CIA-CT

Project Newsletter
November 2009 - NR 1

Center for Industrial Application of CT scanning

EDITORS' NOTE

Dear reader,
welcome to the first issue of our six-monthly newsletter about the CIA-CT project! This first issue contains an introduction to the project, with topics, objectives and involved partners. From the next newsletter, which will be published in May 2010, we will be more specific and detailed with contents and events regarding the world of CT scanning, together with short presentations of the partners and featured articles by the partners. In this issue you can read a first contribution by DTU Mechanical Engineering, presented at the European Society for Precision Engineering and Nanotechnology International Conference in 2009, concerning the production of a replica artefact for the verification of optical scanners and CT scanners.

We hope that you can enjoy the contents.

Greetings

The Editors

INTRODUCTION

The "Center for Industrial Application of CT scanning - CIA CT" is an innovation consortium co-financed by the Ministry of Science Technology and Innovation. The project focuses on the industrial application of CT scanning for advanced 3D measurement, quality assurance and product development. The consortium acts as a national competence center for industrial CT scanning through a number of research activities and initiatives.

The project aims to helping the participating companies and Danish industry with the introduction of CT scanning as measuring technology along with research at international level.

CONSORTIUM AND NETWORK

The consortium consists of nine partners: DTU Mechanical Engineering, Department of Computer Science – Copenhagen University, Niels Bohr Institute – Copenhagen University, IPU, Technological Institute, Novo Nordisk, Danish Meat Research Institute, Yxlon and Deformalyze.

A network has been created around the nine partners. The following companies have already expressed specific interest to follow the consortium activities on CT scanning: 3Shape, Bygge- og Miljøteknik, Danish Crown, Danish Construction Association, Dansk Sintermetal, Grundfos, Haldor Topsøe, InnospeXion, Kirkholm, Lego, Noliac, Rockwool, Struers, Tican, Trelleborg, Zebicon, and others.

RESEARCH PLAN

The project has started on the 1st of September 2009 and will run over 4 years. An overall work plan, with the specific projects, is reproduced in the table below.

		Companies			
		Medico	Food	Equipment	Software
PROJECTS	1) CT scanning for coordinate metrology				
	2) Data processing for high speed scanning				
	3) New beam source and signal conditioning				
	4) Equipment with high stability beam source				
	5) Quality assurance and automation				

Project 1 “CT scanning for coordinate metrology” is focused on procedures for metrological use of CT scanning for geometrical measurements on different objects in different materials; Project 2 “Data processing for high speed data” is devoted to implementing methods and software for processing and post-processing of data from CT scanning; Project 3 “New beam source and signal conditioning” deals with new contrast mechanisms and filter tools for a better characterization of microstructure

in scanned items; Project 4 “Equipment with high stability beam source” deals with the optimization of the X-ray stability; Project 5 “Quality assurance and automation” is aimed at developing methods, software and automatic tools for ensuring and measuring quality in production.

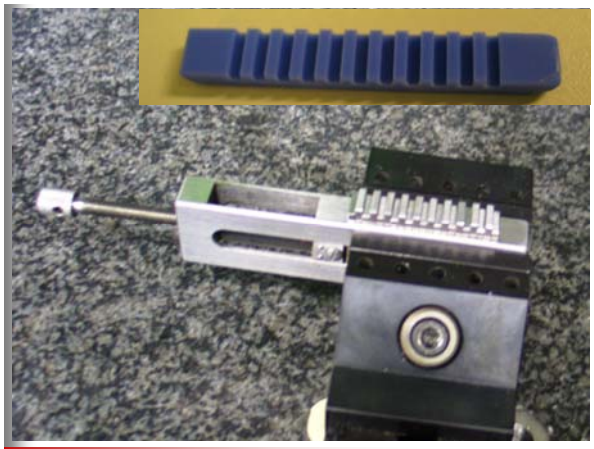
Several dissemination activities are planned: project webpage, a conference to be held each year in June, newsletters to be published in May and November.

The kick-off meeting of the consortium took place at DTU on the 29th of September 2009 The nine partners were represented by 33 participants.

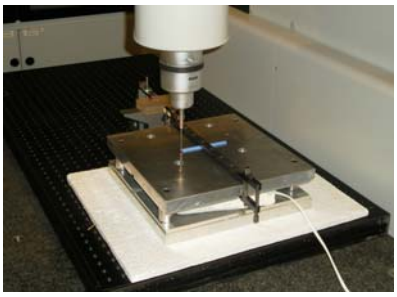
FEATURED ARTICLE

Replica calibration artefacts for optical 3D scanning of micro parts

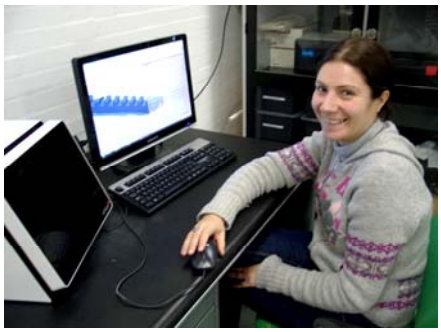
L. De Chiffre, S. Carmignato, A. Cantatore, J. D. Jensen

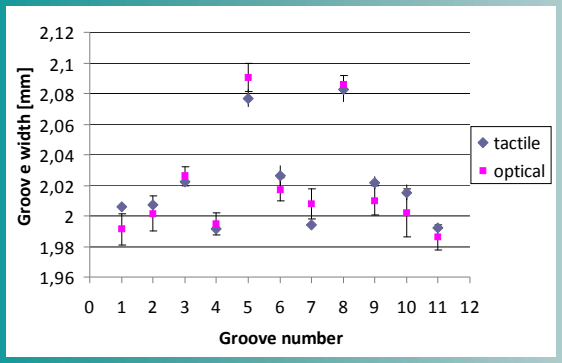


The proposed idea is to fabricate calibration artefacts for optical scanners by using hard replica materials, achieving high quality geometrical reproduction of suitable reference artefacts, high stability, and high surface cooperativeness. A preliminary investigation was carried out using a bisacryl material for dental applications (Luxabite) to reproduce the geometry of a number of artefacts. E. g., a 40mm miniature step gauge was produced by assembling 21 gauge blocks with 2mm reference length and thereafter used as a mould to fabricate a replica step gauge with 11 grooves.



Replication quality and applicability of artefacts to verify the accuracy of optical measurements as well as thermal expansion coefficient and stability of the replica material over time were documented. The replica artefacts were calibrated using a tactile coordinate measuring machine and measured by optical 3D scanning.





Measurements of the replica step gauge single steps using tactile CMM and optical scanner were compared. A measuring uncertainty (k=2) of 10µm was calculated for CMM measurements and 12µm for scanner measurements. The agreement between tactile and optical measurements is adequate, indicating a good applicability of the replica artefact to verify the optical scanner.

Reference:

L. De Chiffre, S. Carmignato, A. Cantatore, J. D. Jensen, “Replica calibration artefacts for optical 3D scanning of micro parts”, Proceedings of the Euspen International Conference – San Sebastian - June 2009, pp. 352-355

CIA-CT Newsletter
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Department of Computer Science – Copenhagen University

Niels Bohr Institute – Copenhagen University

IPU

Technological Institute

Novo Nordisk

Danish Meat Research Institute

Yxlon

Deformalyze

Project website: www.cia-ct.mek.dtu.dk

CIA-CT

Project Newsletter
May 2010 - NR 2

Center for Industrial Application of CT scanning

EDITORS' NOTE

Dear reader,
Welcome to the second issue of our six-monthly newsletter about the CIA-CT project! The first issue, published in November 2009, was mainly addressed to provide a general overview of the project, with topics, objectives and involved partners. From this issue on, we will be more specific and detailed with contents and events regarding the world of CT scanning. In this issue you can read about the second Consortium meeting held at DMRI in March 2010 and all relevant events occurred that day (as the visit to DMRI "Scannerborg" and a seminar carried out by DMRI, concerning high capacity CT scanning in industry). At last we start being acquainted with the single project partners. This number is dedicated to present Deformalyze. We also invite you to attend our Conference on " Application of CT scanning in industry", which will be held at DTU the 8th of June. The detailed program is shown at the end of the newsletter.
The third number will be distributed in November 2010.

We hope that you can enjoy the contents.

Greetings

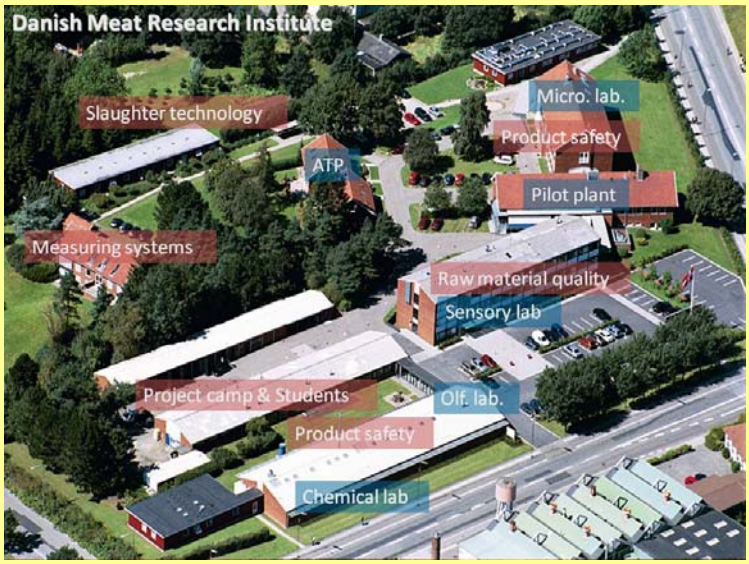
The Editors

RELEVANT EVENTS

The second Consortium meeting held at DMRI (http://www.teknologisk.dk/dmri) on March 18, 2010 and was focused on the detailed description of workpackages and progress reports registered in the first months of activity.

The meeting was attended by 23 people from the Consortium and by Jan Windmüller, from the Ministry of Science, Technology and Innovation.

An interesting part after the meeting was the visit to DMRI Mobile CT Scanning. The mobile unit, baptized “Scannerborg”, was originally donated by Norma & Frode S. Jacobsen Fund in 2004. An X-ray CT scanner (GE CTi/Performix tube) is used to scan pig carcasses and meat products. “Scannerborg” can be attached directly to the slaughterhouses. As an important data validation issue, the “virtual weight” is compared to the real weight of the scanned piece of meat just after the scanning.



The Danish Meat Research Institute is situated in a nice environment Roskilde. It became part of the Danish Technological Institute from October 1, 2009

DMRI Mobile CT Scanning “Scannerborg”

SEMINAR ON “HIGH CAPACITY CT”

Another event that took place at the second consortium meeting was the seminar held by DMRI with the title “High capacity CT”. Lars Bager Christensen, Marchen Hviid and Claus Borggaard introduced a project supported by Højteknologifonden and involving other Danish companies, expert in X-ray and CT scanning, towards the development of an online X-ray system for measuring meat-fat-distribution in pig carcasses or pieces. By measuring the distribution of meat, fat and bones in pork middles, it is possible to adapt the cutting according to current market prices. During the last years, the need for advanced measuring technology for flexible, automated production has increased in Denmark and other high cost countries. At the same time, the necessary technological development has become available and therefore the time is ideal for establishing a CT concept for future industrial production purposes. Preliminary studies have demonstrated potentials and realistic solutions, but have also clarified the extent and complexity of the challenge and risks. A CT scanner for online use in production is new and makes a decisive break with the normal understanding of CT technology, its use, speed and limitations.

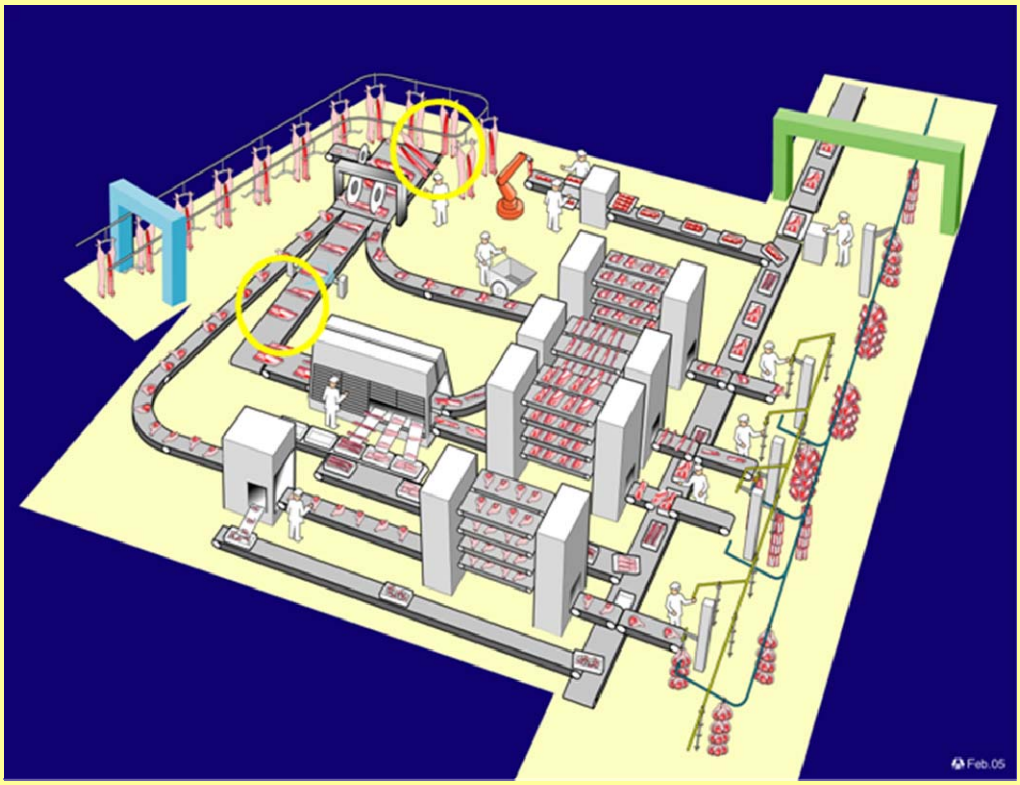
The lead in quality for Danish pork export is under tremendous pressure. Until now, automated production lines have been able to compensate high Danish wages, but increased market demands for product differentiation are an escalating challenge for the high-efficient Danish export industry. The CT scanner will improve the existing facilities to optimize and adjust the cutting of each individual carcass, according to current prices, quality demands and orders. After completion, the project partners will install the CT scanner at relevant Danish pig slaughterhouses. The CT scanner will also be tested on applications within the nearby areas, such as cheese production and cutting of beef and lamb.

The main criterion of success for the project is to implement a robust and cost-effective CT scanner, which can measure online under the environmental conditions and capacity requirements that can be found at the cutting line at a Danish pig slaughterhouse. Measurements should result in the spatial distribution of meat, fat

and bones and deliver an optimal recipe for automatic cutting of pork middles resulting in a return of investment for the slaughterhouse less than 12 month. The CT scanners self-diagnostic and reporting capability generate a detailed operational status including function control.
The main objective is to design an On-line CT-scanner characterized by

- High capacity i.e able to measure 700 pork middles/hour;
- Cost effective corresponding to 12 month return of investment for the slaughterhouse;
- A flexible platform for a broad range of applications.

In a long term perspective the knowhow acquired from this project could be combined with micro-CT, opening up for a completely new field of industrial applications within quality control of high-value products in medical devices.

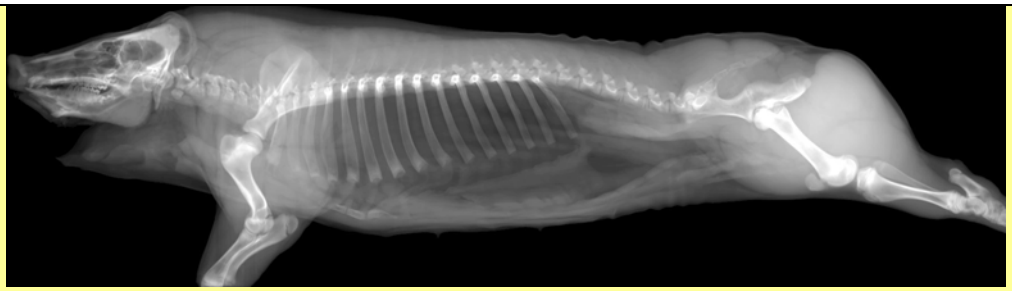


The figure shows the cutting line on a slaughterhouse. The yellow circles indicate possible places for on-line CT

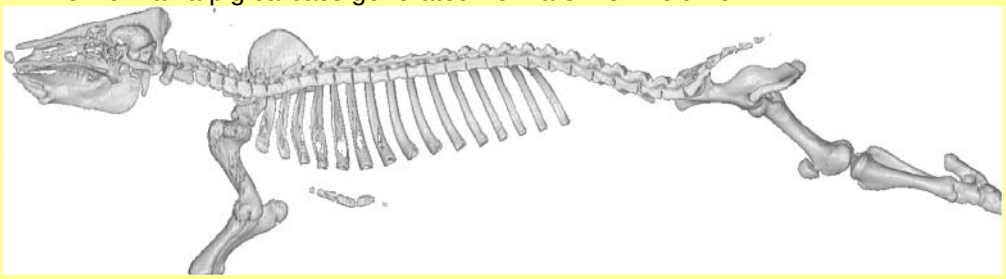
MEETING WITH DEFORMALYZE

Deformalyze provides consulting services and delivers solutions for automated data analysis focusing on industrial applications of CT. Typically a vast amount of data is acquired from CT and it is the analysis and interpretation of such data that Deformalyze is an expert in.

