final report

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Trip Report – DIR 2011 Conference

Digital Radiology and Computed Tomography

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1 Abstract

On behalf of MLA, Soren Erbou and Martin Vester-Christensen from Deformalyze ApS, attended the DIR2011 Conference in Berlin in June 2011. The main purpose was to report any knowledge on topics relevant to MLA research projects on Computed Tomography (CT) applications as well as reporting personal views of technologies of interest to MLA. The main focus of the conference was on industrial CT in relation to metrology, material characterisation and non-destructive testing (NDT). Companies and individuals interested in inline CT for the meat industry were identified and a gantry-based helical CT-scanner similar to inline CT-scanners from security applications is recommended, although more simple systems based on laminography or tomosynthesis should be considered depending on the specific requirements of each application.

2 Executive Summary

On behalf of MLA, Soren Erbou and Martin Vester-Christensen from Deformalyze ApS, attended the DIR2011 Conference in Berlin in June 2011. The main purpose was to report any knowledge on topics relevant to MLA research projects on Computed Tomography (CT) applications as well as reporting personal views of technologies of interest to MLA. The main focus of the conference was on industrial CT in relation to metrology, material characterisation and non-destructive testing (NDT) and companies and individuals interested in inline CT for the meat industry were identified.

The applications presented at the conference focussed more on high resolution and signal-to-noise-ratio (SNR) and less on speed. In an inline meat application scan time is a top priority and resolution less important, as long as the quality measures are obtainable. It is important to be aware of the completely different approach to CT-scanning that the metrology and NDT communities have, compared to the community of medical applications. In industrial CT the object is rotated and in medical CT the source and detector are fixed on a rotating gantry. Industrial CT has limited object size but very high resolution. Depending on the requirements of each specific application, tomosynthesis or laminography should be considered, since these techniques are simpler and most likely cheaper to apply, but offers images of lower quality.

Our recommendation is to adopt the gantry-based helical inline CT scanners available for security applications. It is not feasible to rotate carcases or pieces of meat due to their deformable nature. Helical CT is preferable since the application is continuous inline inspection using a conveyor.

For an inline CT system to function successfully in an abattoir the key requirements that must be addressed are; speed, hygiene, robustness and radiation safety. The system should be designed around these requirements. It would most likely be beneficial for MLA to gain from the Danish Meat Research Institute's (DMRI) experience with building an inline CT-scanner for abattoirs.

These issues must be addressed to successfully apply a CT system inline in an abattoir. However, inline CT is used successfully in security applications, having some of the same requirements of high speed and zero downtime, and these must be met. We would recommend the establishment of collaboration with vendors of CT systems to the security industry. They are definitely a source of knowledge on many of the issues pertaining the use of inline CT in abattoirs.

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4 Background

A specialist CT Conference took place in Berlin in June 2011. The subject matter of this conference is relevant to the projects that are being undertaken or are about to be undertaken in the CT arena. It is important that MLA/AMPC have any relevant knowledge that comes from this conference to assist in evaluating or advancing the research projects that are already underway. Details of the conference can be found at this web link:-

http://www.dir2011.com/

The relevant issues are listed as :-
1. X-ray detectors and sources
2. Radiography (multi-angle)
3. Computed Tomography
4. Laminography & Tomosynthesis
5. Dual and multi-energies
6. Phase contrast
7. Image processing algorithms
8. Quantitative imaging
9. Modelling
10. Data fusion
11. Scattering
12. Defect detection & localisation
13. Feature extraction
14. Dimensional control
15. Standardisation
16. Qualification & system reliability

All of these topics being presented are related to the common issues that have been experienced with the trial work using Computed Tomography and Cone Beam X-Ray, that have been undertaken by MLA/AMPC. It is important that this knowledge be gained and understood by resources within MLA or AMPC for use in the application to solving problems that will be experienced with trial work regarding CT projects and red meat.

5 Project Objectives

The outcomes from this project will be:-

1. A report on the issues that were discussed and are relevant to AMPC/MLA in their decision making on the future development of CT for the red meat industry.

