Industrial X-ray CT Performance Evaluation Method

Reinout Swane, Delft University of Technology

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Executive summary

On October 3rd 2005 I left Holland for initially a 6 month research project at the Suzuki lab of the University of Tokyo that would count as my master thesis for the TU Delft. At that time I just had followed a 2 week workshop in Berlin about Japanese language and culture so I had a rough idea of what to expect. Still I was surprised with how friendly and welcoming the Japanese people were everywhere I went. Especially in the lab, where the first day I was there they had organized a welcome dinner.

The research topic was called "Industrial X-ray CT Performance Evaluation Method". The lab cooperated in research with several Japanese manufacturers and users of industrial CT systems. Because of this I was able to visit these companies and even use their scanners to perform tests. Because there is not any established way to evaluate the performance of industrial CT scanners it is very hard for users to select CT scanners suitable to their objectives. There is a great variety in the price and sizes of different scanners. This research aimed at developing a method to evaluate the performance of a CT scanner.

The performance of a CT scanner can be evaluated through the quality of the images it produces. A test was developed that could give quantitative information about image quality after a scan of a simple aluminum block was made. The test provides information about noise and blurring.

There are many settings and factors that influence the image quality. Because for every object scanned these settings are different it is important to take the influence of these settings and factors into account. To find the relation between all identified factors and settings an experiment was performed at Shimadzu corp. in Kyoto and a simulation model was made. Some results from the experiment were very useful and others were not as expected and needed some further explanation. The simulation model was very helpful in that and with that the reasons behind some unexpected results were found.

As a conclusion to the research it was found that the image quality measurement tool works very well. There are so many influencing factors that determine the image quality that it will be difficult to predict image quality of a scanner using data obtained in an experiment. The final recommendation is to extend the simulation model so that it can take into account every influencing aspect. This way no time and money consuming test needs to be performed on a CT scanner but only the properties of the scanner need to be used as input data.

Personal Data	
Name	**Reinout Swane <R.W.Swane@student.tudelft.nl>**
Address	Soestdijkseweg 344, 3723 HJ Bilthoven, The Netherlands
Home institute	**Delft University of Technology**
Department	Faculty of Mechanical, Maritime and Materials Engineering (3mE), Laboratory for Precision Manufacturing and Assembly
Address	Mekelweg 2, 2628 CD Delft, The Netherlands
Supervisor	dr.ir. A.M.Hoogstrate
Host institute	**the University of Tokyo**
Laboratory	School of Engineering, Department of Precision Engineering, Fine Digital Engineering, Suzuki lab.
Address	Komaba 4-6-1, Meguro, Tokyo 153-8904, Japan, Room #302, RCAST Building #4
Supervisor	Prof. Dr. Engg. Hiromasa Suzuki

Halfway through my stay I decided to extend with 2 months to a total of 8 months because I needed the time and funding was available. Another reason was that I was having a very good time and I was happy to extend it. I can recommend this exchange to everybody and at last I would like to thank the organizers and funders of the DeMaMech program for making this possible.

Exchange student life

The life as a foreigner on a Japanese university is made very easy by the good organization of the international office. They organized a nice and very affordable apartment in a good location in Tokyo and many welcome meetings to inform about everything you need to know and more. With a travel time to my lab in Komaba of 2 minutes walking and walking distance from Shibuya, for Tokyo standards, where you should be happy with anything under one hour away, this was of course an excellent location. Since I didn't spend too much time in my apartment apart from sleeping the 13 square meters were big enough and the clever Japanese solutions to save space like the shower/toilet combination (see figure 1) made it good to live in.

Fig. 1: Clever Japanese toilet/shower combination

In the lab about 15 students were working, most were Japanese and there were some Chinese. The English level of the students in the lab was not very high. Some confessed that I was the first person they actually had spoken English to, even though they had followed years of lessons in school. This made communication sometimes difficult and I don't think everyone always understood my presentations in the weekly lab meetings. After a couple of months and some nice dinners together where they were happily feeding me cow stomach they became more confident and were less afraid to make a mistake which made the communication easier.
Most communication about the research was directly with my professor who spoke very well English and was very helpful with the research.
My effort to learn Japanese ended after 2 weeks in the workshop in Berlin and 2 months of classes in Tokyo, 4 hours a week. I decided to quit since it took too much time and I needed all the time for my research. My progress was also very slow so after 8 months my level would still be too low for conversation.
I did not travel in Japan but I did make a couple of weekend trips to Kyoto and around Tokyo. Two hours away from Tokyo there was small town where one weekend I went skiing next to an active volcano and afterward visiting the typical Japanese "onsen" (hot spring) where after a day of skiing you can relax in the naturally steaming hot water baths smelling of sulfate, according to the Japanese very good for your skin. Everything the Japanese do and eat is good for your health in some way.
In Tokyo there is plenty to do and the only way to see the city is to experience it. It is not like most European cities where you can visit the tourist highlights because they are not really there. The city does not even have a real center. To see Tokyo you need to be there for a longer time to be able to have dinner in all parts of the city which all have very different atmospheres. Discovering this city and the culture is an experience I am very grateful to have been able to have, thanks to the DeMaMech exchange program.