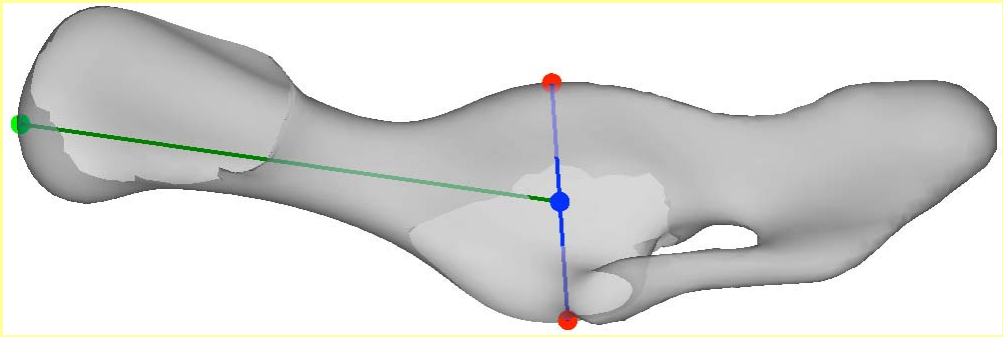
Population-based studies i.e. statistical analyses on composition, shape or specific measurements of a population of scanned objects are typical tasks that provide important insight otherwise unavailable. Building models of a whole population of objects via CT-scanning enables relating population-based insight to a new specific object of interest. This is a very strong tool e.g. for quality or process control.



2D-view of half a pig carcass generated from a 3D CT volume



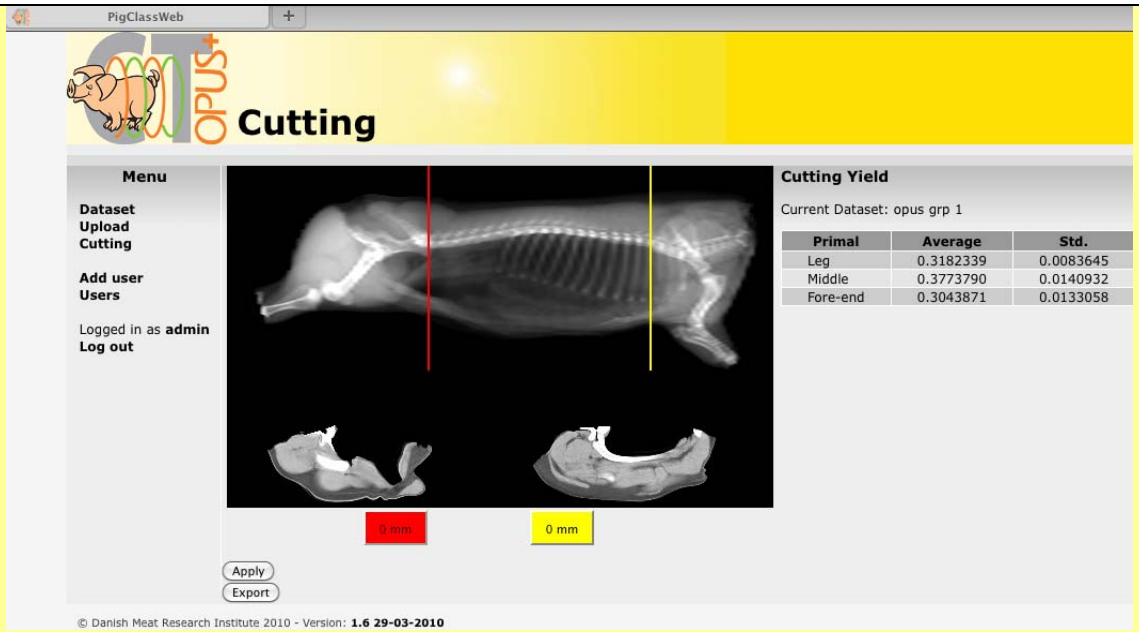
Extracted 3D-surface of skeleton



Statistical model of the pelvic bone made from a population of scans. Measurements can be done in the model, reflecting the variation in the population

Deformalyze is a young and dynamic company, based on 6 years of scientific work at phd-level at DTU Informatics, Technical University of Denmark, in collaboration with the Danish Meat Research Institute. Through this collaboration Deformalyze has gained invaluable knowledge in handling, analyzing and interpreting CT-data for the slaughterhouse industry in Denmark.

Deformalyze has developed and implemented a complete system coined "PigClassWeb", for handling the large amounts of CT-scans acquired by the DMRI in R&D projects. Through advanced image analysis PigClassWeb enables DMRI and the slaughterhouses to perform virtual cuts in a reference pig. These cuts are automatically propagated to the whole population of pigs that are scanned, in such a way that the virtual cuts are anatomically similar for each carcass, irrespective of size, weight and proportions. The ability to very accurately estimate the weight of arbitrary cuts enables Deformalyze to report the yields of the cuts on the population as a whole, as well as on each scanned carcass. The user can access the application through a simple web-browser, adjust the settings of a specific cut through a view of the scanned reference carcass. For the simpler type of cuts the results are ready within seconds, when applying the cut on the whole population. PigClassWeb is scalable in the sense that future scans automatically are processed and included in the "Population of Virtual Pigs". New types of cuts are currently in the pipeline to be included in PigClassWeb keeping it up-to-date and making it a very flexible tool for DMRI in R&D and for the slaughterhouses in the planning of the production.



Screenshot of the PigClassWeb application for applying virtual cuts and computing yields on a population of scanned pig carcasses

The name Deformalyze is a contraction of “deformable body analysis” which is a core competence of the company. Deformable bodies include objects fully or partly comprised by soft tissue types, e.g. biological tissue. Through a close professional network including both academia and industry, Deformalyze keeps updated with advances in cutting-edge methodologies within its fields of research. This enables fast decision-making on how to solve each new challenge appropriately and efficiently. More information can be found on the company website: www.deformalyze.com

Martin Vester-Christensen and Søren Erbou, founders of Deformalyze

Temadag
"Industriel anvendelse af CT scanning"

Conference on" Application of CT scanning in industry"

8. juni 2010 kl. 9-17
DTU, bygning 101, mødelokale 1

Program

9.00-9.30	**Registrering**	
9.30-9.40	**Velkomst og introduktion** Computed Tomography, CT scanning åbner for revolutionerende muligheder og er derfor af meget stor interesse for producerende virksomheder indenfor forskellige brancher. Det 4-årige innovationskonsortium "Center for industriel anvendelse af CT-scanning – CIA-CT", er et større dansk tiltag indenfor området. I løbet af temadagen går vi i dybden med CT scanning som avanceret måleværktøj for verifikation og kvalitetssikring af produkter.	*Leonardo De Chiffre, DTU*
9.40-10.20	**Industrial application of CT scanning** *1* CT scanning is a new technology allowing for 3D measurements inside an object. Principle of operation, performance, and examples of applications to metrology and product development are briefly reviewed.	*Jean-Pierre Kruth, KU Leuven, Belgien*
10.20-10.50	**Pause**	
10.50-11.10	**Metrotomography®- metrology in a new dimension** *2* Computed Tomography has completely arrived in the industry. It is represented worldwide in big tradeshows and offers solutions for various applications in the consumer-, automotive or medical industry. For reduction of R&D times, for faster first part inspection reports or for shorter reaction times on failure analyses: Metrotomography® plays an important role in many serious decisions in the daily industrial life. Plastics manufacturers have changed their testing- and manufacturing processes due to the possibilities of this promising technology.	*Hubert Lettenbauer Carl Zeiss, Tyskland*
11.10-11.30	**CT scanning af industrielle komponenter** *3* I indlægget diskuteres udfordringen ved at verificere industrielle komponenter ved CT-scanning kontra verifikation med traditionelle målemetoder. CT scannings anvendelse til at kalibrere målestrategi på konventionelle målesystemer præsenteres.	*Kim Mortensen, 3D-CT A/S*
11.30-11.50	**CT scanning in medical device development** *4* Præsentationen omtaler Novos overvejelser med anskaffelse og erfaringer med brug af en CT scanner til anvendelse i forbindelse med produktudvikling og kvalitetssikring.	*Jan Andreasen, Novo Nordisk A/S*
11.50-12.10	**Toleranceverifikation ved anvendelse af CT scanning** *5* CT scanning skaber overblik over sammenspil imellem monterede og skjulte elementer, samt muliggør analyse på materiale, indeslutninger og støbefejl. I indlægget beskrives forskellige cases, hvor Zebicon har brugt CT scanning til kvalitetskontrol og produktanalyse, med speciel fokus på toleranceverifikation.	*Kasper Fedde Krogh, Zebicon A/S*
12.10-13.20	**Frokost**	

Program (fortsat)

13.20-13.40 **Traceability of measurements from CT scanning** — *Simone Carmignato, Padova Universitet, Italien*

6 CT scanning allows for complex 3D measurements inside an object but is connected with traceability problems. State-of-the-art calibration artefacts and verification standards to ensure the traceability of CT scan measurements are presented.

13.40-14.00 **Miniature replica step gauge for optical and CT scanners** — *Angela Cantatore, DTU Mekanik*

7 A 40 mm miniature step gauge was produced in a replica material. The artefact was calibrated using a tactile coordinate measuring machine and measured using optical and CT scanning. The stability over time of the step gauge was evaluated over a period of eight months.

14.00-14.20 **"CT Audit" inter-laboratory comparison on CT systems for dimensional metrology** — *Simone Carmignato, Padova Universitet, Italien*

8 "CT Audit" is the first international comparison on Computed Tomography systems for dimensional metrology, organized by the University of Padova and involving important Institutions and companies in Europe, America and Asia. The presentation focuses on motivations, objectives and first results.

14.20-14.50 **Pause**

14.50-15.10 **X-ray imaging at high speed: opportunities and limitations using low-energy X-ray imaging** — *Jørgen Rheinlænder, InnospeXion ApS*

9 This presentation focuses on the basic idea of using low energy X-rays. Specific examples on the usage of on-line X-ray imaging systems for food and natural materials inspection address the challenges of image acquisition, processing and quantification, for ensuring 24/7 performance.

15.10-15.30 **CT scanning for on-line quality control in meat production** — *Lars Bager Christensen DMRI*

10 An optimized workflow for CT scanning of pig carcasses is presented, including real time validation of images, automated tissue assessment and virtual cutting into primals.

15.30-15.50 **Image analysis and modeling in industrial CT** — *Søren Erbou, Deformalyze ApS*

11 CT-scanning calls for advanced mathematical and statistical tools for automatically extracting and comparing the information of interest. Examples from the meat industry are given, ranging from weight models and virtual cutting of pig carcasses to statistical modeling of bone shape.

15.50-16.10 **Pause**

16.10-16.30 **CT scanning with new contrast mechanisms** — *Robert Krarup Feidenhans'l, NBI*

12 The talk will show the perspectives of using phase contrast and dark field imaging for new ways of performing CT-scanning. These techniques enable higher contrast in tissue and give also new opportunities for microstructural imaging.

16.30-16.50 **CT scanning using synchrotron sources** — *Erik M. Lauridsen, Risø DTU M4D*

13 Synchrotrons provide an alternative to laboratory CT systems, allowing for fast measurements with high signal to noise ratios. Examples ranging from industrial R&D applications to more fundamental materials science applications will be presented.

16.50-17.00 **Afrunding af temadagen og afslutning**

TILMELDING

den 14. temadag:

"Industriel anvendelse af CT scanning"

Conference on" Application of CT scanning in industry"

Tirsdag den 8. juni 2010

Bygning 101, mødelokale 1
Danmarks Tekniske Universitet (DTU)
2800 Kgs. Lyngby

Tilmelding til temadagen senest tirsdag d. 1. juni 2010 på følgende link:

https://conferences.dtu.dk/conferenceDisplay.py?confId=58

Gebyr for deltagelse: DKK 1850 - EUR 250

Gebyret omfatter konferencemateriale samt fortæring. Gebyret er momsfrit.

Yderligere oplysninger:

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Invitation

Den Danske Brugergruppe indenfor Koordinatmåling i samarbejde med innovationskonsortiet ”Center for industriel anvendelse af CT-scanning – CIA-CT”, indbyder til

den 14. temadag:

”Industriel anvendelse af CT scanning”

Conference on” Application of CT scanning in industry”

Tirsdag den 8. juni 2010

Bygning 101, mødelokale 1
Danmarks Tekniske Universitet (DTU)
2800 Kgs. Lyngby

Du og dine kolleger indbydes hermed til en ualmindelig spændende temadag. Temadagen er den 14. i en serie af konferencer vedrørende koordinatmåling og geometrisk metrologi, og til dette arrangement har vi sammensat et særligt hold med meget inspirerende foredragsholdere fra Danmark og udlandet.

Temaet er denne gang CT scanning, der er ved at revolutionere den måde, hvorpå man kan foretage industrielle målinger og kvalitetssikring. Med CT scanning får industrivirksomheder mulighed for at se inde i produkterne i forbindelse med udvikling og produktion. Den 1. september 2009 startede det 4-årige innovationskonsortium ”Center for industriel anvendelse af CT-scanning – CIA-CT” som et større, samlet dansk tiltag indenfor området. Oplysninger om konsortiet, der støttes af Rådet for Teknologi og Innovation, kan fås på hjemmesiden: www.cia-ct.mek.dtu.dk.

Temadagen vil give dig en indføring i anvendelse af CT scanning til måling, kvalitetssikring og produktudvikling i fremstillingsindustrien. Programmet omfatter det sidste nye fra udlandet samt konkrete erfaringer fra brugere af CT scanning hos danske industrivirksomheder.

Vi har opbygget denne helt specielle temadag med hele 13 indlæg, hvoraf de fleste holdes på engelsk. Indlæggene er korte og overskuelige, og temadagen fremstår som et intensivt og indholdsrigt kursus om den industrielle anvendelse af CT scanning.

Vi glæder os til at se dig!

www.dtu.dk **www.cgm.dk**
www.ipu.dk

CIA-CT Newsletter
NR2 – MAY 2010

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CIA-CT

Project Newsletter
November 2010 - NR 3

Center for Industrial Application of CT scanning

EDITORS' NOTE

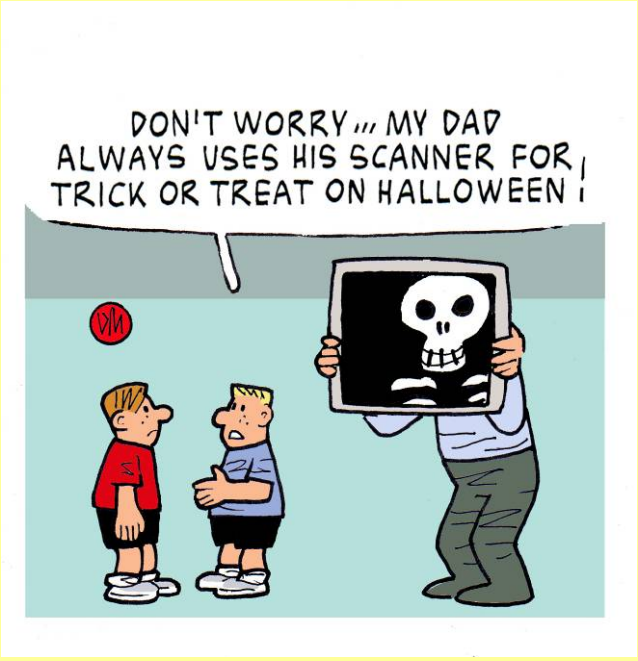
Dear reader,
Welcome to the third issue of our six-monthly newsletter. This issue is full of relevant events, like the first conference organized within the CIA-CT project, which took place on June 8th 2010 at DTU. The event was dedicated to industrial application of CT scanning. Some details concerning the contents and guest speakers are presented. You can also read about other events, e.g. the International Symposium on high-resolution X-ray CT organized by GE Measurement & Control Solutions phoenix|xray and the third Consortium meeting, which took place at Novo Nordisk on September 23rd 2010. The newsletter carries on with a contribution by Niels Bohr Institute and the Danish Meat Research Institute on "Phase-contrast imaging of pig fat at the European Synchroton Radiation Facility". We conclude the issue presenting another partner of the CIA-CT project. This time is the turn of YXLON International A/S.

We hope that you will enjoy the contents.

The fourth number will be distributed around May 2011.

Greetings

The Editors



RELEVANT EVENTS

Conference on "Application of CT scanning in industry"

The conference, organized by the Department of Mechanical Engineering and held on June 8th 2010, was the first of a series of yearly seminars devoted to CT scanning. The event, coordinated and chaired by prof. Leonardo De Chiffre from DTU, gathered more than 70 participants, who enjoyed thirteen presentations held by Consortium partners (DTU, Novo Nordisk, DMRI, NBI, Deformalyze) and CT users and experts (University of Leuven, University of Padua, Zeiss, 3DCT, Zebicon, InnospeXion, DTU Risø).
The main focus was on industrial applications, with presentations by Novo Nordisk in the field of medical industry and by DMRI in meat industry. The potential application of CT scanning in 3D metrology was enhanced by prof. Jean-Pierre Kruth from the University of Leuven, Belgium, in his keynote presentation, as well by dr Hubert Lettenbauer from Carl Zeiss, Germany, who also remarked the importance of having specific standards and physical artefacts for traceability of CT measurements, data exchange and comparison. Traceability problems, state-of-the-art calibration artefacts and verification standards to ensure the traceability of CT scan measurements through actual standards were shown by dr. Simone Carmignato, University of Padua, Italy, in his presentation.
The event was also followed by the Danish technical press and brought to the publication of a article in Jern og Maskinindustrien entitled "Et kig indvendig er guld værd" (http://www.jernindustri.dk/artikel/VisArtikel.aspx?SiteID=JM&Lopenr=106220048).

Figure 1: Professor Leonardo de Chiffre from DTU Department of Mechanical Engineering chaired the conference on "Application of CT scanning in industry".