2. Identification of potential new technologies that may be relevant to MLA.

3. Identification of companies and individuals who are working in the relevant areas of new CT Technology developments

Objectives of this project are to:-

1. Learn more about those issues related to CT that are causing concern experienced with the CT trials undertaken

2. Gain an understanding of how the application of that technology to the meat industry might occur and determine what this means for the path forward.

6 Methodology

Deformalyze attended the conference on behalf of MLA and contacted relevant exhibitors.

7 Results

The DIR2011 conference (Digital Industrial Radiology and Computed Tomography) was organised by the *German Society for Non-Destructive Testing* (DGZfP). The previous conference took place in 2007 and the first one in 1988 and the intention of the conference is to be a venue for scientists, industry and other interested in the topics listed in section 4. 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, standardisation, material characterisation, non-destructive testing (NDT) etc. Both hardware and software vendors were present in the exhibition.

7.1 Presentations

Radiography and Computed Tomography (CT) in relation to NDT were the overall topics and the talks were split into the following 12 sessions:

Mo. 1 - X-Ray Sources:

Reducing the focal spot shift by cooling. Investigating thermal expansion in long scan times (2-3 hours) using micro/sub-micro focus.
Applying liquid metal jet targets instead of solid targets enable higher power loads per area and thereby smaller focal spot sizes at higher energies, i.e. higher brilliance.
Fraunhofer EZRT presented studies from the first stage of their high-energy linear accelerator from Siemens (SILAC) with an energy range up to 9MeV.

The session dealt with optimising x-ray sources for better performance, i.e. better signal-to-noise ratio (SNR) at high resolution and was most of all examples of what parameters the industry currently are looking at to optimise. None of the technologies presented seem interesting from the point-of-view of an inline CT scanner for meat applications, since they are mostly relevant for applications with long scan times and much smaller objects.

Mo. 2 - Dimensional Computed Tomography

Preliminary results from the “CT Audit”, an international comparison of CT-systems for dimensional metrology. Showed results based on mesurements of 4 calibration items.
Comparison with respect to industrial CT metrology, of the Katsevich Algorithm for helical cone beam reconstruction and the Feldkamp (FDK) algorithm for circular reconstruction. Both methods are implemented in the upcoming Volume Graphics Studio Max 2.2.
Wenzel Volumetric presented a comparison of CT and optical scanner systems for generating 3D surfaces.

The comparison of helical and circular reconstruction algorithms is interesting since an inline scanner will most likely have to use a helical approach to meet the time requirements, even though it is an algorithm of higher complexity.

Mo. 3 - Optimisation of Computed Tomography

Fraunhofer IIS presented their software Scorpius XLab for simulation-based planning of CT. It simulates CT-systems from source to detector, taking e.g. beam-hardening artefacts and object orientation into account.
http://www.iis.fraunhofer.de/bf/xrt/ctundmess/xlab/
Scatter-correction by modulation of primary radiation. Compared to traditional methods, Beam Stop Array and Beam Hole Array. No additional scans needed but only mono-materials.
Measuring 2D positional stability and scheme for correcting the shift I y-direction.

The Scorpius XLab from Fraunhofer IIS seems interesting for modelling industrial CT-scans, but it will need customisation for application to gantry-based systems.

Mo. 4 - Computed Tomography Applications

Efficient identification of similar work pieces. Definition of adequate parameters.
Multi-resolution X-ray CT imaging of fiber reinforced composite materials. Details needed on different scales, from cm to nm. Multi-resolution approach, combining sinograms at different source-to-object distances (magnification). Combines sinograms before reconstruction, resulting in a volume with varying resolution.
Material dependent thresholding. Shows examples of how the optimal threshold is dependent on the material, artefacts, detector, etc.

The multi-resolution approach seems interesting, but is still purely academic.

