# A First Look at Differential Hysteresis Processing of X-Ray Images of Porosity

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## Introduction

In a forum sponsored by Connecticut Innovations, Inc., the State of Connecticut's high technology investment organization, two attending organizations met and discovered that they could collaborate on the development of what appears to be an important improvement in the non-destructive testing of die castings. Image Content Technology LLC, or ICT, is commercializing a patented image enhancement technology called Lucis™ that reveals image detail that would otherwise be unable to be viewed. Principals of the Center for Thermofluid and Multiphase Phenomena at the University of New Haven, seeing a presentation by officers of ICT, hypothesized that the ICT image enhancement technology could be successfully applied to the X-ray search for porosity and inclusions in aluminum alloy die castings. Given the lack of clarity and perceivable contrast in most X-ray images of porosity, the image enhancement demonstrated by ICT held the promise of accurately and quickly detecting porosity at the micro-porosity level, opening the door to better quality control and process improvement. The Center entered into a research relationship with ICT in late 1997, and began testing the ICT proprietary Lucis software which was originally developed for applications in electron microscopy. Initial observations of Lucis-processed X-ray images suggested that Lucis could be used to detect voids, cracks, and internal inclusions in metal. Working with PANTAK, a manufacturer of digitized-image X-ray equipment in East Haven, Connecticut, and using castings supplied by Blue Ridge Pressure Castings, Inc., in Lehighton, Pennsylvania, the Center determined that the ICT image enhancement technology greatly improves the ability to detect porosity and inclusions , clearly identifying defects that skilled inspectors reading X-ray films miss or underestimate. The results are significant enough to suggest that a new quality control tool is at hand, one that can be used routinely by a QC inspector in a die casting facility to quickly and accurately detect a variety of casting defects. The Center is embarking on a research program to further develop the methodology. The initial findings, a first look at useful applications, are important to both die casters and to others in the foundry business. For this reason, they are reported in their state of preliminary analysis.


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## Differential Hysteresis Processing of Two-Dimensional Signal Arrays

Lucis software is based upon an algorithm that allows the user to observe contrast differentials in a digitized X-ray image that cannot be seen by the naked eye. The process is called differential hysteresis processing, and was originally confined to two-dimensional signal arrays. Therefore, the depth of a defect in a casting is not measurable: its presence is indicated in two measurable dimensions but not in the third. If the part can be rotated, then the internal defect's position can be determined with accuracy. Since the algorithm is covered by patents in the U.S. and elsewhere, and the software developed and marketed by ICT, details of its logic are of only academic interest[1]. Given an X-ray of a die casting, such as that shown in Figure 1A, what is of great interest is that Lucis, by emphasizing a user-selected range of contrast differentials, can generate an infinite variety of recombinations of all of the information captured in the original image but which is not discernable to the human eye. Manipulation of these recombinations allows the operator to see image detail heretofore hidden in the original image. Because Lucis examines relative contrasts, it reveals image detail simultaneously in dark and bright portions of an image. Porosity and inclusions can become sharply defined by some of the Lucis recombinations, thereby making perfectly clear what was simply a hint or shadow of an imperfection. This clarity is shown in Figure 1B, a Lucis-enhanced image of Figure 1A. The enhancement, best seen on a screen, shows porosity as bright holes and patches. Inclusions appear as dark spots or black objects. Surface irregularities and internal constituent layers may also be inferred from the images, although these have not yet been carefully studied and verified. The porosity Lucis processing reveals is easily verified by cutting up the casting in the areas showing porosity. Results show congruency between an image and actual porosity in a cutaway sample, at least in terms of approximate size and location. Cutting a sample destroys some of the physical evidence, and, as noted previously, the image is two-dimensional with no way to determine depth or size in the third dimension unless an image can be made after turning the sample ninety degrees into that dimension. The Lucis images appear to show information above and beyond porosity and inclusions. Figure 2A, for example, is an X-ray image that gives little hint, if any, to the existence of scratched markings on the back face of the casting, as shown by the enhanced image of Figure 2B. Research currently centers on porosity: Lucis enhancement of images may well become useful in forensic science and failure analysis. It should also be noted that enhancement is only as good as the quality of the digitized X-ray image which serves as input data. If the input is a photograph of an X-ray image, or a fuzzy X-ray film, digitized by an electronic scanner, Lucis output is vague and indeterminate, although of more value than the original image. As with most things, input quality determines output quality.