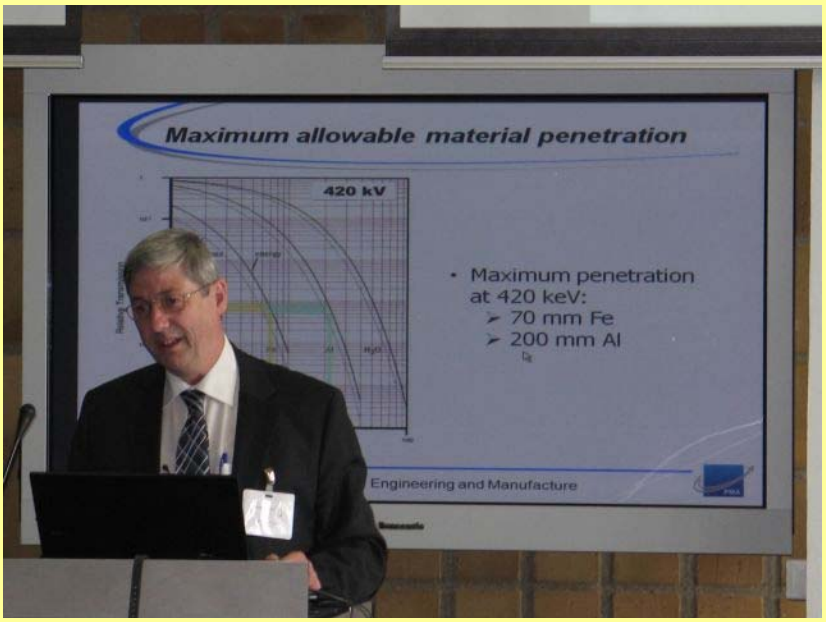


Figure 2: Professor Jean-Pierre Kruth from University of Leuven gave a keynote presentation on CT scanning in industrial application of CT scanning".

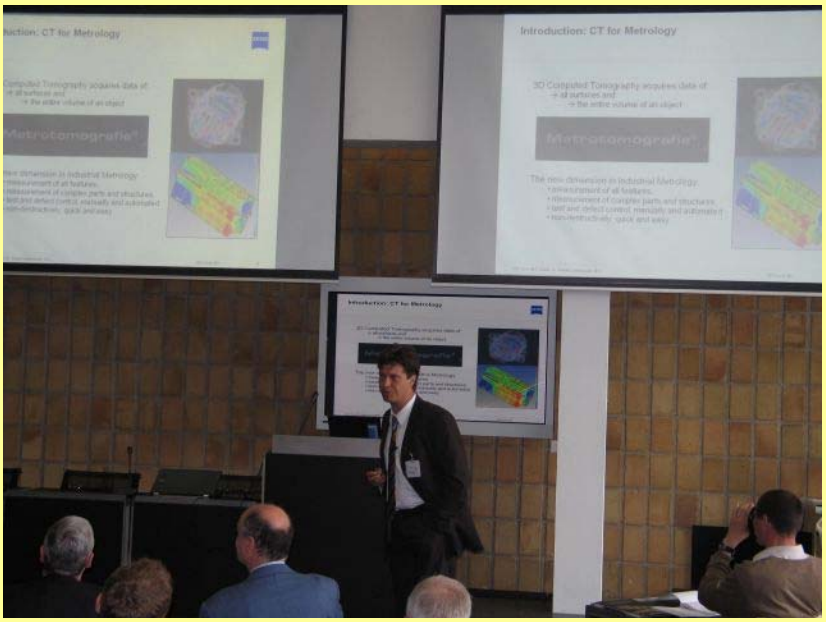


Figure 3: Dr. Hubert Lettenbauer from Carl Zeiss focused his speech on applications of CT scanning in metrology.

Figure 4: Dr. Jan Lasson Andreasen from Novo Nordisk A/S presented applications in the field of medical industry for plastic parts and assembly inspection.

Figure 5: Dr. Lars Bager Christensen from DMRI presented applications in the field of meat industry for online quality control.

Figure 6: Dr. Simone Carmignato, University of Padua, introduced the CT Audit, coordinated by him, for interlaboratory comparison on CT systems for dimensional metrology.

High-resolution X-Ray CT symposium

The International High-Resolution X-ray CT Symposium, held in Dresden from August 31st to September 2nd 2010, is the first event hosted by GE Measurement & Control Solutions phoenix|xray, addressed to experts, current and future users of high-resolution computer tomography. The event was focused on different topics concerning fields of research and industrial applications of computer tomography, with eight devoted sessions:

- 3D Metrology
- Developments: CT Systems, Methods, Equipment
- Materials Research: Metals & More
- Geosciences
- Biomedical research
- CT for Failure Analysis
- CT Data processing: Analysis, Visualization

The Symposium was a success, with 120 participants from 20 countries.
Angela Cantatore and Pavel Müller from DTU, and Jan Andreasen, Bente Eyving and Mette Poulsen from Novo Nordisk attended the event.
In the field of 3D metrology, Mr. Schulze from PTB made a presentation focused on reference objects to characterize dimensional control of µCT measurements. Mr. Salaberger from Upper Austria University of Applied Science presented a very interesting investigation on temperature influence on Nanotom stability. Indeed the heat generated at the target and at the deflection coils leads to an expansion of the whole tube and therefore to a movement of the focal spot. These movements were measured from the position of copper wires that were mounted fixed to the tube and fixed to the rotary table respectively, without and with cooling the system. The usage of the cooling shows a significant decrease in movement of the tube. Maximum

movement of the wires of 14 µm was observed in horizontal direction without cooling. This is reduced to 4 µm when cooling is applied but nearly no decrease of system movement in vertical direction.
During the conference, GE phoenix|xray showed their recent developments directed to improve stability in time and life duration of components and their new CT scanner, nanotom m, which incorporates new systems for improving the stabilitation and monitoring of scanning conditions: a temperature stabilitation system of the core components (X-ray tube and detector, and also environment), a high precision granite base manipulation system and the DXR 500 L flat panel detector, which optimizes contrast resolution and dynamic range, with a significant improvement in spatial resolution.

Figure 7: The Symposium in Dresden was attended by 120 participants from 20 countries.

The third Consortium meeting

The third CIA-CT Consortium meeting took place on September 23rd 2010 at Novo Nordisk (http://www.novonordisk.com/). Progress reports in the first 6 months of activity in each workpackage were presented by the partners.

Figure 8: Novo Nordisk Device R&D is located in Hillerød, close to Novo Nordisk production line facilities.

Figure 9: The meeting was attended by 25 people from the Consortium.

Figure 10: Dr. Jan Lasson Andreasen during his presentation regarding the department Device R&D of Novo Nordisk.

FEATURED ARTICLE

Phase-contrast imaging of pig fat at the ESRF

Torben H. Jensen
Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark

Lars Bager Christensen
Danish Meat Research Institute, Roskilde, Denmark

Robert Feidenhans´l
Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark

Conventional X-ray Imaging is based on the absorption of X-ray radiation as it is has been for over a 100 years. The contrast between the different parts of a sample is given by the differences in the absorption. However, it is very difficult to achieve contrast in soft tissue, where the variations in density and hence in absorption lengths are very small. X-rays are however electromagnetic waves like visible light and hence undergo refraction when passing through a sample. The ability to refract x-rays is in fact larger than the absorption, but more difficult to measure. At Niels Bohr Institute, they use a technique called grating based phase-contrast imaging to measure this refraction. The technique is based on the principle of x-ray grating interferometry and has over the last years been developed by Prof. Franz Pfeiffer and his group at the Technical University in Munich. Phase-contrast imaging is more sensitive to small difference in density and hence offers a significant increase in the contrast in x-ray imaging of soft tissue.
Within the framework of CIA-CT researchers at the Danish Meat Research Institute and the Niels Bohr Institute in collaboration with international partners imaged pig fat using phase-contrast tomography. To obtain the best results possible, we travelled to the European Synchrotron Radiation Facility (ESRF) in France to conduct the experiments. They can deliver a high flux of x-rays with a large degree of transverse coherence, which positively influences the quality of the x-ray images.

Figure 11: View over ESRF, Grenoble, France, with the mountains in the background.

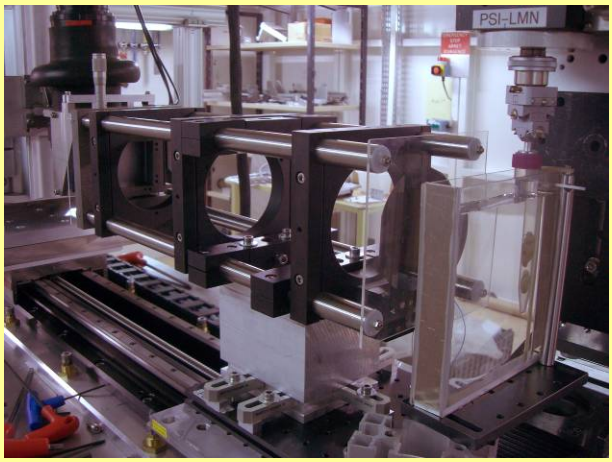


Figure 12: The grating interferometer used for phase-contrast tomography.

One example of the obtained results is presented in the Figure 13. The sample consists of two small pieces of pig fat. The figure shows on the left a frontal slice through the standard CT image of the sample and on the right the corresponding phase-contrast image. The two images are both displayed on a linear gray scale with ranges covering two times the standard deviation. This clearly illustrates the increased contrast available with phase-contrast imaging. To support the impression of the images, the reconstructed Hounsfield Units of a single line is plotted in panel (c). Again we can clearly see that the phase-contrast image provides a much better signal to noise ratio. These results are currently being prepared for publication. (Used for plotting are the Hounsfield Units for Phase HU-P, which are defined analogous to the standard Hounsfield Unit, using the real part of the refractive index instead of the absorption length).

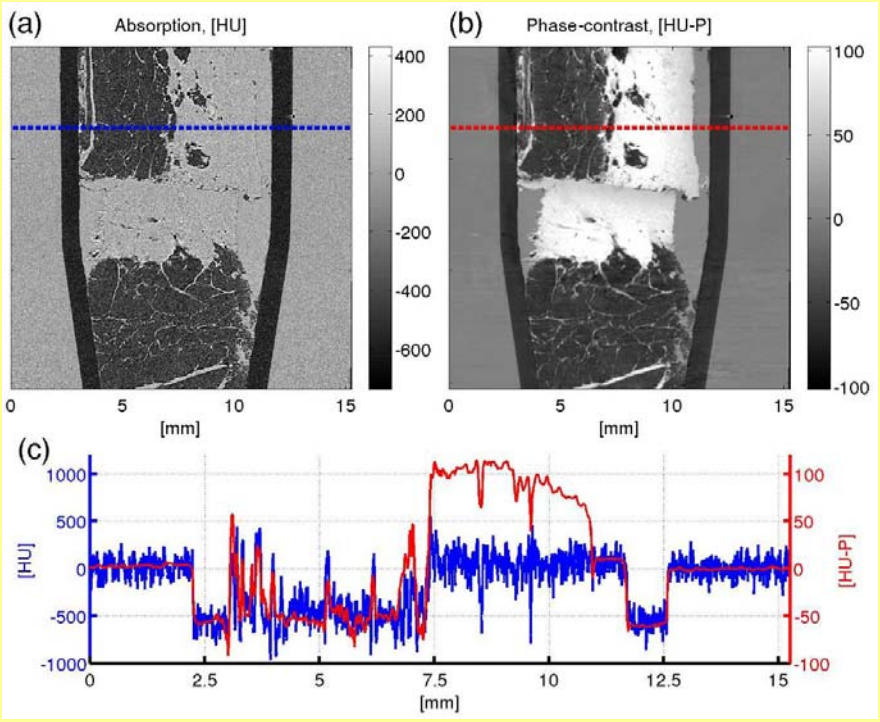


Figure 13: Tomography of pig fat: (a) Standard absorption image of two pieces of fat. (b) The corresponding phase-contrast image. (c) Comparison of the contrast in a single line through the two images.

MEETING WITH CIA-CT CONSORTIUM

YXLON International A/S

YXLON International is an innovative High-Tech company and rich in great traditions. Founded in spring 1998, YXLON International is the direct successor of Andrex (Denmark), Philips Industrial X-Ray (Germany) and LumenX (USA/Ohio). YXLON International today offers X-ray and CT based non-destructive testing systems and services all over the world. In the field of pipe- and vessel construction, automotive, electronics, aerospace and other industry, YXLON International offers X-ray and CT solutions which fit to any manufacturing process, to guarantee highest quality and safety standards for industrial products.
YXLON Internationals core competence lies in generating X-rays, and finding the right solution for the customer, through a constant improving of high voltage generators, control electronics, control software and mechanical constructions.
Some applications pertain to pipe inspection machines, able to handle steel pipes up to a length of 25m. The pipe inspector is usually installed in inline quality control systems. The system is used to check for cracks in the welding YXLON builds these machines with own sources, mechanical construction and software.

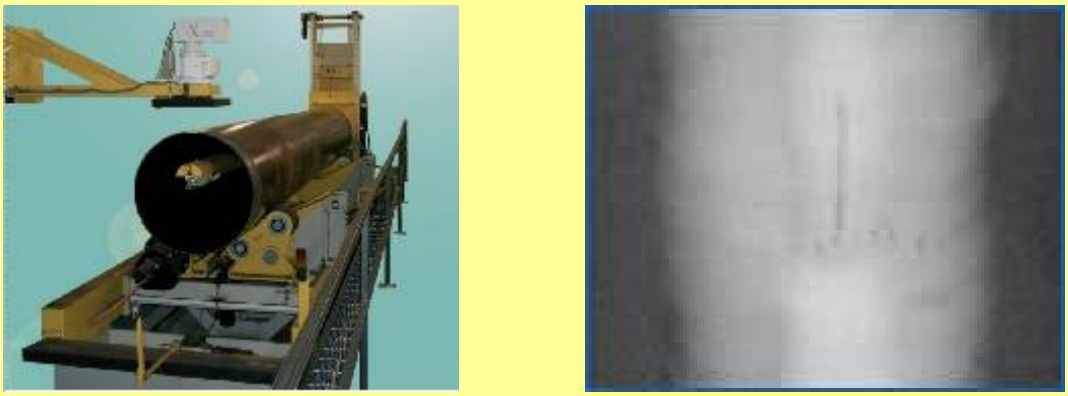


Figure 14: Pipe inspection machine, able to inspect steel pipes up to 25 m length (on the left); Crack in welding seen in steel pipe (on the right).

Another application concerns automatic failure detection in aluminium casting of car wheels. As the rim leaves the mould it is inspected with either a standard imaging machine or with a CT scanner, prior to final processing.

Figure 15: Processed car wheel and porosity found in casting of it.

The Danish part of YXLON International focuses on lightweight portable X-ray

equipment, mobile equipment and high specialised and customised inspection machines used worldwide.
An X-ray source consists of a few complex building blocks; X-ray tube, high voltage generator and control electronics. YXLON continuously faces with problems related to improving high voltage generators and challenges in insulating and thermal properties by finding the best trade-off also in terms of size and weight reduction of equipment.
YXLON in Denmark manufactures portable equipments for traditional film applications, but they are also used in automatic inspection machines with real time imaging. Real time imaging is sensitive to fluctuations in high voltage, because they affect the quality of resulting images. Some of these variations can be filtered out in the final X-ray image, but with the risk of lose important information and increasing the processing time. High signal to noise ration are important to increase the speed at production line, so reducing noise. This can be achieved by stabilizing X-ray source. The goal for YXLON International is to find the optimum between stability of the X-ray source and an acceptable level of noise.

Figure 16: Portable X-ray sources, manufactured by YXLON in Denmark.

CIA-CT Newsletter
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Project Partners:

DTU Mechanical Engineering

Department of Computer Science – Copenhagen University

Niels Bohr Institute – Copenhagen University

IPU

Technological Institute

Novo Nordisk

Danish Meat Research Institute

Yxlon

Deformalyze

Project website: www.cia-ct.mek.dtu.dk

CIA-CT

Project Newsletter
May 2011 - NR 4

Center for Industrial Application of CT scanning

EDITORS' NOTE

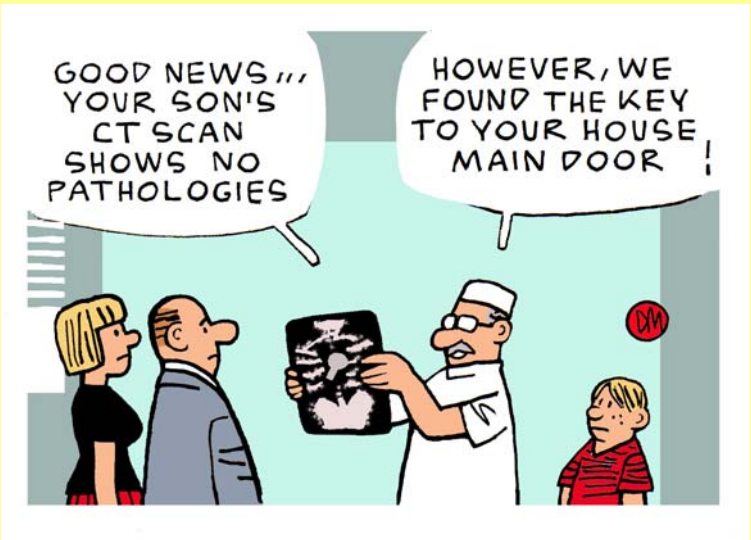
Dear reader,
Welcome to the forth issue of our six-monthly newsletter. The forth Consortium meeting, which took place at Danish Technological Institute on March 15th 2011 and the seminar held by dr. Jochen Hiller on "Industrial CT and CT metrology" are relevant events occurred the last sixth months. In particular the seminar was centered on industrial CT scanning and dealt with specific problems and solutions through practical examples. This issue carries on with a contribution from Niels Bohr Institute, University of Copenhagen on CT scanner simulations for testing, in advance, the real-time performance of CT scanners in the field of industrial CT. The section "Meeting with CIA-CT Consortium" is dedicated to IPU.
We also invite you to attend the second edition of Conference on "Application of CT scanning in industry", which will be held at the Danish Technological Institute the 31st of May. The detailed program is shown at the end of the newsletter.