Summary

Doing a master thesis in Tokyo was an unforgettable and valuable experience in very grateful to have had. The research topic was an interesting one for my field of study and in Delft they had no experience with an industrial CT scanner. Through this program knowledge is being exchanged between countries. Because of all the new things to get used to the research takes a little bit longer than it would in a familiar environment but this is very much worth it.

Industrial X-ray CT Performance Evaluation Method

Introduction

In the fine digital engineering laboratory, part of Research Center for Advanced Science and Technology (RCAST) of the University of Tokyo, research in the field of industrial Computed Tomography (CT) scanners is being performed in cooperation with two Japanese manufacturers of industrial CT systems, Shimadzu Corp. and Hitachi. CT is being used more and more in industrial applications. As the production process is becoming more digitized over the world the CT scanner can play an important role in this digitalization process. The principle advantage of CT is that it non-destructively provides quantitative densitometric (that is, density and geometry) images of an object. It is used to find voids in cast pieces and to provide digital geometrical information about objects. Another application is to find defects in objects that cannot be found after they are opened up, like for example defects in the battery of a mobile phone. A large scanner has been manufactured by Hitachi and used by the Toyota Motor Corp. to scan engine blocks for the automotive industry. Engine blocks can be scanned to detect imperfections in the casting process, such as voids and cracks, and to compare the final cast piece with the initial CAD model to measure the accuracy of the production process. An example of a CT scan is shown in figure 2

Fig. 2: Engine head scanned by Toyota: (a) Cross section obtained by scanning, (b) Volume rendered reconstruction from CT data

CT scanners have been used for a long time in medical applications to scan human bodies. For this application extensive testing techniques have been developed and have been in use for a long time. In the past years rapid advancements have been made in X-ray Computed Tomography (CT) scanners for industrial applications. For industrial applications these tests do not always give enough information or are not applicable because different scanning techniques are being used than in medical scanners. There has not been any established way to evaluate performance of industrial CT scanners. This makes it very hard for users to select CT scanners suitable to their objectives.

Research approach

The performance of a CT scanner can be measured by the quality of the images it produces. A tool needs to be developed which can measure image quality of a CT scanner. The image quality alone does not give sufficient information since the CT scanner has many settings and factors that influence this image quality. For a scan at different settings the image quality can be very different. For the performance evaluation of a scanner these influencing factors need to be taken into account. To find the relation between image quality and these influencing factors an experiment has been designed and a simulation model has been developed. The approach is visually explained in figure 3

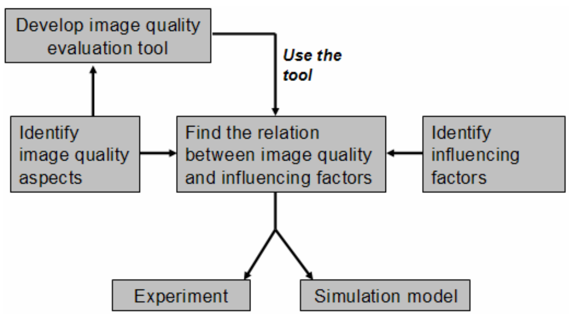

Fig. 3: Research approach

Image quality measurement tool

In order to quantify the performance of a CT scanner the images are tested for image quality. A test was developed for CT scanners that could quantify the image quality after a scan of a simple square aluminium block was made. The information about image quality are the Modulation Transfer Function (MTF) and the Signal to Noise Ratio (SNR). The MTF is a function of spatial frequency plotted against the spatial frequency response (contrast). The spatial frequency response is measured from the step response which is the Edge Response Function (ERF) of the block and the air. After differentiation and Fourier transformation the MTF is obtained. This process is visually explained in figure 3. The MTF gives information about the contrast of the image as a function of spatial frequency, or the size of features. Every image is a little bit blurred which is why resolution alone does not give any information about the visibility of small features. De SNR gives information about the relation between noise and contrast in the image.