From the perspective of a die caster, enhanced X-ray imaging of the type provided by Lucis gives quality control additional firepower in the hunt for porosity. Since porosity is the primary target, an inspector can quickly identify it in an enhanced image. If the sample is first X-rayed with a powerful machine that gives a real-time image of the part, a digital file can be immediately made of any image which appears to warrant enhancement. A Lucis analysis can then be performed on that file to seek a clear picture of the porosity present, if any. This is fast quality assessment, fast enough to be used in process control at the casting machine to achieve zero-porosity castings. If the porosity is chronic, the enhanced images may be helpful in re-designing the die, assessing cooling effects, and modifying the shot profile. Managing porosity is easier if one can plainly see it.

## Validation and Analysis

Although Lucis provides a great deal of visual information and accentuates porosity and inclusions, the question of validation of the images is only partially answered. Center researchers tested matched pairs of die cast specimens, X-rayed both members of a pair, located porosity with Lucis, then systematically sliced one specimen to compare actual porosity with the corresponding enhanced X-ray image. These comparisons validated the presence of porosity and its indicated presence in both enhanced and in non-enhanced images of a given specimen. Materials included A413, A380, and 218 with no differences noted. Some artifacts are documented in Lucis, and these were observed but judged to be irrelevant to the identification of porosity. Enhancement appeared to be highly useful in answering the basic question in aluminum die casting quality assurance: is porosity present, and, if so, where is it located in the part? Secondarily, are there inclusions, and, if so, how large are they and where are they located? The mere presence of significant porosity, or of large inclusions in an area to be machined, may trigger part rejection by a customer. Lucis' speed and ease of use make rapid scanning of sample parts feasible, assuming an X-ray machine with digitizing capability is available on-site. On an assembly line, the system could conceivably be used for 100% inspection of die castings just before their potential use in subassemblies. Once trained, factory inspectors and QC personnel should be able to use Lucis routinely and accurately, at least for porosity and inclusion checks. The advantage over non-enhanced X-ray images is so substantial that long term cost savings from better QC performance are likely to be remarkable.

## Program Continuation

Initially, research addressed the possibility that the Lucis technology might be of value to the die caster who is experiencing difficulty in identifying porosity in parts that must exhibit very low porosity for pressure-sealing or structural strength reasons. Supplied with high quality digitized X-ray images, Lucis identifies porosity by exaggerating contrasts inherent in the original image so that the human eye can detect them. Porosity on X-ray film, or shown on a real-time monitor, is typically indistinct and shadowy, and takes a trained and experienced eye to translate into judgements about the specimen under analysis. Inclusions tend to be less difficult to observe because they usually block X-rays and hence appear as dark, distinct objects on film or on a monitor. Research indicates that all types of porosity, and all kinds of inclusions, are vividly defined by Lucis, thereby making the job of inspection much less error-prone.

Porosity detected by Lucis was confirmed by cutting apart specimens and comparing the actual observed porosity with that shown in a Lucis-enhanced image. Inclusions were often destroyed by cutting, hence a variety of inclusions were artificially studied by drilling small holes into specimens and forcing hard materials, such as carbon steel, into them for X-ray analysis. Enhanced images clearly delineated such inclusions, giving better clarity than delivered by non-enhanced X-ray images. The utility here lies in the ability to detect both large and very small inclusions, the former a potential defect and the latter an indicator of casting process problems. Yet it is porosity depiction that looms large as a significant improvement in die casting quality assurance technology. A clear visual image of porosity on or near the shop floor makes prompt remedial action at the casting machine a just-in-time reality. The ability to quickly achieve a low-porosity process may prove to be the major benefit of Lucis to the foundry industry. The die caster who rapidly adopts useful new technology, especially when it is available at low cost, is a step ahead of the competition[2].