We hope that you will enjoy the contents.

The fourth number will be distributed around November 2011.

Greetings

The Editors



RELEVANT EVENTS

Seminar on "Industrial CT and CT metrology"

The seminar was organized by the DTU Department of Mechanical Engineering and was held on November 9th 2010 by dr. Jochen Hiller (ex Fraunhofer EZRT, now DTU Department of Mechanical Engineering). The seminar registered ca. 15 participants. Leonardo De Chiffre, Angela Cantatore, Hans Nørgaard Hansen, Pavel Müller, Jais Angel, René Sobiecki and Jakob Rasmussen from DTU Mekanik and Jan Lasson Andreasen and Yongying Dai from Novo Nordisk attended the seminar.
Applications with CT in industry were presented with focus on CT specific problems and solutions. In particular, methods which require a specific reference object as well as image processing solutions for reducing and correcting image artifacts like beam hardening and scatter radiation were introduced. In order to investigate the multitude of influence quantities in CT metrology and to estimate uncertainties at dimensional measurements, a method based on deterministic CT simulations in combination with a Monte Carlo approach was presented.

Figure 1: Dr. Jochen Hiller from DTU Department of Mechanical Engineering held the seminar on "Industrial CT and CT metrology".

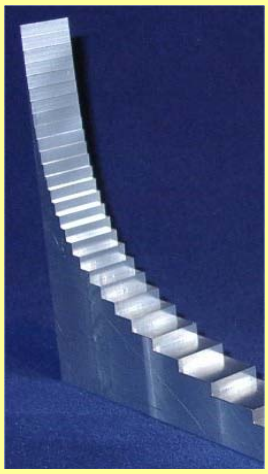


Figure 2: Step wedge sample used for correcting beam hardening artifacts.

The forth Consortium meeting

The forth CIA-CT Consortium meeting took place on March 15th 2011 at the Danish Technological Institute (http://www.dti.dk/). Progress reports in the different workpackages in last six months were presented by the Consortium partners.

Figure 3: The Danish Technological Institute is located in Taastrup. The Department of Metrology and Quality Assurance is marked with a red oval.

Figure 4: The meeting was attended by 23 people from the Consortium (picture by Jan Nielsen, Danish Technological Institute).

FEATURED ARTICLE

CT simulations for testing real-time performances of industrial CT scanners

Jonas Bardino, Brian Vinter
Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark

CIA-CT@eScience-KU is working on methods to simulate CT scanners to enable what-if testing of scanner designs before building the scanner, and testing the realtime performance one may obtain for industrial CT applications. One case is focused on developing and building a solution for efficient analysis and cutting of pork carcasses in slaughterhouses. The analysis is based on CT scanning and online reconstruction of the intersection images in the actual production line, so the results must be available within seconds in order to keep up with the production flow. As an example the meat intersection image in Figure 5 below could result in detector readings as visualized in the sinogram, and we can then use e.g. filtered back projection to reconstruct an estimate of the actual intersection.

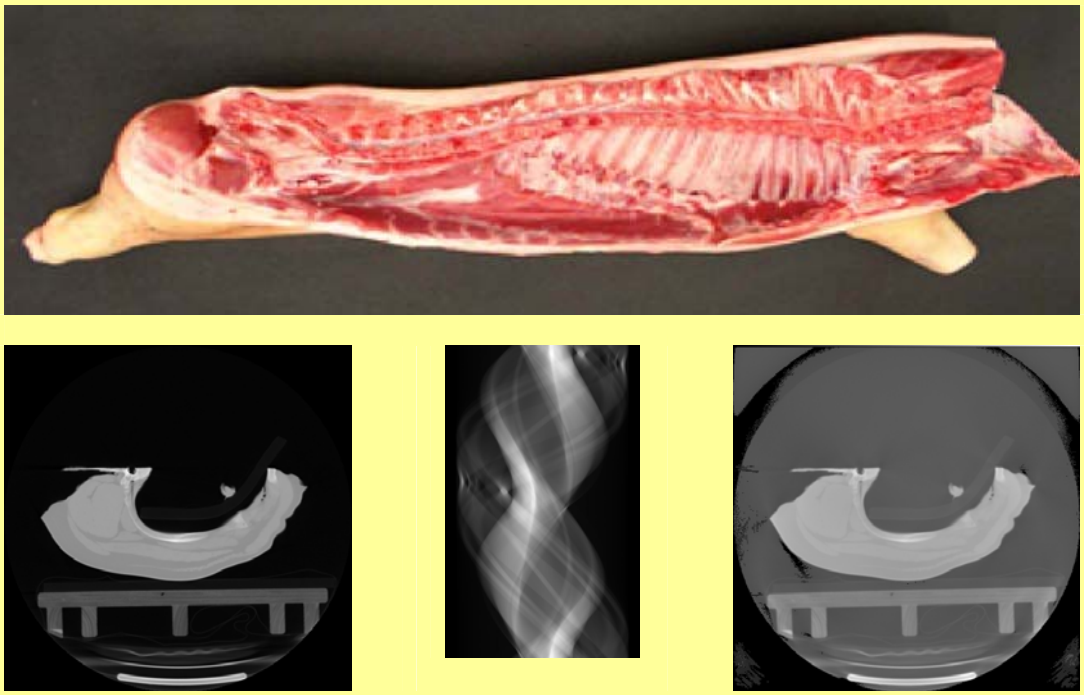


Figure 5: Half a pork carcass (top), intersection of similar meat lying on a conveyor belt (left), the resulting scanning sinogram (center) and the reconstructed image (right).

The case requires very high continuous usage of the CT scanner. Thus a number of design choices for the scanner had to be tested. Our first technical task at KU was to provide inputs for the scanner setup decisions. First we implemented a grid enabled web portal providing interactive image reconstruction with variable source count and position (excerpt in Figure 6). Using the portal the project participants could easily investigate the image quality and thus the feasibility of various stationary source solutions.

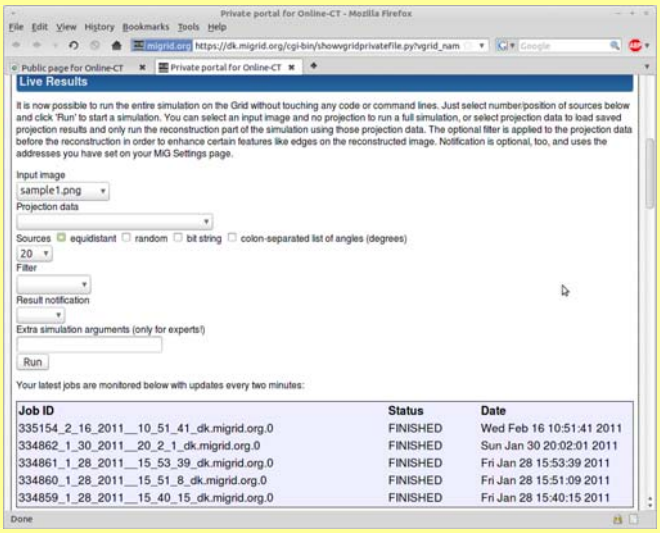


Figure 6: Web portal with live image reconstruction.

The different simulated scans can then be passed to both quantitative and qualitative quality analysis.
In our experiments the move from step and shoot fan beam to spiral cone beam CT removed a lot of mechanical challenges but instead introduced a huge amount of extra computation required in the already short period available in the production line. Thus the idea of using limited parallel optimization requirements had to be refined.
CIA-CT@eScience-KU group has started to investigate spiral cone beam reconstruction implementations and the optimizations needed for the short time frame. It still seems to be possible to build a fitting solution using state of the art GPU hardware and a highly optimized implementation of the reconstruction algorithms but this target is still away from the required performance.
The group is currently working closely with the project engineers in building a working prototype of the scanner and showing that it is actually possible to reconstruct usable images albeit in a longer time frame. Once achieving this target, attention will be focused to image reconstruction performance and to integration with the further image analysis tools on the way from image to the cutting machine.
The simulation environment, and the hundreds of CPUs that powers it, provides for a very convenient platform for testing CT scanner designs. In the future more reconstruction algorithms will be supported and a number of filters for the reconstructed images will be offered as well.

MEETING WITH CIA-CT CONSORTIUM

IPU

IPU was established at the Technical University of Denmark (DTU) in 1956 as a financially and administratively independent organisation with the objective to serve the industry with expert services in the development of products, materials, processes, manufacturing systems, organisation and management. IPU operates on commercial terms, receiving no government subsidies and paying for accommodation in the university campus. The company, which employs 45 peoples, offers professional development assistance to industrial companies and research organisations in both the public and private sector.

The IPU Division for Technology Development has a reputation for leading edge research in the field of forming processes, material- and surface technology, tribology, surface finishing and geometrical metrology. IPU has carried out process analysis and optimisation for a large number of national and international companies.

Figure 7: IPU, established at the Technical University of Denmark (DTU) in 1956, operates as a financially and administratively independent organisation with the objective to serve the industry with expert services in the development of products, materials, processes, manufacturing systems, organisation and management.

IPU offer varying kind of services, like:

- Strict product, process or material development
- Technical advice, problem solving and arbitration
- Project facilitation, process management, benchmarking,…
- Implementation of new methods and procedures
- Strategic analysis and planning
- Organisational development
- Continuing education and on-the-job training

IPU consists of two primary divisions: Product Development and Technology Development. Process Technology, who takes part in the CIA-CT project, is one of four groups in Technology Development. The Process Technology Group has 11 employees working in the field of: Material and friction tests, numerical modelling of forming processes, geometrical metrology, laser technology, design of machines and equipment, micro technology, healthcare and refrigeration and energy technology.
The role of IPU in the CIA-CT project is to coordinate and take active part in especially work package 4, where the stability of the beam is investigated and improved. At present IPU has in close collaboration with Yxlon measured the stability of the CT-scanners at Novo Nordisk in Hillerød and at Teknologisk Institut in Taastrup.

Figure 8: The CT-scanner at TI with the Yxlon detector for measuring the stability of the beam

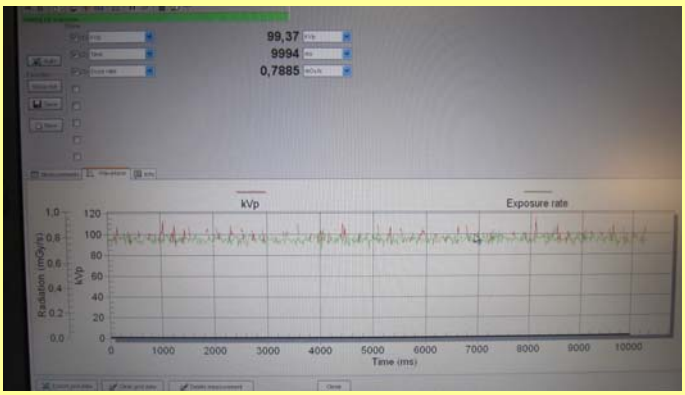


Figure 9: The output of the stability measurements at TI

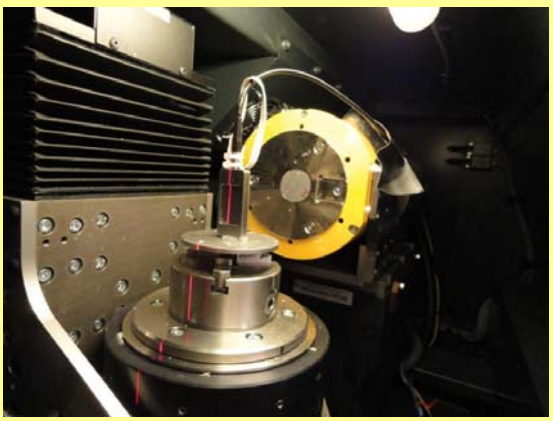


Figure 10: Measuring of beam stability at Novo Nordisk A/S

CONFERENCE
"Application of CT Scanning in Industry"

Conference at the Danish Technological Institute - Measurement and Quality

Gregersensvej 1, Conference Hall

DK-2630 Taastrup

31st May 2011

Program

08:30-9.00	**Registration and coffee**	
09.00-09.15	**Welcome to Danish Technological Institute**	*Maria Holmberg DTI, DK*
09.15-09.30	**Introduction**	*Prof. Leonardo De Chiffre, DTU, DK*
09.30-10.10	**Improving the Production using X-Ray Computed Tomography – Potentials and challenges**	*Prof. Robert Schmitt, RWTH Aachen University, Germany*

1

X-Ray Computed Tomography (CT) is a non-destructive imaging technology. By means of CT an object can be acquired holistically including exterior and interior features, which are inaccessible for tactile or optical sensors without destroying the part. From the images taken at various angles the object can be reconstructed volumetrically at very high point density, i.e. providing a geometric model in 3 spatial dimensions plus the material density. Thus, in the recent years the X-Ray Computed Tomography has become interesting for production metrology. The volumetric model can then be used for dimensional measurement, non-destructive material testing and assembly control making CT a versatile inspection technology. Using a CT scanner as coordinate measuring machine requires that different tasks have to be addressed, e.g. the estimation of an uncertainty in measurement, the traceability to the national standard of length, the capability of the measurement process. To achieve the high accuracy of actual tactile coordinate measuring machines the CT has to be improved regarding the hard- and software of a CT scanner. The presentation outlines the state of the art for CT in industrial application describing potentials and current challenges. Areas in need of improvement are identified and approaches are presented which will enable the CT not only to be a mean for checking the object specification but providing detailed feedback to improve the production process.

10.10-10.40	**Coffee break**	
10.40-11.00	**Measuring micro features with dense point clouds – Scanning with tomography, microprobes and laser**	*Detlef Ferger, Werth Messtechnik GmbH, Germany*

2

During the last years modern sensors like computer tomography (CT) and tactile-optical sensors have been integrated into coordinate measuring machines. The presentation gives an overview of the available sensor technology and shows the achievable accuracy of CT by comparing the results to measurements of a traceable tactile-optical sensor. Especially dimensional measurements of multiple points on micro features will be addressed. This includes measurements on teeth implants and scanning of micro gears. Furthermore injection nozzles of common rail systems for automotive applications were analysed.

It will be shown that modern CT systems with highest structural resolution have an immense accuracy. Even better results on micro features will be achieved by raster tomography or region of interest CT, which will also be explained. Due to the physical principle of X-ray computer tomography, methods for the compensation of remaining systematic errors are very important too. Methods to compensate these errors, like Werth AutoCorrection or Helix CT, will also be discussed.

11.00-11.20 **Nano- and Microtomography for materials science** *Bart Pauwels, SkyScan, Belgium*

3 Micro- and Nano-computed tomography (micro-CT/nano-CT) is a very powerful technique to visualize and measure the internal microstructure of different types of material, both biological as non-biological, in a non-destructive way. This talk will focus on the use of micro-CT and nano-CT in materials science. Some examples, where micro-CT has an added value and gives new insights in materials and processes, will be discussed. These examples range from materials and devices for biomedical applications (e.g. scaffolds, implants …) over art to the study of sample rocks for oil exploration.
The result of a micro-CT reconstruction is a set of thin, virtual slices through the object and opens a unique possibility for the numerical analysis of the object's internal microstructure. 3D analysis software allows extracting these numerical characteristics, such as internal porosity, size distribution for pores or grains, orientation analysis, surface/volume ratio, etc.
Programs for realistic visualization show the reconstructed microstructure as a realistic 3D object on the screen. Dependent on the task, surface or volume rendering can be used. In both cases realistic visualization includes possibilities for virtual sectioning, viewing to the object from any point including internal positions and creating movies of flights around and inside the object.
Micro-CT doesn't only allow scanning static structures, but can also visualize microstructural changes during loading, tension, cooling, heating, etc. Special object stages can be used for such in-situ experiments. The final information in this case becomes 4-dimensional and reflects the behavior of the object's internal microstructure under the specific external interaction.

11.20-11.40 **Industrial Computer Tomography and Precision** *Christof Reihart, Volume Graphics GmbH, Germany*

4 Over the past years Computer Tomography (CT) has become a well recognized tool in metrology. The efforts of national metrology and material research labs, expert committees, the CT manufacturers and software companies have made CT a reliable tool for metrology in many applications. These efforts have made CT these days a technology trusted by a rapidly growing users community.
However often industrial CT - if it is in CT system design or in CT data processing - still does not utilize the know-how generated in CT metrology. In CT data processing e.g. we often experience that binarization by using a global threshold is used as the first step of a complex data processing chain, wasting more precise information actually available in the original CT data.

This presentation will demonstrate how Volume Graphics enhances its CT data analysis tools for different applications by taking advantage of all the information that is available in the original CT image data. It will also show up known limitations of CT imaging that can't be overcome by data processing and therefore limit the "precision" of the analysis results.

11.40-12.00 **Automating Analysis** *Martin Vester-Christensen / Søren Erbou, Deformalyze ApS, Denmark*

5 Moving from exploratory to automated analysis of CT-data is a major challenge, especially when dealing with biological tissue. Nonetheless, it is crucial when up scaling to large amounts of data in order to ensure objective measurements as well as for reducing time-consuming manual handling. A complete web-based framework for automated upload, handling, book-keeping and analysis of CT-scanned pig carcasses is presented. The user

supplies the raw CT-scans, and after upload production-specific parameters can be set and results for the whole database are returned before finishing the next cup of coffee…

12.00-13.00 **Lunch**

13.00-13.20 **Aspects of traceability of dimensional CT measurements**

6

Dr. Markus Bartscher PTB, Germany

Traceability of dimensional measurements is achieved by creating a metrological chain between the SI unit of length - the meter, material standards of different type and specific industrial parts.