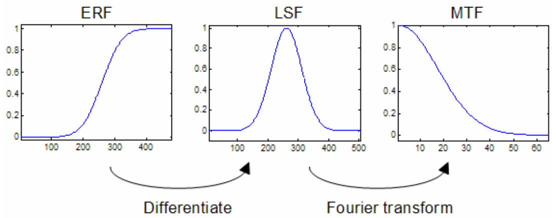

Fig. 4: The process from ERF to MTF

Influences on image quality
Many settings of the scanner and other factors like properties of the object scanned have influence on the image quality. Three of these influencing factors are shown in figure 5. On the left the Source to Image Distance (SID) and the Source to Object Distance (SOD) are shown. If either one of these variable settings change it has an influence on the MTF. In the middle the Object surface angle is shown. If the object has a small angle with the x-ray beam the edge will be more blurred. The Object material also has an influence on the MTF and SNR. Many other settings and factors have been identified and evaluated but in this short summary they can not all be discussed.

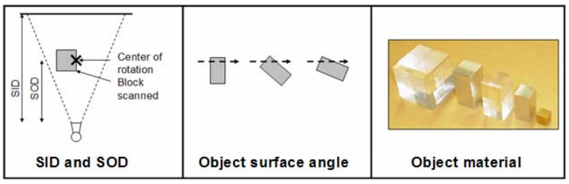

Fig. 5: Settings and factors that influence image quality

Experimental results
In an experiment conducted with the Shimadzu 225 KeV cone beam scanner in Kyoto blocks were scanned changing one setting at a time. The MTF results for all different factors were smooth lines that can be interpolated. One exception was the MTF for the brass block, the black line in the right side graph. A simulation model is developed to find the reason for this irregular shape.

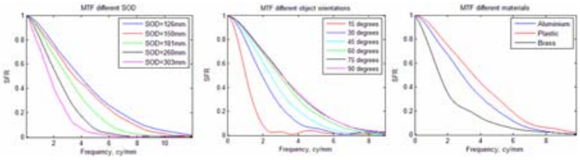
Fig. 6: MTF results from experiment

The SNR results obtained by the experiment are not as good as the MTF results. The results are shown in figure 7. The SNR should increase with an increasing exposure time and decrease with increasing SID. This is not always the case. Reason for the unexpected SNR results could be scattering or bad calibration. More scans need to be made to have a full understanding of the results.

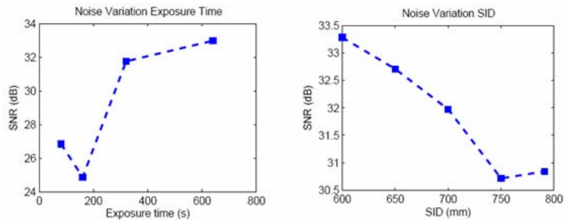

Fig. 7: SNR results from experiment

Simulation results
Among other unexpected results for the experiment the irregular shape of the MTF curve of the brass block has been investigated using simulation model developed in MATLAB. In the model imperfections can be isolated and simulated to see the effect of one single cause. After simulation it was found that “beam hardening” was the cause of the irregular shape of the MTF. Because the x-ray beam contains photons in a spectrum of different energies the lower energy photons are attenuated easier than the higher energy photons. This causes the average energy of the x-ray beam to rise which has as a consequence that it a smaller part is attenuated as it passes through the material. This makes the attenuation curve non linear. In the reconstruction process (Filtered backprojection) this results in dark streaks aligned with flat surfaces. The edges of the object also appear denser than the center. With the simulation a very similar image was obtained as with the real scan, indicating that beam hardening took place. Other unexplained results have also been clarified using the simulation model.

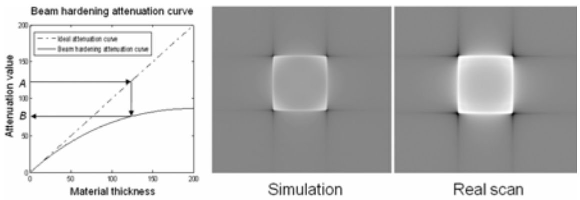

Fig. 8: Beam hardening

Conclusion

The Image quality measurement tool works very well except when excessive beam hardening takes place. There are so many influencing factors that determine the image quality that it will be difficult to predict image quality of a scanner using data obtained in an experiment. The final recommendation is to extend the simulation model so that it can take into account every influencing aspect. This way no time and money consuming test needs to be performed on a CT scanner but only the properties of the scanner need to be used as input data.