Tu. 1 - Phase Contrast Imaging

Effects of cooling vs. no cooling in phase contrast imaging.
Differential phase contrast. Applying interferometry utilises the phase shift in the signal contrary to regular CT which utilises the absorption. Other features can be visualised. Requires much higher energies, only available in synchrotron facilities, i.e. only of academic interest.
Application of phase contrast tomography in lab-based micro-CT systems. Shows other methods for utilising the phase in the signal. Applicable to mono-materials only.

This session was very research-driven, with no results or knowledge of immediate interest to MLA.

Tu. 2 - Radiographic Simulation

Experimental validation of Build-Up Factor predictions. 3 validation schemes. Talk 2.2 cancelled.
Radiographic simulator ARTIST and simulation of Probablity of Detection POD.

Session irrelevant to MLA

Tu. 3 - Micro-CT Applications

Porosity detection in carbon fiber reinforced plastics (CFRP). Uses Volume Graphics Analyser + Porosity Detection modules.
GE Sensing (Phoenix X-Ray) presents an overview of high resolution CT-system and a comparison to synchrotron-based CT.
Application of the DIRECTT algorithm to fuel-cell analysis. An iterative algorithm for reconstruction that shows impressive results w.r.t. artefacts compared to standard reconstruction algorithms. The drawback is that it is more time-consuming.

The micro-CT applications are not of any specific interest to MLA, but the results of the DIRECTT algorithm are definitely worth to look at, if conventional reconstruction does not seem adequate.

Tu. 4 - Qualification

This session treated different aspects of standardising CT-measurements, making them comparable and traceable w.r.t. metrology standards. This is relevant, especially when dealing with rigid objects, for performing CAD-comparisons etc. It is not relevant when dealing with soft tissue measurements at a larger scale. Work is done to form an international society bringing together all (non-medical) players within CT.

We. 1 - Film Replacement And Standards

Talks on replacing conventional film with digital detectors and comparing them to standards. Session not relevant for MLA

We. 2 - Other X-Ray Applications

X-ray technology for detection of explosives based on spectrometric methods.
Field NDT, explosives and bore pipes.
Not relevant to MLA

We. 3 - 3D Reconstruction Algorithms

Geometric corrections in coplanar translational laminography. Used for objects too large for applying conventional CT, e.g. lightweight planar constructions such as turbine blades, windmill blades and electronic circuit boards. The source and detector are translated in opposite directions while the object is fixed, resulting in focus plane with sharp features and blurred features outside this plane. The image quality in conventional CT is better, but laminography could be interesting to MLA in the case that a conventional CT system is not cost effective. The key issue is if the features detectable using laminography are sufficient for the specific application.

We. 4 - Image Processing

Data fusion for improving classification. A Bayesian framework for fusing features of different nature into a combined classifier. The application is automated detection of defects from x-ray images.
Reference-based radioscopic inspection of turbine blades. Simple segmentation methods applied, results were not convincing.
Applying an Industrial CT reference standard for cast free-form shaped work pieces. Suggests a standard reference and measures for comparison w.r.t. metrology.

This session did not prove itself interesting for MLA w.r.t. image processing, although the Bayesian scheme for combining features in general is a reasonable choice, see any textbook on machine learning.

7.2 Exhibitors

9 exhibitors are relevant to know for MLA, 5 hardware- and 4 software-vendors.

7.2.1 Hardware

The hardware vendors present specialize in industrial CT, i.e. using a rotary table and a fixed source/detector opposed to medical scanners, where the source and detector is fixed on a rotating gantry, and the object does not rotate.

North Star Imaging (http://www.xviewct.com/)
Make turnkey X-ray and CT solutions for industrial applications. Their eXpress-CT system is an inline CT scanner for inspection of components (~10-15cm) in six seconds. The application was military so the could not give us any further application-specific details. NSI constructs and build the mechanical parts and use 3rd party vendors for the source and detector. They have no experience in building gantry-based scanners, but would definitely be interested in such a project. Their strength seems to be that they have actually made a complete system for inline CT.

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Nikon Metrology (http://www.nikonmetrology.com/)
Offer a complete range of measuring systems for metrology. Acquired the company Metris in 2009. They presently have two CT-scanners for metrology, and are not interested in customising are CT-scanner for meat applications.