This unbroken chain is ideally accomplished by measurements with a known and valid measurement uncertainty. But achieving traceability of dimensional measurements is a challenging topic for a complex measurement technique like computed tomography (CT). It requires the - at least empirical - knowledge about all relevant influence factors, about definitions of e.g. reference methods and about processes to assess all these items. The talk will highlight and discuss some aspects of the traceability of dimensional CT measurements. One focus is the reference measurement of the part under study for the case of freeform shapes. Attention has to be directed to the correct probing of these surfaces in the case of tactile measurements and to the correct software processing (actual nominal value comparison) for the reference and the CT data sets. A second topic is the analysis of measurements of a dismountable reference standard with inner geometries and the discussion of the recent approach of the VDI/VDE draft 2630-2.1 . Finally, the talk will give a short outlook to reference standards for micro CT measurements and their potential benefit for a better traceability of CT measurements.

13.20-13.40 **International round robin on dimensional computed tomography**

7

Dr. Simone Carmignato, Padova University, Italy

This work reports the preliminary results obtained from the first international intercomparison of CT systems for dimensional metrology. This comparison, called “CT Audit”, has been organized by University of Padova and involves important institutions and companies in Europe, America and Asia, including national metrology institutes, CT systems manufacturers, research institutes, and industrial users. Further information on the intercomparison can be found on the project’s website: www.gest.unipd.it/ct-audit.

13.40-14.00 **CT metrology – CT Round Robin**

8

Ph.d. student Jais Angel, DTU, Denmark

Inter laboratory comparison of industrial CT scanners for dimensional metrology, organized by DTU Department of Mechanical Engineering and involving 4 institutions and companies in Denmark. The presentation focuses on motivations, objectives and first results.

14.00-14.30 **Coffee break**

14.30-14.50 **Image Analysis for Volumetric Industrial Inspection and Interaction**

9

Prof. Rasmus Larsen, DTU, Denmark

X-ray computed Tomography (CT) allows for industrial inspection of 3D solids. In this presentation I will give examples on how model based image analysis can be used to derive relevant properties of the 3D solid from recorded CT scans. We will be concerned both with fixed and deformable geometry objects. Moreover, we will touch upon how these images can used in a image guide interaction with the solid.

14.50-15.10 **CT scanning strategy: Prediction of image quality**

10

Post Doc Jochen Hiller, DTU, Denmark

The range of objects inspected by means of industrial computed tomography (CT) scanners usually much differ in size, form, and material. In comparison to medical CT in industrial CT it is often difficult to assure the optimal scanning parameters to achieve the highest performance level of the system for a given set of boundary conditions (physical and technical

limits of the CT system, magnification factor, scanning time etc.).

As a consequence the influence of the operator on the result is very high. In this talk, a semi-empirical method for optimal object-specific CT scanning is discussed.

15.10-15.30 **Influence Parameters in CT scanning** — *Ph.d. student Pavel Müller, DTU, Denmark*

11

This presentation focuses on CT scanning applications for industrial and metrological purposes, where attention is on the current challenges in CT scanning, i.e. identification of influence factors and their elimination. State of the art of influence factors in CT scanning, a theoretical analysis and an experimental investigation will be presented. In particular, experimental investigations concern methods and techniques to correct and reduce errors and artefacts due to a defined parameter, both as they are realized in literature and performed by the authors.

15.30-16.00 **Coffee break**

16.00-16.20 **Measurement of micro moulded parts by Computer Tomography** — *Dr. José A. Y: Fabra, University of Zaragoza, Spain*

12

Accuracy and time exigencies are getting tighter and tighter in the field of manufacturing engineering and smaller mechanical parts are characterized by smaller tolerances to be verified. The evolution of dimensional metrology has to be capable of meeting these demands. Thereby, apart from the optimization of traditional metrology equipment, new technologies based on new measuring concepts are being developed. One of them is Computed Tomography (CT) metrology using X-rays. This talk focuses on dimensional verification of two micro-injection moulded components, selected from actual industrial productions, using CT metrological tools. In addition to CT scanning, other Coordinate Measuring systems allowing fast measurements suitable for in-line quality control were employed as validation instruments. The experimental work carried out and the analysis of the results provide valuable conclusions about the advantages and drawbacks of using CT metrology in comparison with conventional Coordinate Measuring Systems when these techniques are employed for quality control of micro moulded parts.

16.20-16.40 **Accuracy in biology** — *Lars Bager Christensen, DMRI, Denmark*

13

Determination of spatial features in biological specimens often suffers from lack of a proper reference. As many features includes assessment of tissue and many tissues are elastic by nature measurements in tissues as meat and fat differ highly from many other industrial materials. The talk will touch upon important topics of some CT-based applications within the meat industry as experienced by DMRI. These topics include mixed voxels, validation with no true reference, thickness of elastic layers and objectivity in assessment of meat, fat and bone.

16.40-17.00 **Closing and Summary** — *Maria Holmberg DTI, DK*

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Invitation

We would like to invite you for a one-day conference at Danish Technological Institute in Taastrup, Denmark, 31st May 2011 regarding;

Application of CT Scanning in Industry

with main focus on the metrology area, such as traceability and round robin, as well as on image analysis and modeling of CT Scanning.

Speakers from both industry and academia have been invited, and all participants are welcome to bring scientific, technical or educational posters.

The program, abstracts and information regarding registration can be found at;
http://www.dti.dk//30509.1,1

Price for the conference is DKK 1.850,00 (all included). An invoice will be sent to the address that are used in registration for participating in the conference

For more information you are also welcome to contact Maria Holmberg on mahg@teknologisk.dk

CIA-CT Newsletter
NR4 – MAY 2011

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The "Center for Industrial Application of CT scanning - CIA CT" is an innovation consortium co-financed by the Ministry of Science Technology and Innovation

Project Partners:

DTU Mechanical Engineering

Department of Computer Science – Copenhagen University

Niels Bohr Institute – Copenhagen University

IPU

Technological Institute

Novo Nordisk

Danish Meat Research Institute

Yxlon

Deformalyze

Project website: www.cia-ct.mek.dtu.dk

CIA-CT

Project Newsletter
November 2011 - NR 5

Center for Industrial Application of CT scanning

EDITORS' NOTE

Dear reader,
Welcome to the fifth issue of our six-monthly newsletter. This issue is rich of relevant events for the CT community, which occurred in the last six months, like the 11t^{h} International Conference of the European Society for Precision Engineering & Nanotechnology, the Conference on "Application of CT scanning in industry" and the International Symposium on "Digital Industrial Radiology and Computed Tomography". The fifth Consortium meeting took place on the 21st of September at Niels Bohr Institute, attractive both for its scientific and historical meanings. The issue carries on with a contribution by University of Leuven, Belgium, about their current research activities and challenges in the Computed Tomography field. The issue concludes with the presentation of another member of the Consortium: Danish Technological Institute.

We hope that you will enjoy the contents.

The sixth newsletter will be distributed around May 2012.

Greetings

The Editors

RELEVANT EVENTS

11th International Conference of the European Society for Precision Engineering & Nanotechnology (euspen 2011)

The International Conference of the European Society for Precision Engineering & Nanotechnology is an annual event promoted by euspen (**eu**ropean **s**ociety for **p**recision **e**ngineering and **n**anotechnology), a big community, founded in the 1999, with the aim of linking together and ease the share of knowledge between the best expertise in industry and research institutes in the field of precision engineering, micro engineering and nanotechnology. The 11th International Conference of the European Society for Precision Engineering & Nanotechnology took place from the 23rd to the 27th of May in the beautiful scenario of Villa Erba, Cernobbio, Italy, by Como lake.

As every year the conference was organized in different devoted sections:

- Ultra precision replication techniques
- Nano & micro metrology
- Ultra precision machines & control
- High precision mechatronics
- Ultra precision manufacturing & assembly processes
- Important/Novel advantages in precision engineering & nano technologies

Every session included oral and posters presentations. The conference was attended by Angela Cantatore, Pavel Müller, Guido Tosello, Hans Nørgaard Hansen and René Sobiecki from DTU.

Same works in the field of Computed Tomography (CT) for dimensional metrology were presented in the Nano & micro metrology session. Dr. Angela Cantatore from DTU (Denmark) gave an oral speech about verification of a CT scanner using a miniature step gauge. Influences of workpiece orientation, magnification, source-object-detector distances and surface extraction method on metrological performances of a CT scanner were evaluated. The work was carried out by DTU, Novo Nordisk and University of Padova.
Dr. José A. Y. Fabra from University of Zaragoza (Spain) gave an oral talk on dimensional verification of micro-injection moulded components using CT scanning. Results obtained with CT scanning measurements were compared with “traditional” techniques, as tactile and optical Coordinate Measuring Machines´ (CMM) results. The work was developed by University of Zaragoza in collaboration with DTU and University of Padova.
Dr. Simone Carmignato from University of Padova described preliminary results of the “CT Audit”, the first international intercomparison of Computed Tomography systems for dimensional metrology. Four calibrated items (with detailed measurement procedures) were made circulated among different companies and institutions in Europe, America and Asia, involving 16 CT systems in total.
In the poster session, Mr. Pavel Müller from DTU presented an investigation on geometrical measurements on silicone rubber using Computed Tomography. Measurements performed on a CT scanner were compared to measurements on a coordinate measuring machine (CMM), being used as reference. The work was developed from DTU in collaboration with University of Cluj-Napoca (UTCN), Cluj-Napoca, Romania.

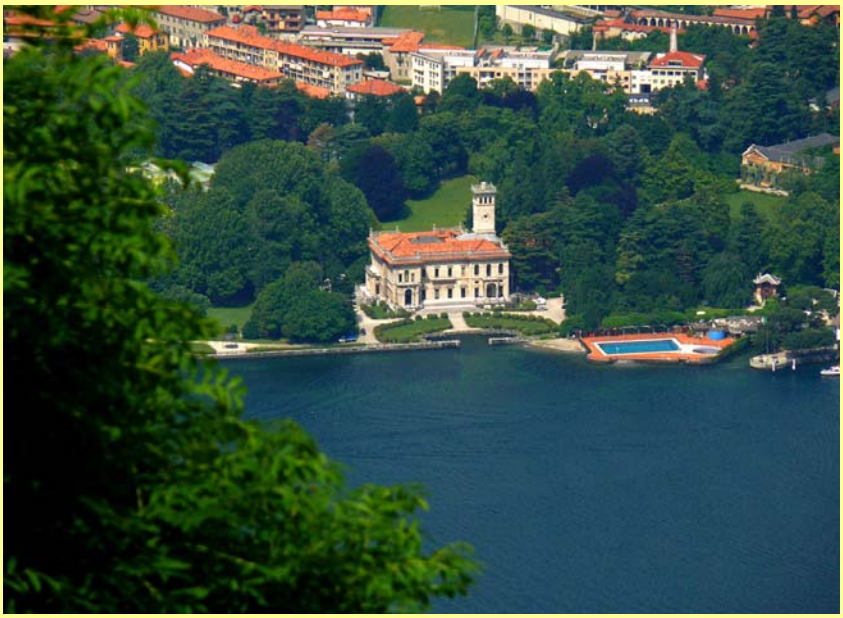

Figure 1 : Aerial photograph of Villa Erba (Cernobbio, Italy) which hosted the 11th International Conference of the European Society for Precision Engineering & Nanotechnology (euspen 2011).

Conference on "Application of CT scanning in industry"

The Danish Technological Institute (DTI) hosted the second conference on "Application of CT scanning in industry". The seminar, yearly organized within the CIA-CT project, took place the 31st of May 2011 and was coordinated and chaired by Dr. Maria Holmberg, Department of Metrology and Quality Assurance, DTI and prof. Leonardo De Chiffre, Department of Mechanical Engineering, DTU. The conference was attended by 70 participants from Denmark and Europe.
The keynote presentation was hold by Professor Robert Schmitt from RWTH Aachen University regarding 'Improving the Production using X-Ray Computed Tomography – Potentials and Challenges'. Focus topics were dimensional metrology and measurement traceability, image analysis and image quality assessment. Dr. Markus Bartscher from PTB, Germany held a talk regarding traceability of dimensional CT measurements, Dr. Simone Carmignato from University of Padova, Italy, presented preliminary results concerning the first international intercomparison using Computed Tomography and Dr. José A. Y. Fabra from the University of Zaragoza, Spain, gave a talk on measuring micro moulded parts with CT scanning. Professor Rasmus Larsen from Department of Informatics and Mathematical Modelling at DTU held a talk regarding image analysis and industrial inspection and interaction, and Lars Bager Christensen from DMRI spoke about accuracy in biology. There were three talks from Department of Mechanical Engineering, DTU. Dr. Jochen Hiller gave a talk on prediction of image quality from CT scans, Pavel Müller and Jais Angel, PhD students from the same department at DTU gave talks related to CT Scanning and metrology. From industry representatives from Werth Messtechnik, SkyScan, Volume Graphics and Deformalyze gave presentations showing their products within CT scanning and their capacities within different areas.

The participants at the conference also visited the laboratories at the centre of Metrology and Quality Assurance, where they had the possibilities to see the CMM

and optical measurement facilities, the different apparatus in the calibration laboratory and the CT scanning equipment, as well as continuing networking and having discussions on possibilities and challenges within using CT Scanning from industrial applications.
The event was also followed by the Danish technical press and brought to the publication of an article in Jern og Maskinindustrien entitled “CT-scanning vinder mere indpas I industrien”.

Figure 2 : Professor Robert Schmitt from RWTH Aachen University, Germany, focused is keynote talk on current challenges of Computed Tomography for improvement of manufacturing processes and production (picture by Jan Nielsen, Danish Technological Institute).

Figure 3 : Dr. Markus Bartscher from PTB, Germany, gave a speech concerning traceability of CT scanning for dimensional metrology (picture by Jan Nielsen, Danish Technological Institute).

Figure 4 : Dr. Simone Carmignato from University of Padova, Italy, presented preliminary results concerning the "CT Audit" project, organized and coordinated by University of Padua (picture by Jan Nielsen, Danish Technological Institute).

Figure 5 : Professor Rasmus Larsen from Department of Informatics and Mathematical Modelling at DTU provided a talk about image analysis for volumetric industrial inspection and interaction (picture by Jan Nielsen, Danish Technological Institute).

Figure 6 : Mr. Jais Angel presented planning and preparation of a proficiency testing for industrial CT scanning, focusing attention on selected items and circulation plan (picture by Jan Nielsen, Danish Technological Institute).

Figure 7 : Dr. José A. Y. Fabra presented results concerning measurement of micro moulded parts by Computed Tomography, focusing advantages of CT scanning with reference to traditional Coordinate Measuring Machines (picture by Jan Nielsen, Danish Technological Institute)

International Symposium on "Digital Industrial Radiology and Computed Tomography"

The DIR2011 conference (Digital Industrial Radiology and Computed Tomography) was organized by the German Society for Non-Destructive Testing (DGZfP) and BAM and took place in Berlin, Germany from 20th to 22 June 2011. The previous conference took place in 2007 and the first one in 1988 and the intention of the conference is to be a venue and provide an intellectual knowledge exchange for scientists, industry and other interested in the following topics:

- X-ray detectors and sources
- Radiography (multi-angle)
- Computed Tomography
- Laminography & Tomo-synthesis
- Dual and multi-energies
- Phase contrast
- Image processing algorithms
- Quantitative imaging
- Modelling
- Data fusion
- Scattering
- Defect detection & localization
- Feature extraction
- Dimensional control
- Standardisation
- Qualification & system reliability

It started out as a German conference, but today it is an international conference with more than 50% non-German participants out of a total of approximately 150. The community behind the conference works within classical metrology, standardization, material characterization, non-destructive testing (NDT) etc. Both hardware and software vendors were present in the exhibition.
Martin Vester-Christensen and Søren Erbou from Deformalyze, Jan Andreasen, Bente Eyvin, Yongying Dai, Mette Poulsen, Torben Ruby, Trine Sørensen and Charlotte Pia Haagensen from Novo Nordisk and Maria Thomsen from Niels Bohr Institute participated at the Conference.

The fifth Consortium meeting

The fifth CIA-CT Consortium meeting took place on the 21st of September 2011 at the Niels Bohr Institute – University of Copenhagen (http://www.nbi.ku.dk/). Progress reports in the different workpackages in last six months were presented by the Consortium partners.

Figure 8: The meeting was attended by 20 people from the Consortium.

Figure 9: Picture of Bohr´s desk. Bohr´s office represents a piece of history. Pictures of Bohr, of his staff in the Institute are still hanging on the wall, like Bohr left it.

FEATURED ARTICLE

One step further---Going beyond inspection

Jean-Pierre Kruth, Win Dewulf, Ye Tan
University of Leuven, Division PMA, and University College Group T,
Leuven, Belgium

Since the first CT scanner built by the Nobel Prize winner Hounsfield in 1969, CT has successfully entered several domains: medical imaging in the 1970s', material analysis and non-destructive testing (NDT) in the 1980s' and most recently CT metrology. Accurate measurement and control of dimensional and geometric tolerances are essential elements for modern mechanical production. Nowadays, with the help of additive manufacturing techniques parts with complex internal structures can be easily produced, but dimensional quality control remains a problem. Industrial computed tomography (CT) tries to answer this challenge with its unique power of seeing into objects. The first attempts to perform dimensional measurement using existing CT scanners appeared around 1991, but accuracy was not better than about 0.1 mm. The first dedicated dimensional CT machine was exhibited at the Control Fair in Germany in 2005 (see CIRP Annals, Vol. 60/2/2011, p. 821). Since then, CT metrology has gained more and more interest from researchers and the industry.

