB Forschungszentrum Deutschland, Hottinger Baldwin Messtechnik GmbH, Instituto de Engenharia de Sistemas e Computadores - Microsistemas e Nanotecnologias (INESC-MN), MESAP Innovation Cluster "Smart Products and Manufacturing", University of Sarajevo Faculty of Mechanical Engineering, VDI/VDE Society Measurement and Automatic Control, Myna-Project.org s.r.l., Spektra Schwingungstechnik und Akustik GmbH Dresden and TNO (NL).

The validation system (objective 3) for establishing a long-term available online service will enable industry to get certification on the usage of the D-SI metadata format (objective 1). A prototypical setup of this service has been established on a web server hosted by partner Ostfalia HAW. A full online service from PTB is planned for public release in 2022.

Impact on the metrology and scientific communities

The SmartCom project will support and facilitate the metrology and scientific communities in the set-up and use of new services based on the provision of DCCs and automatic extraction of calibration values. The project will also support European NMIs in taking a leading role in providing quality-assured metrology information for Industry 4.0 and the IoT ecosystem.

To disseminate the project to the metrology and scientific communities, it has been presented at CIPM and to regional metrology organisations such as Euro-Asian cooperation of national metrological institutions (COOMET), Inter-American Metrology System (SIM) and Asia Pacific Metrology Programme (APMP).

The SmartCom project's second demonstrator was also used to showcase to the legal metrology community the use of the UniTerm application developed in Objective 4. The UniTerm demonstrator showed how the legal weighing industry can use UniTerm in future technologies such as cloud applications, distributed systems and smart technologies, in order to support the launch of innovative products faster. The demonstrator was validated by partners PTB, Taltech, Sartorius, Mettler-Toledo and Ostfalia-HAW.

Further to this, first versions of the DCCs based on the SmartCom project's definitions are being currently being tested by the GEMIMEG II project (https://www.gemimeg.ptb.de/startseite/). The GEMIMEG II project which is funded by the German government and started in August 2020, is focussed on the establishment of a national quality infrastructure, in which the quality of acquired data and the reliability of the statements and conclusions derived from them are guaranteed.

The SmartCom project has worked closely with the related EMPIR project 17IND12 Metrology for the factory of the future (Met4FoF). This has ensured that related results from both projects can be shared and used effectively and in order to prevent the duplication of work within the metrological community. The successful collaboration between the SmartCom and Met4FoF projects has resulted in the joint definition of demonstrators within the 17IND12 project – one for the use of the OPC-UA communication standard and one for use in MEMS testing. In the latter, a basic version of the DCC for temperature (adopted within the SmartCom project for INRiM's use case) and was used by the 17IND12 Met4FoF project, for the calibration of their MEMS service. Within the automated equipment testing system in the MEMS service, this basic DCC enabled the traceability of units and further development is planned by 17IND12 partner INRiM in collaboration with the GEMIMEG II project.

Finally, the SmartCom project has disseminated it's results to the metrology and scientific communities via training course and workshops, including a DCC workshop and training course on the development of digital calibration certificates within the SmartCom project in 2019, SmartCom DCC Netinar in 2020 and a EURAMET online session: Digital processes in the quality infrastructure: the digital calibration certificate in 2021.

Impact on relevant standards

The project's promotion of SI units for digital communication of metrological data at the International Committee for Weights and Measures (CIPM) led to the foundation of the CIPM Task Group "Digital-SI" which is pursuing the future harmonisation of SI units in digital applications. The German Calibration Service (Deutscher Kalibrierdienst, DKD) has also picked up the project's DCC concept and is now in discussions about how to establish their format for the mass and weighing industry.

In addition to this, the SmartCom project has been presented to the Open Platform Communications United Architecture OPC-UA working group and to the FIWARE foundation. FIWARE provides the future open-source eco-system for a majority of IoT applications and is part of the EU's rolling plan for the ICT standardisation.

Furthermore, the project's outcomes were dissemination to CECIP (the European Weighing Industry Association), EURAMET TC-IM 1448, EURAMET TC-IM 1449, EURAMET TC-L, British accreditation body UKAS, and German accreditation body DAkkS, Though EURAMET TC-IM 1448, the project's DCC concept of was also highlighted to the OIML, the international organisation for legal metrology.

Finally, the project's results were presented to ISO TC 213 10 ("Dimensional and geometrical product specifications and verification"), ISO TC 69 ("Applications of statistical methods"). DIN NATG ("standards committee technical bases"), the PSK (Finnish) Standards Association and VDI/VDE GMA 7.21 ("Industrie

4.0"). A presentation on the project was also given at the VDI/VDE GMA 3.31 ("coordinate measuring machines") annual meeting in October 2021.

Longer-term economic, social and environmental impacts

A long-term economic benefit for future markets involved in the IoT can be realised by the adoption of secure, unambiguous and uniform communication specifications for the exchange of data in communication networks, where metrological data is used. As developed by this project, such secure, unambiguous and unified communications should result in shorter timespans from product to market, reduced downtimes, fewer rejected parts, improvements in quality control, better organised maintenance, and better conservation of energy and resources. An example of end users who will benefit from the application of such data exchange systems are goods transporters particularly via harbours and containers. Since July 2016 the International Convention for the Safety of Life at Sea (SOLAS) has required the Verified Gross Mass of all containers to be delivered to the vessel carrier (as it is needed for the stowage plan of the vessel to optimise the ship's stability). The project's DCC demonstrator using a smart overhead crane (at partner Aalto) with secure exchange of mass and position data of containers in harbours as a part of a logistics chain, and hence a more equal weight distribution on container ships shows the potential long-term benefits.

Another long-term impact of the project is the increased confidence that organisations will gain by being able to exchange measurement information digitally, safe in the knowledge that the necessary metadata relating to units and uncertainties have also been exchanged using validated protocols. The long-term benefit of this will be a significant decrease in financial and societal risks resulting from the misinterpretation of data.

List of publications

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3. Mustapää, T.; Nikander, P.; Hutzschenreuter, D.; Viitala, R. "Metrological Challenges in Collaborative Sensing: Applicability of Digital Calibration Certificates," Sensors 2020, 20, 4730, doi: 10.3390/s20174730
4. Hutzschenreuter, D.; Müller, B.; Loewe, J. H.; Klobucar, R. "Validation of SI-based Digital Data of Measurement using the TraCIM System", Journal of Sensors and Sensor Systems 2021, 10 (2), pp. 289-295, https://jsss.copernicus.org/articles/10/289/2021/

This list is also available here: https://www.euramet.org/repository/research-publications-repository-link/

Project start date and duration:		June 2018, 40 months
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Internal Funded Partners: 1 PTB, Germany 2 CMI, Czech Republic 3 NPL, United Kingdom 4 UM, Slovenia	External Funded Partners: 5 Aalto, Finland 6 Ostfalia-HAW, Germany 7 Taltech, Estonia 8 UNICAS, Italy	Unfunded Partners: 9 Hexagon, Germany 10 KRISS, Korea, Republic of 11 Mitutoyo, Germany 12 Mettler-Toledo, Switzerland 13 NIM, China 14 Sartorius, Germany 15 Zeiss, Germany
RMG 1: UM, Republic of Slovenia (Employing organisation); PTB, Germany (Guestworking organisation)		