Research is in progress at the Center and at SLS Applied Research LLC, a New Haven-based technology transfer company, with the objective of fully documenting die casting defects and phenomena observed with Lucis enhanced imaging. Lucis-enhanced X-ray images provide information on surface finishes, constituent interfaces, and skin compositions. Some alloys appear to generate their own signature images and artifacts, all of which must be fully analyzed before explanations can be forwarded. Artifacts may be created by the X-ray emitter via reflections from nonlinear surfaces or by the effects created by incidental heating of the target specimen. Identification and validation of all parts of a Lucis image constitutes a program that is expected to take a year to complete. A diagnostic manual is the expected end product of the research effort. For the die caster, these future assessments will likely produce a new tool for the non-destructive testing and analysis of any die casting, making production of a high quality product for the customer a little less difficult.

## References


[1] Peters et al, United States Patent No. 5,563,962, " Two Dimensional Digital Hysteresis Filter for Smoothing Digital Images," October 8, 1996.

[2] Sommers, Alexis N., " What Does the Custom Die Caster Do About R & D?," Die Casting Management, March 1998, pp 28-30.

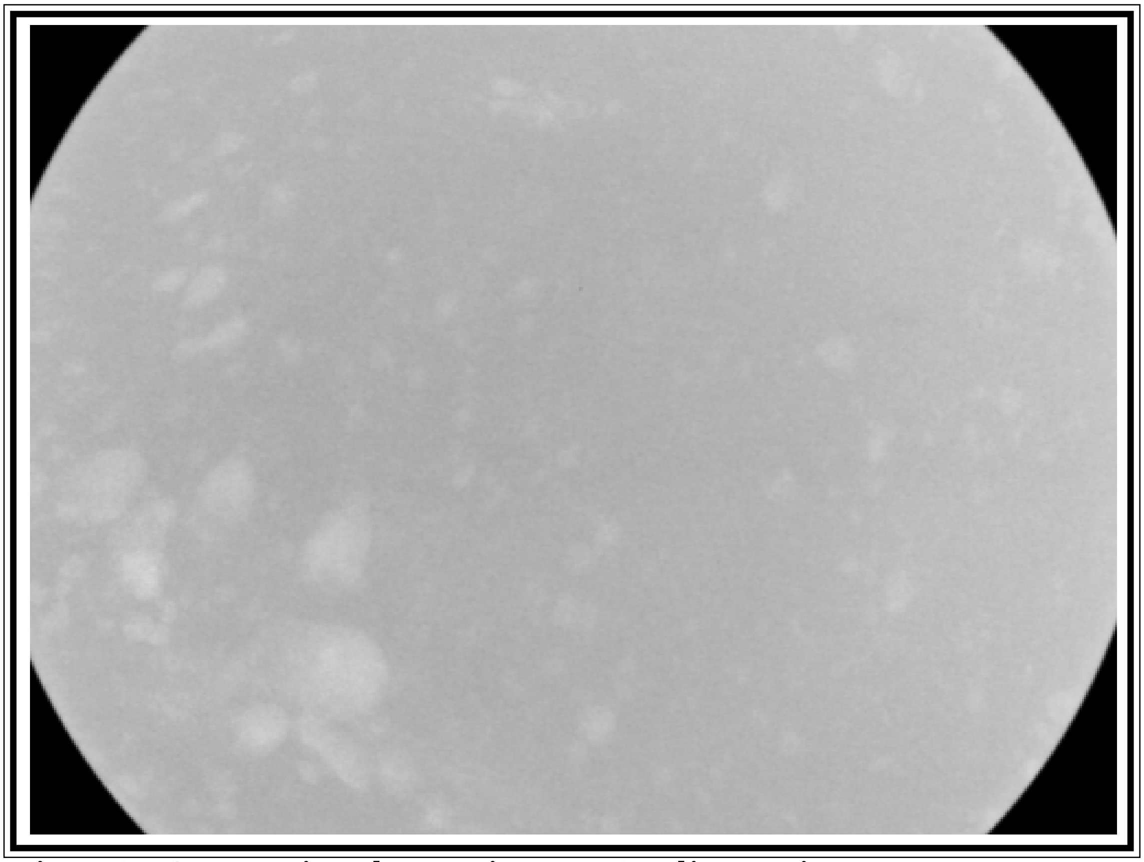

**Fig. 1A. Conventionalx-ray image, AI die casting**

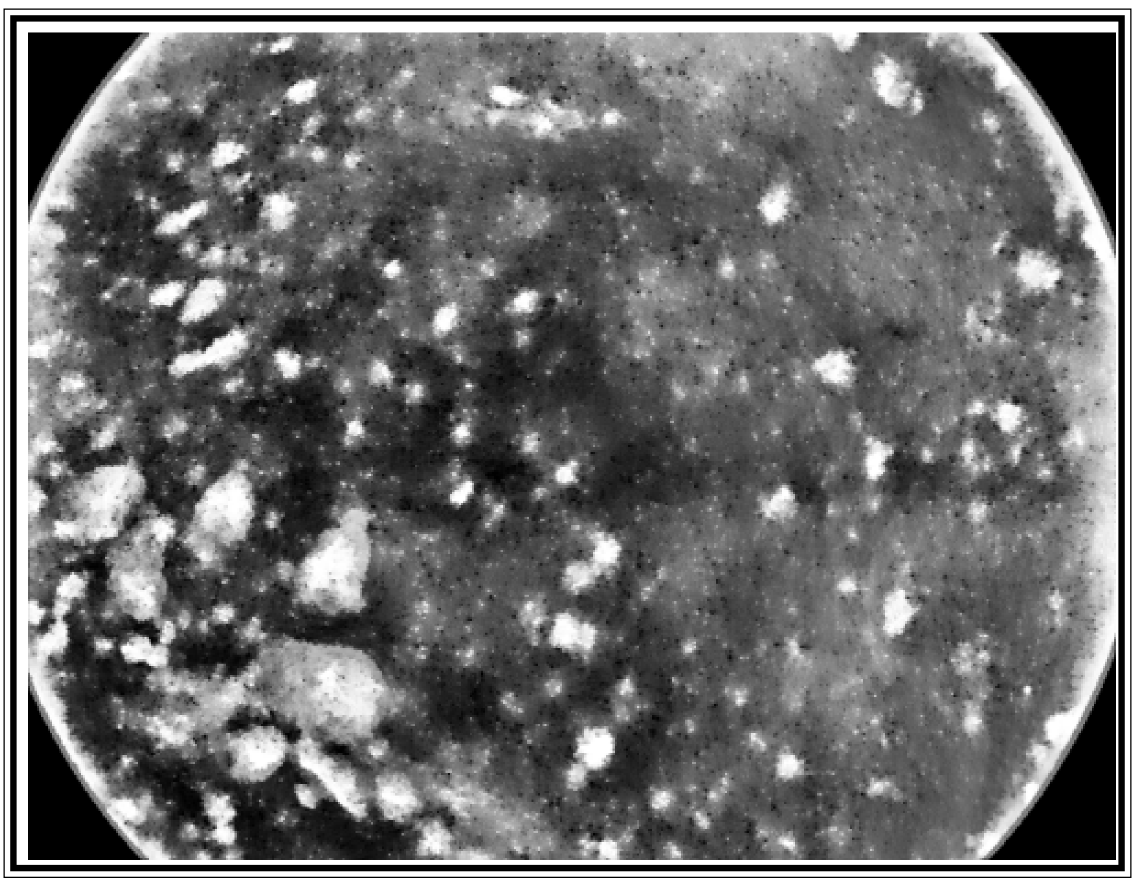

**Fig. 1B. Lucis-enhanced image of Fig. 1A**

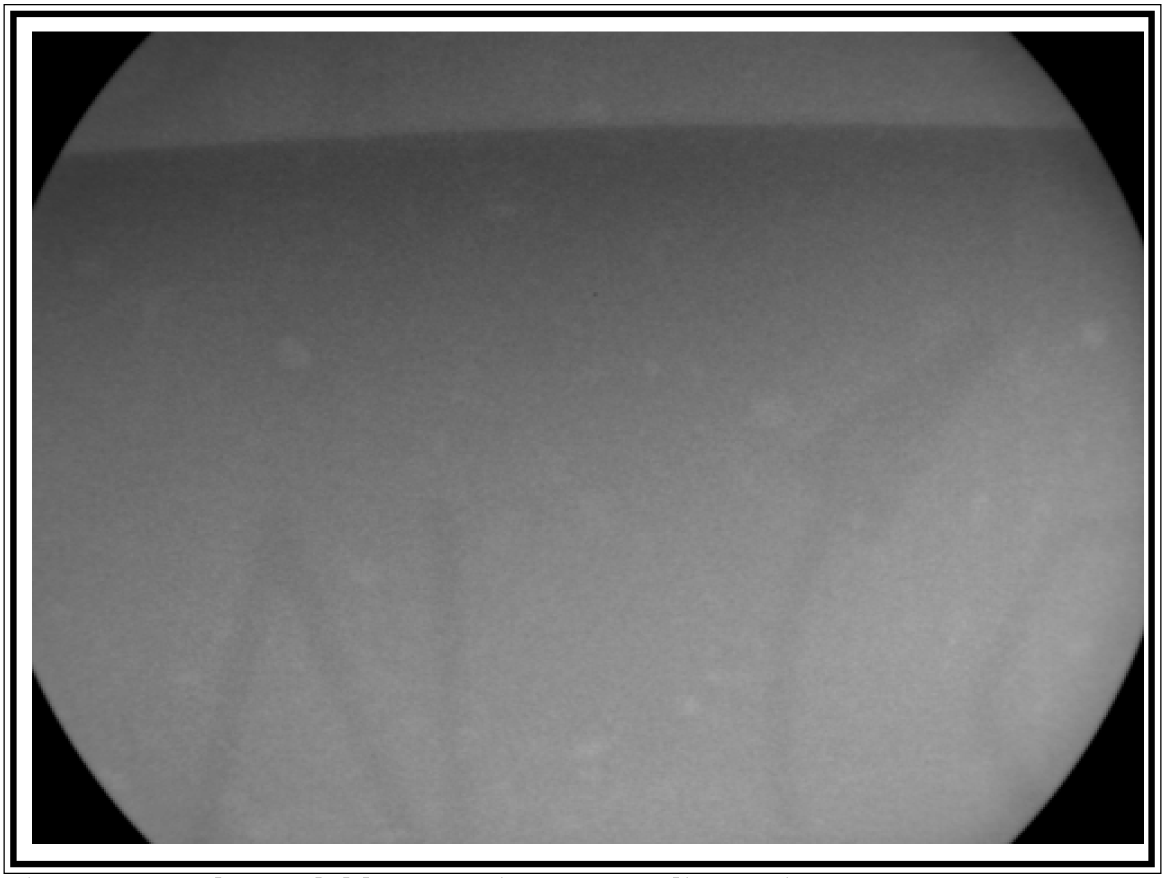

**Fig. 2A. Barely readable x-ray image, AI die casting**

**Fig. 2B. Lucis-enhanced image of Fig. 2A**