Since 2008, the metrology group of K.U.Leuven (PMA division of the Mechanical Engineering Department) started to work closely with its association partners (Group T International University College and Lessius University College) under the umbrella of a successful TETRA (technology transfer) project on CT metrology. The CT team cooperates with more than 20 industrial partners (Nikon Metrology, Skyscan, Materialise etc.) in order to boost CT metrology in the industrial field.
Our activities within the frame of TETRA – CT project can be classified into two major categories:

- ***Metrology research***

When talking about CT metrology (micron level accuracy), the machine stability becomes an important issue. The drift of the target during a CT scan should be avoided, thus the preferable location for fixing the X-Ray gun is in the front (Fig. 10). Experiments have been designed to investigate the influence of target drift on the measurement accuracy.
Moreover, procedures for accurate thresholding are essential for CT metrology. An Aluminium artefact (cactus step gauge) has been designed to allow for simultaneous calibration of both the rescaling factor and the edge detection process. As shown in figure 12, the cactus step gauge comprises edge dependent distances as well as edge independent distances between the parallel planes. This allows to determine edge offset errors easily.
Other CT metrology research covers measurement repeatability tests, the influence of machine settings (X-ray power, magnification, workpiece orientation), multi-material investigations and quantification of the CT measurement uncertainty.

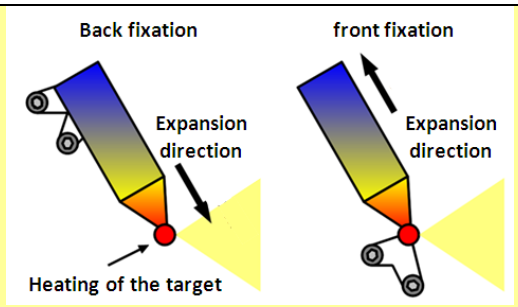

Figure 10: X-ray gun fixation and expansion direction

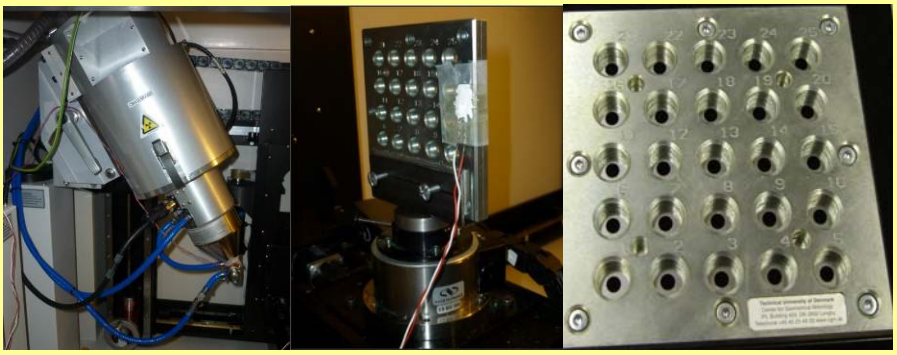

Figure 11: Measurement designed to test the machine stability

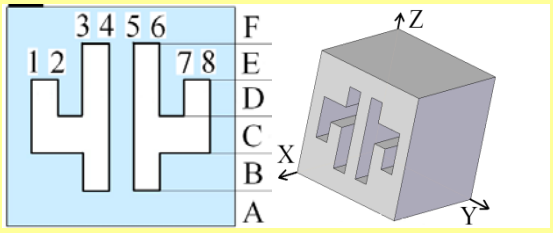

Figure 12: Aluminium calibration artefact (cactus step gauge)

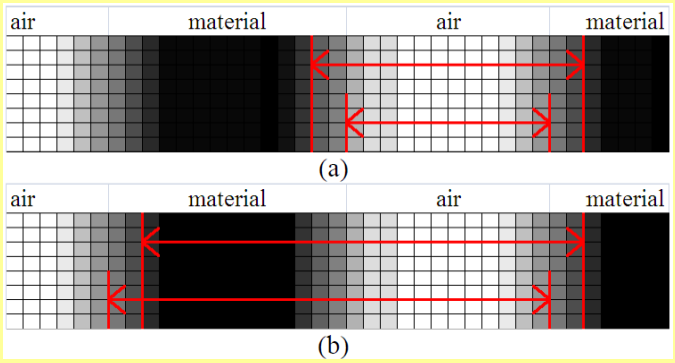

Figure 13: The edge dependent and edge independent features

MEETING WITH CIA-CT CONSORTIUM

Danish Technological Institute

The Danish Technological Institute (DTI) is a self-owned, non-profit institution that develops, applies and disseminates research and technologically based knowledge for the Danish, as well as international, enterprises and industry. DTI collaborate with leading research and educational institutions, both in Denmark and abroad, in development projects that are of use to society. Furthermore, DTI carry out consultancy and standardisation services and has activities within education, certification and lectures.

DTI is approved by the Ministry of Science, Technology and Innovation as a GTS-institute (Approved Technological Service Institute).
The most important task for DTI is to ensure that new knowledge and technology are converted into value for our customers in the form of new or improved products, materials, processes, methods and organisational structures. We work together with new and existing companies, either individually or in groups, on ways to enhance technological and management restructuring and efficiency. The areas DTI focus upon are:

- Innovation and competitiveness
- Training and management
- Sustainable exploitation of resources
- Cost-effectiveness in company and society

Metrology and Quality Assurance at DTI is a centre with competences and activities within 3D geometrical measurements, as well as calibration within the length area. The commercial activities in the centre are mainly within non-destructive 3D measurements using CMMs (coordinate measuring machines), CT Scanning or optical measurements on items of different shape and size, as well as with different material characteristics (such as density, porosity and mechanical strength). Besides from commercial activities within 3D measurements and calibration, the centre also participates in research and development project – including the Innovation Consortium CIA-CT. Furthermore, as part of DPLL (Danish Primary Laboratory for Length) the centre also participate in activities within metrology, both in Denmark and abroad, including participation in Key Comparison and TC-L (Technical Comity for Length within EURAMET).

Figure 14: Calibration lab.

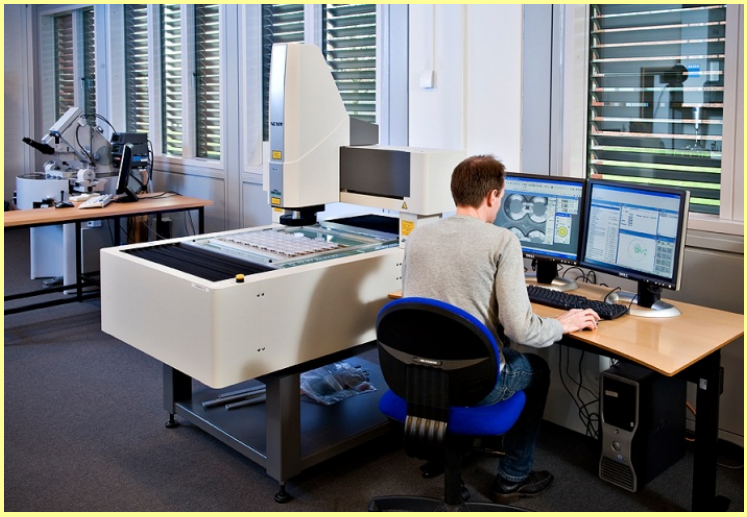

Figure 15: Nikon Nexiv VMR-655 optical instrument.

Figure 16: Metrotom 1500 by Zeiss at DTI.

CIA-CT Newsletter
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IPU

Technological Institute

Novo Nordisk

Danish Meat Research Institute

Yxlon

Deformalyze

Project website: www.cia-ct.mek.dtu.dk

CIA-CT

Project Newsletter
May 2012 - NR 6

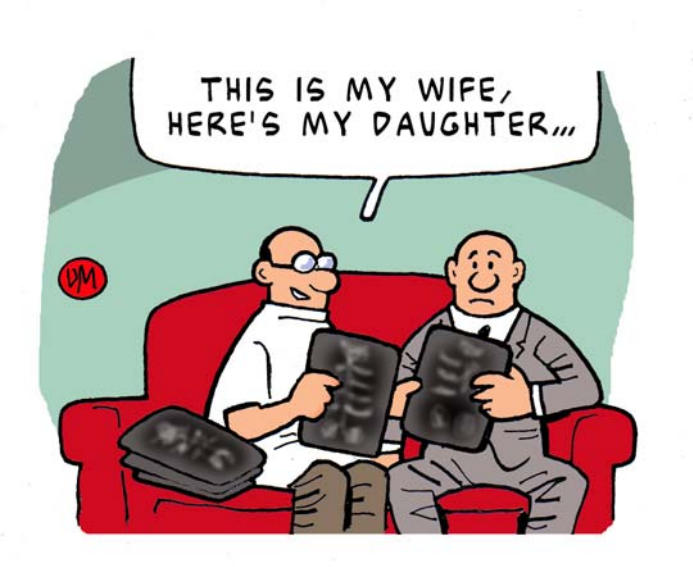
Center for Industrial Application of CT scanning

EDITORS' NOTE

Dear reader,
Welcome to the sixth issue of our newsletter. The sixth Consortium meeting, which took place at Yxlon on March 29th 2012, and the CT Audit Workshop, held and organized by University of Padova, are relevant events occurred in the last sixth months. In particular the CT Audit Workshop, which took place on October 26th 2011, is the final event connected to the CT Audit, the first International intercomparison of Computed Tomography systems in dimensional metrology. Details about the event and main results of the CT Audit are reported in the current issue. The issue carries on with a contribution by Niels Bohr Instutute, about the Nexim research project.
We also invite you to attend our Conference on " Application of CT scanning – Possibilities & Challenges", which will be held at DTU the 12th of June 2012. The detailed program is shown at the end of the newsletter.

Greetings

The Editors



RELEVANT EVENTS

The sixth Consortium meeting

The sixth CIA-CT Consortium meeting took place on the 29th of March 2012 at Yxlon International A/S (http://www.yxlon.com). Progress reports in the different workpackages in last six months were presented by the Consortium partners.

Figure 1: The meeting was attended by 17 people from the Consortium.

CT Audit Workshop

University of Padova has organized and hosted the CT Audit international workshop, which took place the 26th of October 2011. The Workshop was the final event connected with the "CT Audit: Interlaboratory Comparison of Computed Tomography Systems for Dimensional Metrology", the first international intercomparison of Computed Tomography systems in dimensional metrology.

During the workshop the intercomparison results were officially presented by the Audit coordinator, Dr. Simone Carmignato, and discussed among the Audit participants. More details concerning the CT Audit will be presented later in the newsletter.

The CT Audit Workshop was also the place for the first meeting of the international network in CT dimensional metrology, involving the CT Audit Participants, the other organizations which were involved indirectly in the CT Audit and others working actively in the field of computed tomography for dimensional metrology, with the focus aims of deepening the knowledge in CT dimensional metrology and promoting further international initiatives in the field of industrial CT
A picture of people attending the international Workshop is reported in Figure 2.

Figure 2: CT Audit international Workshop, held in Padova, Italy, on October 26th 2011

FEATURED ARTICLE

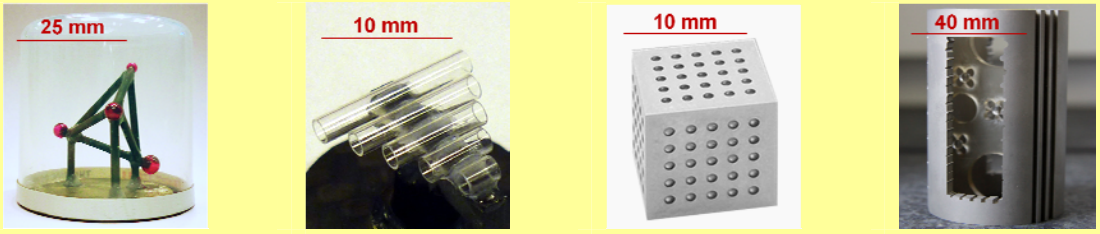
First international comparison of CT systems for dimensional metrology

Simone Carmignato
University of Padova, Italy

The first international interlaboratory comparison of CT systems used for dimensional measurements, called 'CT Audit', was carried out in the period from March 2010 to March 2011, involving 15 CT systems in Europe, America and Asia, operated by expert users. The project was organized and coordinated by the Laboratory of Industrial and Geometrical Metrology, University of Padova, Italy. The participants are listed in the following in alphabetical order:

- AIST - NMIJ, National Metrology Institute of Japan (Japan);
- BAM, Federal Inst. for materials research and testing (Germany);
- Elettra Sinc. S.C.p.A., Trieste (Italy);
- Human Technology Research Institute at AIST (Japan);
- Industrial Technology Center of Tochigi Prefecture (Japan);
- Katholieke Universiteit Leuven (Belgium);
- Nikon Metrology, X-Tek Systems Ltd (UK);
- Novo Nordisk A/S, Device R&D (Denmark);
- Novo Nordisk A/S, DMS Metrology & Calibration (Denmark);
- Pratt & Whitney, Austin (USA);
- RayScan Technologies GmbH (Germany);
- RWTH Aachen University, WZL (Germany);
- Universidad de Zaragoza (Spain);
- University of Erlangen-Nürnberg, QFM (Germany);
- Werth Messtechnik GmbH (Germany).

Four calibrated samples were chosen for the circulation, representing a variety of dimensions, geometries and materials. The samples are shown in Figure 3.



(a) (b) (c) (d)

Figure 3: The four CT Audit samples: (a) CT Tetrahedron, (b) Pan Flute Gauge, (c) Calotte Cube, (d) QFM Cylinder

Figure 4 shows the distribution of Participants on the world map. Besides the 15 CT Audit Participants, other Organizations are indicated in Figure 4: (i) other Organization that measured with their CT systems the calibrated samples, but not participating directly in the CT Audit comparison, and (ii) the three Organizations that provided the calibrated samples:

- University of Padova – Lab. of Industrial and Geometrical Metrology (Italy), providing samples 1 and 2;
- PTB, Physikalisch-Technische Bundesanstalt, Braunschweig (Germany), providing sample 3;
- University of Erlangen-Nürnberg – QFM (Germany), providing sample 4.

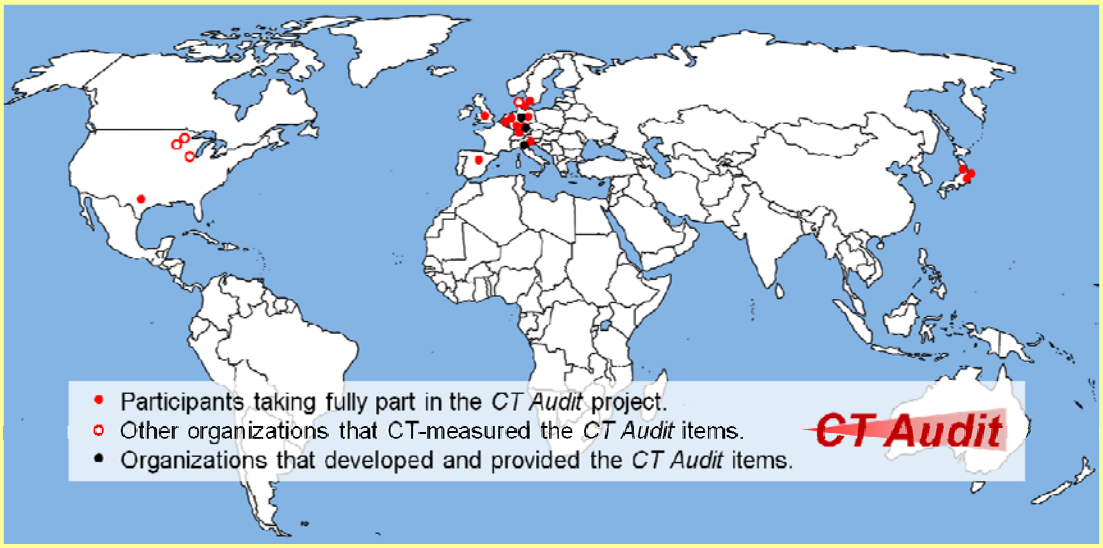


Figure 4: Distribution of CT Audit Participants on the world map

The intercomparison allowed testing several measurement characteristics on the 15 CT systems, for a total of more than 5000 dimensional measurement results collected from the participants. The main results of the intercomparison are summarized here below.

- Most participants perform CT dimensional measurements with sub-voxel accuracy. In specific cases, for size measurements, measurement errors in the order of 1/10 of the voxel size are clearly reachable.
- Measurements of form are more problematic than measurements of size because they are more affected by the influence of the intrinsic noise of CT data.
- The comparison with specified maximum permissible errors of length measurement showed that only a minority of participants are able to perform length measurements with errors below their CT systems' specification.

- Furthermore, less than half of the participants' measurement results have a valid uncertainty statement.

Results document that traceability of CT dimensional measurements is still a major challenge, even for expert users. In order to enhance the current industrial CT practice, international standards are needed to establish proper procedures for uncertainty evaluation and metrological performance verification of CT systems.

Further details on CT Audit may be found in the two following publications:

1. Carmignato S. "Accuracy of industrial computed tomography measurements: Experimental results from an international comparison". CIRP Annals (2012), http://dx.doi.org/10.1016/j.cirp.2012.03.021.
2. Carmignato S., et al., "First international interlaboratory comparison on computed tomography for dimensional metrology". Submitted to Precision Engineering.