Contact: Andrew Ramsay
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Yxlon (http://www.yxlon.com/)
Make X-ray and CT-systems for NDT, e.g. laminography systems for scanning windmill blades. They have no experience with gantry-based CT and were not interested in customising such a system. Instead they suggested a system with several fixed sources and detector, and then a reconstruction algorithm customised for the specific geometry. Such a solution would be comparable to laminography or tomo synthesis. Yxlon presented a rotational laminography system customised for the windmill industry for scanning windmill blades (~1m €).

Contact: Malte Kurfiss
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Hamamatsu (http://www.hamamatsu.com/)
Produce flat-panel detectors. They were very clear in that they did not want to provide X-ray detectors for inline applications, and they could only tell us that it was a strategic decision made up higher in the organisation.

Contact: Mr. S. Kappelsberger
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Perkin Elmer (http://www.perkinelmer.com/)
Produce (aSi) flat-panel detectors for both medical and industrial (NDT) applications and have recently acquired Dexela (CMOS detectors). They provide detectors for many CT scanner systems. Seems to be a leading detector provider and should probably be involved at some point.

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7.2.2 Software

Digisens (http://www.digisens.fr/en/)
Deliver fast GPU-based (Graphics Processing Unit) reconstruction algorithms, both for end users as well as for OEM partners. Showed examples of very high performance reconstruction algorithms, which makes them interesting to MLA due to the time constraints.

Contact: Maxime Wiot
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Volume Graphics (http://www.volumegraphics.com/en/)
The leading supplier of software for analysis and visualisation of industrial CT data. The software is module-based and the reconstruction module is GPU-based. It is used by the majority of end users with an industrial CT-scanner. They provide a software development toolkit (SDK) for incorporating customised algorithms into the VG software. As experts in classical industrial CT applications, MLA should be aware of their presence.

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VSG, Visualisation Sciences Group (http://www.vsg3d.com/)
Make 3D Visualisation software for both science and industry, e.g. materials research, NDT and industrial inspection. Provides SDK for customising algorithms. Focus on visualisation, which is not a top priority in the meat applications, but they could probably also deliver the analysis software.

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3DII, 3D Industrial Imaging (http://3dii.co.kr/eng/)
Korean start-up from 2010 making software for CT inspection systems. Applications in the automobile industry. Much smaller and less experienced than the other software exhibitors, but very willing to build customised software. Probably the software vendor of least interest to MLA.

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7.3 Other Solutions

From the perspective of MLA it should be noted that the DIR2011 conference does not cover any medical CT applications, i.e. gantry-based systems, and no suppliers of such equipment were present. The conference was aiming at the metrology, NDT and material science communities. Industrial applications of CT focus a lot on high resolution (nm/µm/mm scale) and SNR, and less on scan time. In an inline meat application scan time would be a top priority and resolution less important, as long as the quality measures are obtainable.

Looking towards medical and security CT applications where gantry-based systems is the standard and the object size corresponds (more or less) to that of meat applications would probably be the most viable way.

SAIC Security and Transportation Technology (http://www.saic.com/products/security/reveal/) developed a dual-energy inline CT-scanner for detection of explosives in baggage, at a speed of 226 bags per hour (~16 sec/bag), with maximum dimensions of 63x63x120cm. It is however unclear if this product applies a helical cone-beam, i.e. continuous scanning, or not.

Reveal CT-80DR. Courtesy of SAIC Security and Transportation Technology.

Analogic (http://www.analogic.com/solutions-security.htm) provides the CT-technology for the eXaminer Family of Airport Security scanners provided by L3 Communications (http://www.sds.l-3com.com/products/checked-baggage.htm). The eXaminer XLB has a throughput of 1200 bags per hour (3 sec/bag), highlighting the ability of continuous-flow scanning, applying helical cone-beam CT.
Analogic is a supplier of most parts needed within CT technology, e.g. advanced detector systems, integrated gantries, reconstruction software, as well as high reliability power systems (http://www.analogic.com/products-medical-computer-tomography.htm).

eXaminer XLB. Courtesy of L3 Communications and Analogic

These inline CT-scanners for security applications seem much closer to the specs needed for meat applications than any other solutions that we have seen, especially taking the built-in conveyor, the item dimensions and the resolution into account.