NEXIM - a new strategic research project

Mikkel Schou Nielsen, Robert Feidenhans'l
University of Copenhagen, Copenhagen, Denmark

Using the collaboration in CIA-CT as a springboard, the consortium partners from NBI and DMRI have started a new research project called "New X-ray Imaging Modalities for Safe and High Quality Food (NEXIM)", together with the Department of Informatics and Mathematical Modelling at DTU and the Department of Food Science at KU. Several companies are associated with the project including Arla, Danish Crown, Toms, Daloon, Tican, Lantmannen/Schulstad, Bisserup Havbrug, Foss and InnospeXion.
The project has received nearly 20 million DKK in funding from the Strategic Research Council. It aims to develop new imaging techniques for on-line inspection of food products as well as application of X-ray CT in high-resolution studies of food products for developing high quality food.
One of the promising aspects is to use new X-ray imaging modalities for detection of hard-to-find foreign bodies in food products. Refraction- and scattering-based contrast principles can be used to detect pieces of paper or insects in food as complementary to conventional absorption contrast which is used already today for detection of glass, metal or stones. Figure 5 shows an example of a piece of minced meat where the pieces of glass are seen using absorption contrast (middle) and the paper is detected using scattering contrast (bottom).
Another aim is determination of the distribution of ingredients in the product. These can be for instance nuts or berries in chocolate bars or the holes in cheese, which are important quality parameters for the consumers. The idea is to apply X-ray imaging using several modalities to obtain a quantitative measure for the distribution.
These two kinds of inspections are performed using radiography yielding 2D images.
In another area of the project, the aim is to perform CT studies using synchrotron radiation facilities for studying food products at high resolution.

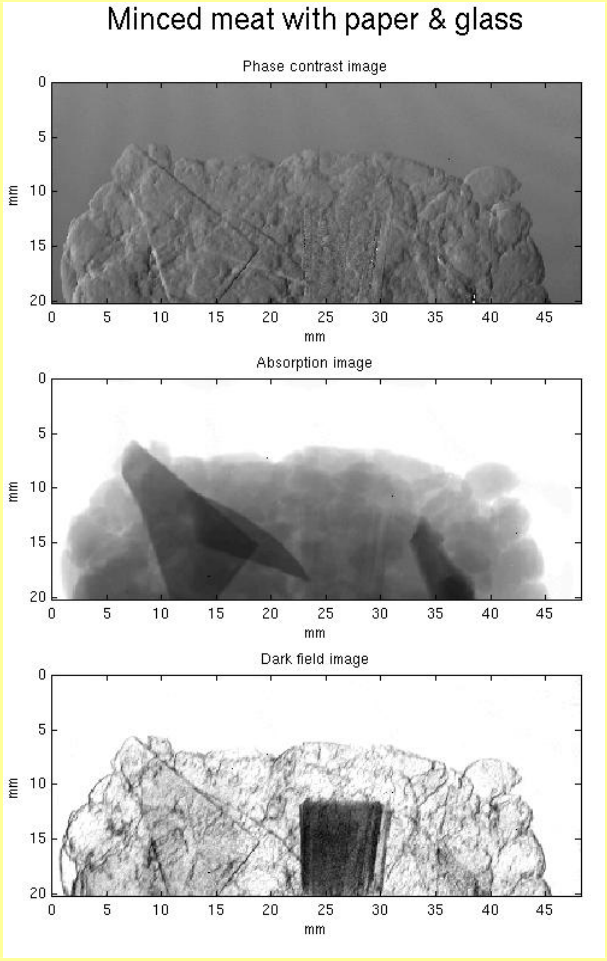


Figure 5: A piece of minced meat containing pieces of glass (left and right) and paper (middle) imaged using three X-ray modalities: Refraction, absorption and scattering

A possible CT-study can be the interaction of fat and water-soluble proteins in meat emulsions which are used for e.g. sausages. Healthier food could be obtained by replacing animal fat with vegetable oils but it is known not much about the difference in terms of interactions on small-scale. Another investigation can be the interaction between filling and chocolate in chocolate bonbons which is a complicated heterogenic system. As seen in Figure 6, the use of several imaging modalities are also useful for the study of chocolates with filling. The next step would be to replace the radiography study presented in Figure 6 with a CT scan.

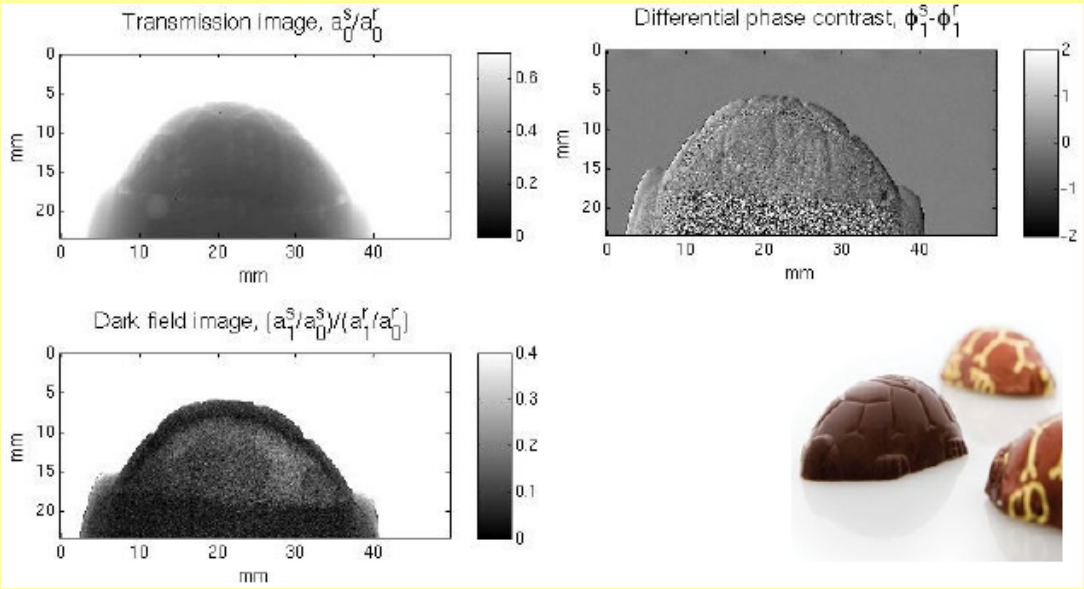


Figure 6: Radiograms of a "Toms skildpadde" chocolate with filling using absorption- (upper left), refraction- (upper right) and scattering-based contrast. The contrast between filling and chocolate is largest using the scattering contrast.

The NEXIM project had an official kick-off meeting the 22nd of February and is scheduled to run for four years.

Conference
"Industrial Applications of CT Scanning – Possibilities & Challenges in the Manufacturing Industry"

June 12, 2012, 10:00-16:30
DTU, Building 101, meeting room 1
Kgs. Lyngby, Denmark

Program

9.30-10.00	Registration and coffee	
10.00-10.10	Welcome	*Mogens Arentoft, IPU, Denmark*
10.10-10.20	Introduction	*Leonardo De Chiffre, DTU, Denmark*
10.20-11.00 *1*	Keynote "Computed Tomography on Large Objects – Theoretical and Practical Solutions with Extended Field of View and ROI-CT"	*Jürgen Stephan, Siemens, Germany*
11.00-11.20	Break	
11.20-11.40 *2*	"CT scanning in pump manufacture"	*Thomas Kjærgaard, Grundfos, Denmark*
11.40-12.00 *3*	"Applications of CT scanning in electronics"	*Ralf Poder, SP Electronics, Sweden*
12.00-12.20 *4*	"CT scanning in the medical device industry"	*Trine Sørensen, Novo Nordisk, Denmark*
12.20-13.30	Lunch	
13.30-14.00 *5*	"Computed Tomography: From Lab Application to In-line Use"	*Dietrich Imkamp, Carl Zeiss, Germany*
14.00-14.30 *6*	"Results of Digital Laminography with 600kV"	*Malte A. Kurfiss, Yxlon, Germany*
14.30-14.50 *7*	"CT scanner selection for industrial case solutions"	*Michael D. Bentzon, DTI, Denmark*
14.50-15.00	Break	
15.00-15.40 *8*	Keynote "How accurate is Computed Tomography for Dimensional Metrology?"	*Simone Carmignato, Univ. of Padova, Italy*
15.40-16.00 *9*	"Evaluation strategies in CT scanning"	*Jochen Hiller, DTU Mekanik, Denmark*
16.00-16.20 *10*	"A new intercomparison for industrial CT scanners"	*Erik Larsen, IPU, Denmark*
16.20-16.30	Summary and closure	

CIA-CT Newsletter
NR6 – MAY 2012

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Project Partners:

DTU Mechanical Engineering

Department of Computer Science – Copenhagen University

Niels Bohr Institute – Copenhagen University

IPU

Technological Institute

Novo Nordisk

Danish Meat Research Institute

Yxlon

Deformalyze

Project website: www.cia-ct.mek.dtu.dk

Center for Industrial Application of CT scanning

EDITORS' NOTE

Dear reader, welcome to the seventh issue of our six monthly newsletter from the CIA-CT project! The seventh consortium meeting which took place at IPU on September 25, 2012 and a workshop held at DTU on November 27, 2012 to launch a new international Inter laboratory comparison on Industrial Computed Tomography are relevant events that took place during the last six months. In particular, the workshop has led to the finalization of a Technical Protocol for the "CIA-CT comparison" involving 25 participants worldwide. This issue also contains the featured article "New reference object for metrological performance testing of industrial CT systems". Finally, we pre-announce that the next annual CIA-CT Conference will be held at Niels Bohr Institute on June 19, 2013, followed by the CIA-CT Comparison Final Workshop at DTU on June 20, 2013.

We hope that you will enjoy reading.

With greetings,

The Editors

RELEVANT EVENTS

The seventh Consortium meeting

The seventh CIA-CT Consortium meeting took place on the 23rd of October 2012 at IPU (http://www.ipu.dk). Progress reports in the different work packages over last six months were presented by the Consortium partners.

CIA-CT Comparison Workshop

A final workshop was held at DTU on September 5, 2012 concerning the CIA-CT audit (Inter laboratory comparison of industrial CT scanners) carried out in the period November 2010 to July 2012.

The intercomparison involved six participants from institutes, universities, industrial companies and CT systems manufacturers in Denmark and Germany. The circulation took place between March 2011 and June 2011. Three audit items, similar to common industrial parts, were selected for circulation: a single polymer complex geometry part (Item 1), a simple geometry Item made of two polymers (Item 2) and a step gauge (Item 3) used for optical scanners verification.

The comparison provided useful experience and results but also showed that two of the selected items (item 2 and item 3) created some difficulties due to material stability and form errors. It was therefore agreed at the workshop that a new comparison involving industrial items should be organized based on the experience from the first audit.

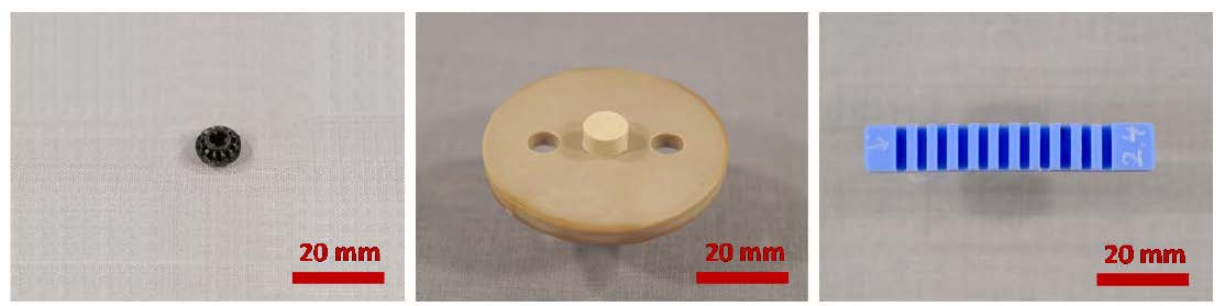


Figure 1: The three items used in the first CIA-CT Inter laboratory comparison of industrial CT scanners. From the left Item 1, Item 2 and Item 3.

A second workshop was consequently held at DTU on November 27, 2012 to launch a new international inter laboratory comparison on Industrial Computed Tomography. In particular, the workshop led to the finalization of a Technical Protocol for the new “CIA-CT comparison”.

The ‘CIA-CT comparison - Inter laboratory comparison on industrial Computed Tomography” is organized by DTU Mechanical Engineering within the Danish project “Centre for Industrial Application of CT scanning - CIA-CT”. The comparison aims to collect information about measurement performance in state-of the-art industrial Computed Tomography. This investigation focuses mainly on operator influences on the measurement result including the evaluation of uncertainty of measurement for the establishment of measurement traceability.

The goals of the comparison:

- To test applicability of CT scanning for measurement on small objects commonly measured in industry, which are less accurate and stable than reference artefacts.
- To evaluate the impact of instrument settings and operator decisions on the measurement of items of two different materials and geometries.
- To investigate measurement errors and their causes.
- To share knowledge on practical aspects related to the traceability of measurements using industrial CT scanning.

Figure 2: A workshop was held at DTU on November 27, 2012 to launch a new international Inter laboratory comparison on Industrial Computed Tomography.

Two items are used, selected among common industrial parts: a polymer part and a metal part, as shown in Figure 3. The items will be measured by 25 participants from different countries. Parallel circulation of 25 sets with the two items will take place in January 2013. The whole circulation is planned to take place within one month. Participants' results will be analyzed and a draft report produced and discussed at a final workshop on June 20, 2013. The single participants will be kept anonymous.

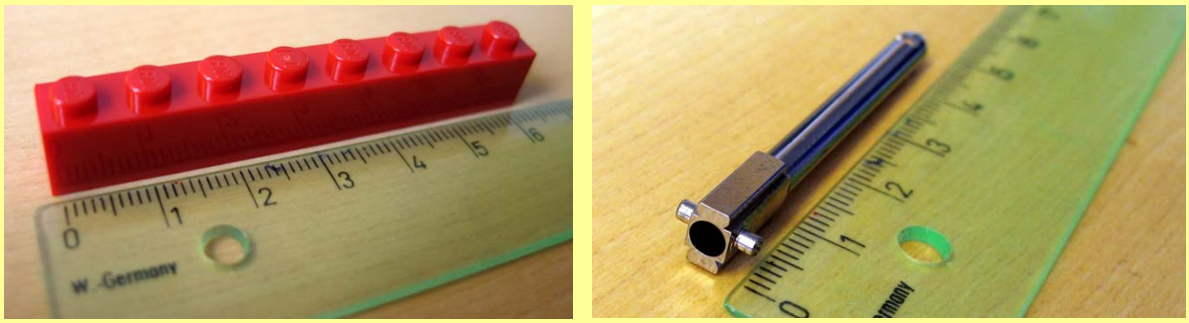


Figure 3: The two items used in the second CIA-CT Inter laboratory comparison of industrial CT scanners. From the left Item 1 and Item 2.

FEATURED ARTICLE

New reference object for metrological performance testing of industrial CT systems

P. Müller, J. Hiller, A. Cantatore, G. Tosello, L. De Chiffre
Department of Mechanical Engineering, Technical University of Denmark, Kgs. Lyngby, DK

Introduction

Computed Tomography (CT) is the third generation of measuring techniques used in the field of dimensional metrology. Its main advantages in contrast to tactile or optical measurements rely in short scanning time, possibility to measure internal features and high information density. Due to a large number of influence quantities occurring in the whole CT process, and the fact that CT systems are multi-purpose measuring devices, measuring uncertainties are in many cases unknown. This is also because standards and procedures are still under development [1]. The attempt is to develop reference objects, similar to objects used in classical coordinate metrology, for the identification of error sources and their correction. This work presents a new reference object, a “CT ball plate” (Figure 4 left), used for performance assessment of CT systems, its calibration using a coordinate measuring machine (CMM) and the first tests using a CT system. This object enables to measure probing errors and length measuring errors in accordance to procedures applied in classical coordinate metrology.

Design and calibration

The CT ball plate features a regular 5x5 array of ruby spheres with a nominal diameter of 5 mm. The balls are glued on a carbon fibre plate using a two-component epoxy resin, ensuring long-term stability of the position of the balls. Carbon fibre is a material widely used in CT scanning applications due to its high penetrability rate to X-rays. The concept of the CT ball plate is similar to the calotte plate developed by Physikalisch-Technische Bundesanstalt (PTB) [2]. In our case, the ruby balls feature well defined geometries compared to the calottes on the calotte plate, and therefore minimize manufacturing inaccuracies.
The calibration of the artefact was carried out using a Zeiss OMC 850 tactile CMM at the laboratory of the Technical University of Denmark (DTU). The calibration procedure combines the use of the reversal method and the guidelines for the application of DIN EN ISO 10360. The traceability was transferred by measuring a calibrated ball plate commonly used for calibration of CMMs (Figure 4 right). Calibration was repeated three times in two positions (D0 and D180) defined by turning the part by 180 degrees, and reproduced in three different days. The CT ball plate was re-positioned in the fixture when measured in different days. Measuring uncertainties were calculated for four selected measurands: diameter of spheres and X-, Y- and Z-coordinates of sphere centers. Three uncertainty contributors were taken into account in the uncertainty budgeting:

- Uncertainty from the calibration certificate of the ball plate
- Uncertainty during to the traceability transfer
- Uncertainty from measurement repeatability (D0+D180).

Measuring uncertainties were assessed as maximum expanded uncertainties at 95% confidence level for each measurand, taking into account all 25 balls, calculated in different days, and are summarized in Table 1. The calculated uncertainties yield high measuring reproducibility with complete comparability of measuring results obtained in the different days.

Table1: Expanded uncertainties for calibration of the CT ball plate.

	Diameter	X-coord.	Y-coord.	Z-coord.
U(k=2) in µm	0.9	2.2	1.7	4.0

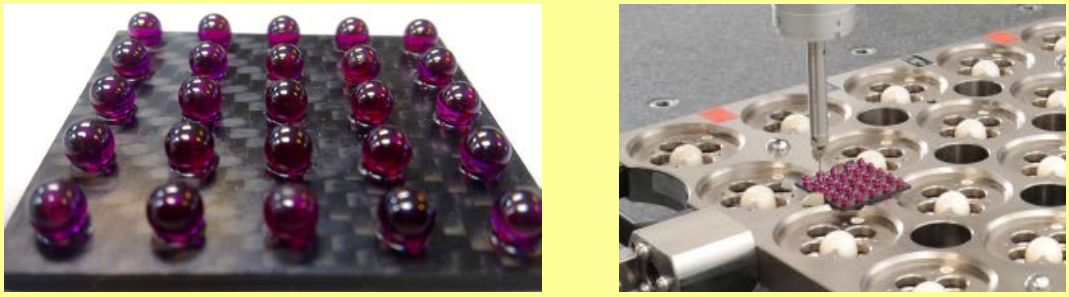


Figure 4: CT ball plate (left) and a setup for traceability transfer using a ball plate as part of the calibration procedure of the CT ball plate using CMM (right).

First test on µCT systems

The CT ball plate was scanned using a Nikon Metrology XT H 225 ST CT scanner at PTB Braunschweig (Figure 5 left). The test procedure involves measurement of center coordinates of spheres, their diameter and form error, similarly to the procedures applied to CMMs. This allows the determination of length measuring errors, sphere distance errors and probing errors. The reference object was scanned according to VDI/VDE 2630 – Part 1.3 [3]. This guideline suggests scanning an object at two different magnifications and orientations. In this way, spatial distribution of errors can be determined. In addition, the test method involves correction of scale errors in all space directions. Errors found for different positions and orientations of the object in the CT volume are a result of anisotropies in the measuring volume of the CT system. Figure 5 (right) shows four positions of the object in the CT volume.

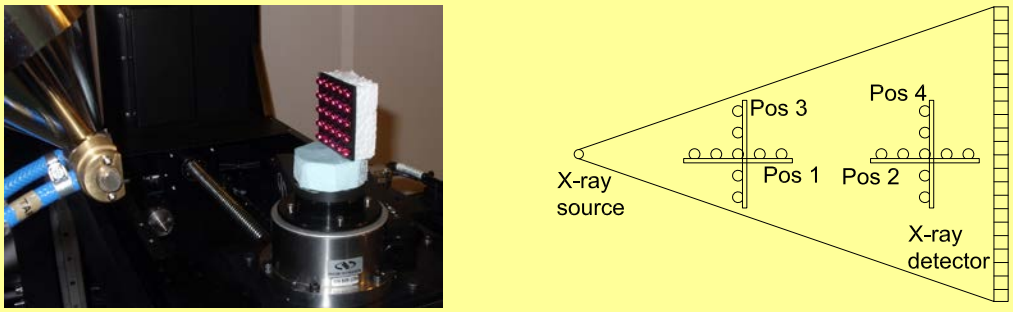
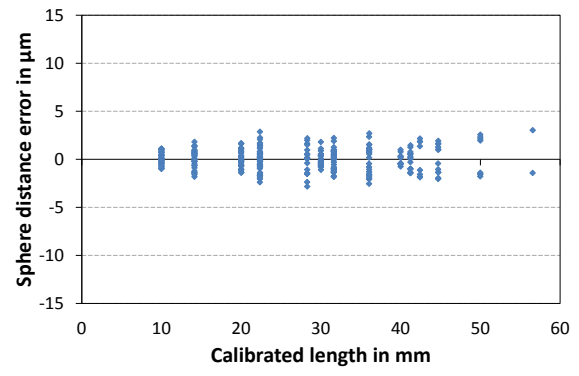


Figure 5. Scanning of the CT ball plate using Nikon Metrology CT scanner (left) and four positions of the CT ball plate in the CT volume in side view (right).

Figure 6 presents results of length measuring errors which occurred at positions 1 and 3. The results were corrected for scale errors applying linear regression function. A clear difference in the magnitude of the errors can be observed between the two positions. This is caused by the fact that the object is scanned at the borders of the X-ray detector (position 3) where errors due to Feldkamp effect are pronounced [1].



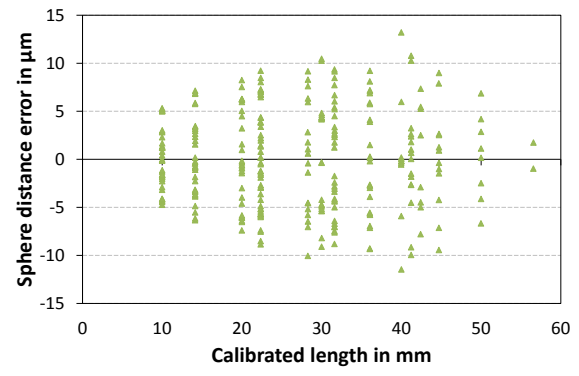


Figure 6: Sphere distance error at position 1 (left) and position 3 (right) for scanning of the CT ball plate using Nikon Metrology CT scanner.

Conclusion and outlook

The new reference object – CT ball plate – appears to be a useful tool for performance testing of CT systems. The object will be further applied in connection with quantification of measuring errors in the CT volume.

References

[1] Kruth, J.P., Bartscher, M., Carmignato, S., Schmitt, R., De Chiffre, L. and Weckenmann, A. (2011). Computed Tomography for Dimensional Metrology, keynote paper, CIRP Annals, 61/2, 821-842.

[2] Bartscher, M., Hilpert, U., Goebbels, J., Weidemann, G. (2007). Enhancement and Proof of Accuracy of Industrial Computed Tomography (CT) Measurements, CIRP Annals, 56/1, 495-498.

[3] VDI/VDE 2630 - Part 1.3 Computed tomography in dimensional measurement,
Guideline for the application of DIN EN ISO 10360 for coordinate measuring machines with CT sensors, 12/2011.

CALENDAR OF UPCOMING EVENTS

Public defense of Pavel Müller's PhD thesis *"Coordinate Metrology by Traceable Computed Tomography"* will take place at DTU on **March 8, 2013.**

Next annual CIA-CT Conference will be held at Niels Bohr Institute, University of Copenhagen on **June 19, 2013.**

The CIA-CT Comparison Final Workshop will be held at DTU on **June 20, 2013.**

CIA-CT Newsletter
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The Niels Bohr Institute, eScience

The Niels Bohr Institute, Condensed Matter Physics

Danish Technological Institute, Metrology and Quality

Danish Technological Institute, Danish Meat Research Institute

IPU

Novo Nordisk

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CIA-CT

Project Newsletter
June 2013 - NR 8

Center for Industrial Application of CT scanning

EDITORS' NOTE

Dear reader, welcome to the eighth issue of our six monthly newsletters from the CIA-CT project! Pavel Müller's PhD defense, the eighth consortium meeting which took place at DTI on March 12, 2013 and the new Inter laboratory comparison on Industrial Computed Tomography are relevant activities that took place during the last six months. In particular, the comparison involving 27 participants worldwide has been successfully carried out and its preliminary results are presented and discussed at a workshop at DTU on June 20, 2013. In this issue we present LEGO that in 2013 has joined the CIA-CT as a new project partner. We also recall the 4th CIA-CT Conference on "Applications of Computed Tomography in Industrial Production" held at the University of Copenhagen on June 19th, 2013. The detailed program is presented at the end of this newsletter.

We hope that you will enjoy reading.

With greetings,

The Editor

RELEVANT EVENTS

PhD defense by Pavel Müller

Pavel Müller defended his PhD with the title “Coordinate Metrology by Traceable Computed Tomography”. The defense took place at DTU on Friday, March 8th, 2013. The appointed examiners were Professor Jean-Pierre G. Kruth, Univ. of Leuven, Assistant Professor Simone Carmignato, Univ. of Padova, and Associate Professor Giuliano Bissacco, DTU. Associate Professor Guido Tosello, DTU chaired the defense.

Figure 1: From left: Dr Simone Carmignato, Professor Jean-Pierre G. Kruth, Dr Giuliano Bissacco, Dr Guido Tosello, Prof. Leonardo De Chiffre, and Dr Pavel Müller.

The eighth consortium meeting

The eighth CIA-CT Consortium meeting took place on the 12th of March 2013 at Danish Technological Institute (http://www.teknologisk.dk). Progress reports from the different work packages over the last six months were presented by the Consortium partners.

CIA-CT Comparison – Interlaboratory comparison on Industrial Computed Tomography

The ‘CIA-CT comparison - Inter laboratory comparison on industrial Computed Tomography” is organized by DTU Mechanical Engineering and involves 27 participants from 8 different countries. The comparison aims to collect information about measurement performance in state-of the-art industrial Computed Tomography. This investigation focuses mainly on operator influences on the measurement result, including the evaluation of uncertainty of measurement for the establishment of measurement traceability.

Two items are used, selected among common industrial parts: a polymer part and a metal part. The items have been measured by the participants in a parallel circulation which has taken place in January 2013. Valuable information has been collected and is currently under analysis. A draft final report has been produced and will be discussed at a workshop with the participants on June 20, 2013. The single participants are kept anonymous.

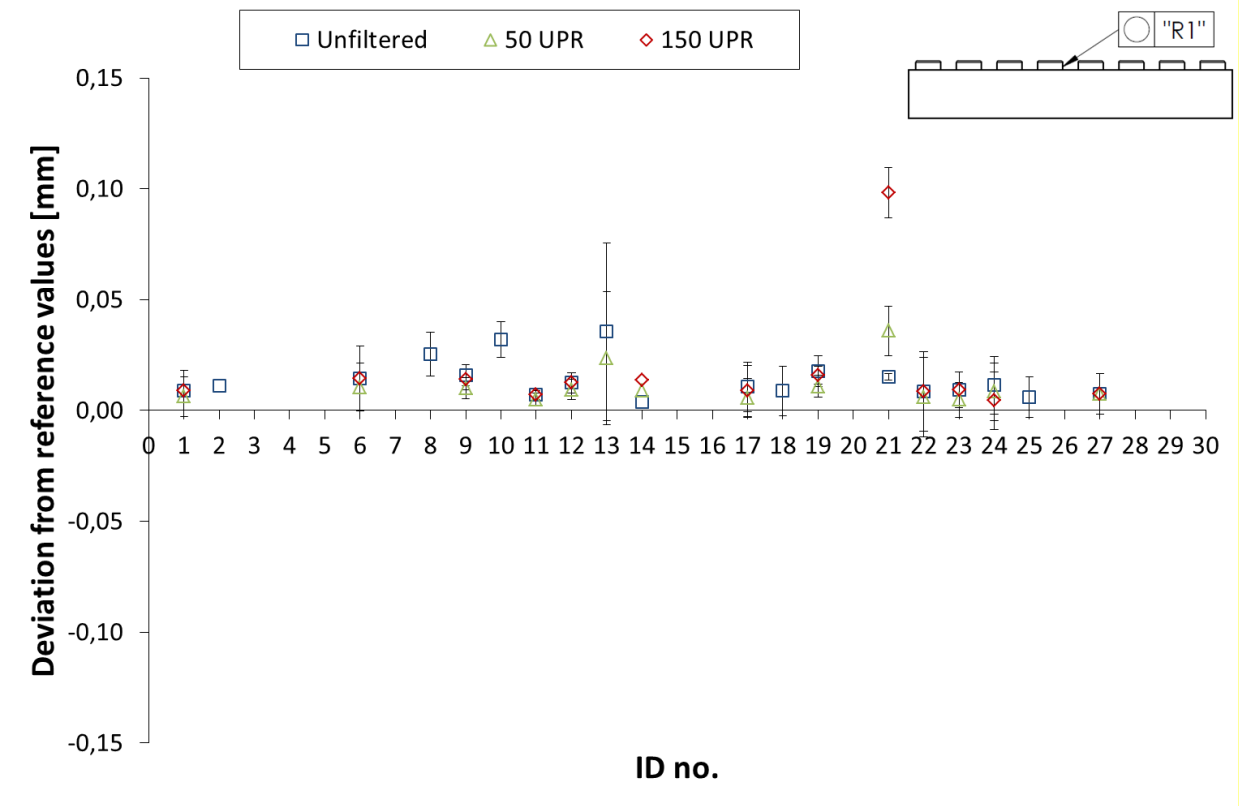


Figure 2: Example of preliminary results from the CIA-CT Inter laboratory comparison of industrial CT scanners. Participants' deviations from reference values for the case of roundness of a knob on item 1. Results from twenty participants only are considered in this graph.

MEETING WITH THE CIA-CT CONSORTIUM

In this issue we present LEGO that in 2013 has joined the CIA-CT as a new project partner.

LEGO

The LEGO Group is a privately held company based in Billund, Denmark. The company is still owned by the Kirk Kristiansen family who founded it in 1932.

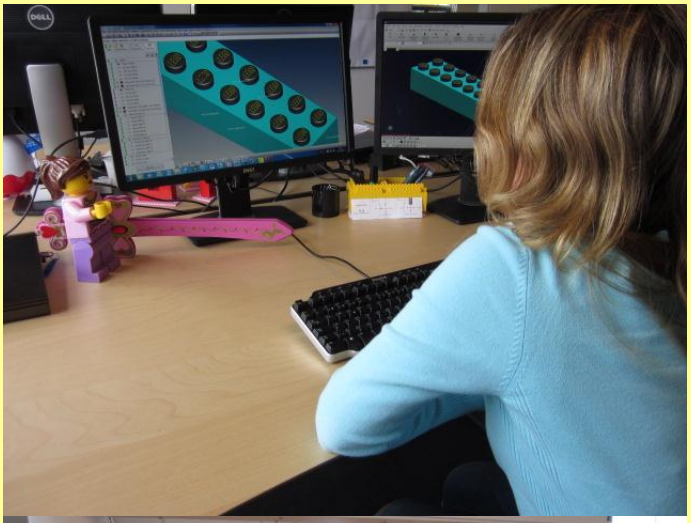
The LEGO Group is engaged in the development of children's creativity through playing and learning. Based on the world-famous LEGO® brick, the company today provides toys, experiences and teaching materials for children in more than 130 countries. The LEGO Group has approximately 10,000 employees, and it is the world's third largest manufacturer of play materials.

Our head office is in Billund, Denmark but we have subsidiaries and branches throughout the world, and LEGO products are sold in more than 130 countries.

Verification department is responsible for measuring and testing of LEGO elements from new production moulds. The test results are used as a basis for approval and release of new elements -therefore of moulds – and are an important contribution in the value chain of mould

manufacturing.

The LEGO elements are measured either by the use of 3D Coordinate Measuring Machine or manual measuring equipment. The idea is to measure as many elements as possible by machine, but today around 75% of the element features are still measured manually due to limitations of the technology on our existing equipment. However, many elements feature complex geometries and are therefore sent for CT scanning. These elements feature high aspect ratios and hidden positions, where measurements by common means are not possible. As of today, at Verification we are newly equipped with a CT scanner, which will further support our quality control of the moulds.



4th CIA-CT Conference on "Applications of Computed Tomography in Industrial Production"

June 19, 2013, 10:00-16:30
University of Copenhagen
Niels Bohr Institute, Auditorium M
Blegdamsvej 21, Copenhagen, Denmark

Program

9.30-10.00	Registration and coffee Introduction	
10.00-10.10	Welcome	*Robert K. Feidenhans'l, KU-NBI, Denmark*
10.10-10.30	"Centre for Industrial Application of CT scanning (CIA-CT) – four years of results"	*Leonardo De Chiffre, DTU Mekanik, Denmark*
10.30-10.50	Break Session on "Physics of Computed Tomography"	
10.50-11.10 *1*	"Principles of Computed Tomography"	*Robert K. Feidenhans'l, KU-NBI, Denmark*
11.10-11.30 *2*	"Image quality enhancement in Computed Tomography"	*Jochen Hiller, Carl Zeiss, Germany*
11.30-11.50 *3*	"3D imaging using different sources"	*Erik Mejdal Lauridsen, DTU Energy Conversion, Denmark*
11.50-12.10	Break Session on "Metrology of Computed Tomography"	
12.10-12.50 *4*	Keynote "CT for dimensional metrology"	*Ralf Christoph, Werth Germany*
12.50-13.10 *5*	"Practical solutions to the measurement of micro structure resolution"	*Simone Carmignato, Padova University, Italy*
13.10-14.20	Lunch Session on "Industrial applications"	
14.20-14.40 *6*	"CIA-CT inter laboratory comparison on industrial computed tomography"	*Erik Larsen, IPU, Denmark*
14.40-15.10 *7*	"Applications of Computed Tomography in Industrial Production"	*David Bate, Nikon Metrology, UK and Wenjuan Sun, NPL, UK*
15.10-15.30 *8*	"Applications of CT in the manufacturing industry"	*Martin Simon, Wenzel, Germany*
15.30-15.40	Break	
15.40-16.00 *9*	"Tree D Furniture – CT in wood"	*Jørgen Rheinlænder, InnospeXion, Denmark*
16.00-16.20 *10*	"Computed Tomography solutions in the food industry"	*Lars Bager Chistensen, Teknologisk/DMRI, Denmark*
16.20-16.30	Closure	

CALENDAR OF UPCOMING EVENTS

4th CIA-CT Conference on ”Applications of Computed Tomography in Industrial Production” at Niels Bohr Institute, University of Copenhagen on **June 19, 2013.**

The CIA-CT Comparison Final Workshop at DTU on **June 20, 2013.**

The German-Austrian-Danish Workshop Industrial CT Scanning at TUM, Munich, Germany on **October 23-25, 2013.**

The fifth Conference on Industrial Computed Tomography (iCT2014), Wels, Austria on **February 25-28, 2014**.

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