Medical applications also have many gantry-based solutions, but they would all need to be customised for inline use, a non-trivial task, which the security industry seems to have handled to some extent regarding CT-scanner solutions.

Tomosynthesis is also an interesting technology. It resembles conventional CT, but with a much smaller rotation angle and thereby degraded image quality. Similarly to Laminography it would probably be a cheaper solution to build a system based on that, compared to a helical CT system. The preferable system depends on the image quality requirements.

The Danish Meat Research Institute (DMRI - http://www.dti.dk/27244), which is now a division at the Danish Technological Institute, is engaged in a project for building an inline CT-scanner for scanning the middle part of pig carcases in abattoirs. DMRI posses a substantial amount of experience in applying both CT scanning of pig carcases and in building machines for automation of procedures in abattoirs. Deformalyze work closely together with DMRI and deliver software for the analysis and validation in this project.

8 Discussion / Conclusion

The main outcome of the DIR2011 conference is the knowledge of what are the hot topics within industrial CT and speaking to relevant exhibitors on applying CT for red meat applications.
The applications presented at the conference focussed more on high resolution and SNR and less on scan time. In an inline meat application scan time would be a top priority and resolution less important, as long as the quality measures are obtainable.
It is important to be aware of the completely different approach to CT-scanning that the metrology and NDT communities have, compared to the community of medical applications. In industrial CT the object is rotated and in medical CT the source and detector are fixed on a rotating gantry. Industrial CT has limited object size but very high resolution. Depending on the requirements of each specific application, tomosynthesis or laminography should be considered, since these techniques are simpler and most likely cheaper to apply.

We believe that the most obvious solution is to adopt the gantry-based helical CT. It is not feasible to rotate carcases or pieces of meat due to their deformable nature. Helical CT is preferable since the application is continuous inline inspection using a conveyor.

For an inline CT system to function successfully in an abattoir three key requirements must be addressed; speed, hygiene and robustness.

Speed in a CT system is a trade off between a high SNR/resolution and the required line speed. The key is to ensure enough signal in each pixel in the detector area, within the given time span, and being able to read out and process the signals fast enough. Here the energy of the source and the speed of the detector array are crucial. An optimisation of the number of projections can be made on the expense of lower SNR.
Reconstruction of the CT volume from X-ray projections seems to be available at the speeds needed. The analysis of the CT-volume, extracting the needed information requires knowledge within image analysis, statistics and machine learning, as well as domain-specific knowledge on red meat.
Other factors of influence are the speed of the conveyor and the rotational speed of the gantry.

Another major issue in building a CT-system for the meat industry is hygiene and radiation safety. The system should be designed around these requirements from the beginning. It would most likely be beneficial for MLA to gain from DMRI’s experience with building an inline CT-scanner.

An inline CT system must have next to no downtime, which naturally requires a very robust system. In order to meet the speed requirements the CT system is continuously operated. This of course shortens the lifespan of all components of the system. The rotation of the gantry places the X-ray source, the power and the detector array under substantial G-forces. Transferring power and signal to and from the gantry is solved in traditional CT-applications using sliprings and Analogic seem to have a mature version of this principle. The X-ray source is transmitting constantly. The encapsulation of the system may lead to build up of heat, thus requiring substantial cooling. Furthermore, the environment in which the CT system is placed is very hot and humid which also contributes to the overall wear and tear of the system.

All these issues must be addressed to successfully apply a CT system inline in an abattoir. However, inline CT is used successfully in security applications, having some of the same requirements of speed and zero downtime, and these must be met. We would recommend the establishment of collaboration with vendors of CT systems to the security industry. They are definitely a source of knowledge on many of the issues pertaining the use of inline CT in abattoirs.