A New System for Fully Automatic Inspection of Digital Flat-panel Detector Radiographs of Aluminium Castings

Theobald FUCHS, Ulf HASSLER, Ulrich HÜTTEN, Thomas WENZEL, Fraunhofer Development Center X-ray Technologies, A Cooperative Department of IZFP Saarbrücken and IIS Erlangen, Fürth, Germany

Abstract. The aim of our work was the integration of various newly-developed methods into a system for fully automatic radioscopic inspection of arbitrary casting parts. Using a 16-bit flat-panel detector, projections in arbitrary directions through the part are acquired and analysed.

The software tool for inspection can be separated into five stages: registration, calibration, image processing, fault segmentation, and quality assessment. Thereby, each step is realized with full 16-bit data processing.

Within the first processing stage, information about the physical length and density of the aluminium structures is extracted from the primary projections. Next, the primary image is registered with a reference image, which was acquired previously. Afterwards, the third stage combines both reference image-based and reference-less testing. A filter is applied, which adapts automatically to the local object structure by referring to the properties of the reference. Thereby, the self-adapting filter selects its size, direction and filter method optimally according to the local situation. Similar to the reference-less procedure, a subtraction is followed by a threshold operation, resulting in a map of regions that are suspected to be faulty.

The fourth step aims at an elimination of false-positive detections. Again, two methods are applied successively: evaluation of local image features at suspicious positions and a classification based on teachings independent of position and orientation of the faults. Within the last step the quality criteria are applied. These criteria may concern fault size and depth, the density of faults in critical regions and a minimum distance between two or more faults.

1. Aims

Automatic X-ray inspection of light-alloy castings is mandatory for almost 10 years, especially with security relevant applications. In the case of automobile industry hence results the necessity of testing millions of parts during the everyday production while keeping pace with processing cycle [1].

The goal of our development was to implement a fully automatic system for radioscopic quality control in the production of aluminium castings. Projections in arbitrary directions through the part are digitally acquired and analysed while keeping up with the production speed. Thereby the conditions listed below have to be fulfilled:

- no assumptions are made about shape and complexity of the part to be tested
- processing of an arbitrary number of projection images in arbitrary directions
- integration of 16-Bit flat-panel X-ray detection device
- fully 16-Bit image processing at all stages
- combination of reference-based and reference-less image processing
- determination of longitudinal dimension of defects, i.e. their depth in direction of the X-rays
- flexible integration of arbitrary image processing methods for special applications like detection and inspection of a weld-seam which are based on gradient calculations

In the following, we will describe the concept we developed to meet the mentioned requirements [2]. Afterwards we will present a first prototype implementation of the ISAR V5 system and discuss its performance in industrial routine.

2. Conceptions

A reference image is prepared for every image that is analysed. The reference is measured with a part that has shown to be without faults. The current image and the reference are registered and calibrated afterwards.

Although the general tendency in recent time went towards reference-less systems [3, 4], we reintroduce the usage of the evaluation of reference information for different reasons. One aspect is the weakness of local reference-less filtering methods in case of very big flaws, where information about the true object geometry is necessary. In addition, slowly varying modifications or ageing of the moulds can thus easily be taken into account. In order to account for inexact positioning of the object, evaluation of reference information is combined with reference-less methods.

Another advantageous utilization of the reference is the possibility to suppress the troublesome influence of scatter effects and image lag, i.e. the remains of previous images still visible in the current projection. If the complete testing system is working under stable conditions and with constant testing rate the reference image are acquired during routine testing of fault-less parts. Thus, the reference images show exactly the same contributions of scatter and image lag. By subtraction of each currently tested image and the reference, these effects are cancelled automatically. This approach works regardless if the residual image information is caused by the read-out electronics or the finite decay of the scintillator signal.

Two different approaches of image processing are applied. The material length image itself is median-filtered and subtracted from the original image. On the other hand, the reference image is subtracted from the current image. Within both resulting subtraction images the non-vanishing pixels are segmented leading to regions, which are suspected to show defects (material missing in general) or other faults like foreign materials or bubbles (pore nests).

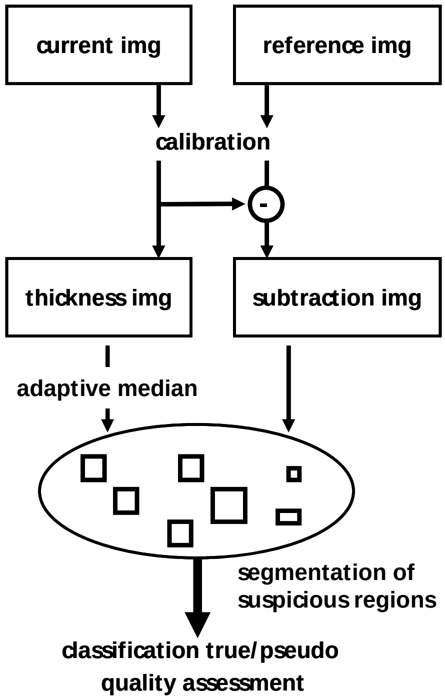

Figure 1: System set-up and flowchart.

2.1 Registration

Each part that is processed during inline testing is not necessarily measured at the identical position. Due to mechanical instabilities, long-term changes of the moulds and slight differences between the moulds in use, an automatic registration step is needed. The registration is done with a reference image. Optimally, a reference part is used which has been cast in the same mould. In this case, it is necessary to identify the current mould. Mould-ID recognition can be done in the first x-ray projection image of each part. Alternatively, there is the option to register the current image with a standard reference, thereby disregarding the slight variations between different moulds.

The registration itself is based on user-defined landmarks. The algorithm makes use of a grey-scale adjustment of the two images and a multi-scale approach to provide fast data processing.

2.2 Calibration Issues

The information measured within the projection image is evaluated with respect to the imaging physics. Routinely, the primarily acquired image is adjusted according to a bright- and a dark-image. Bad pixels are detected and corrected.

In order to allow for quantitative measurement of the depth of faults, i.e. to extract their length in direction of the incoming radiation, a physical calibration object is evaluated. We use step-wedges made out of the same material as the part and with typically 10 to 15 steps with each 5 mm increment of thickness. The dependency of grey values on the length of the irradiated material is modeled as superposition of exponential attenuation modes to account for various effects like scatter and beam hardening (Fig. 2).

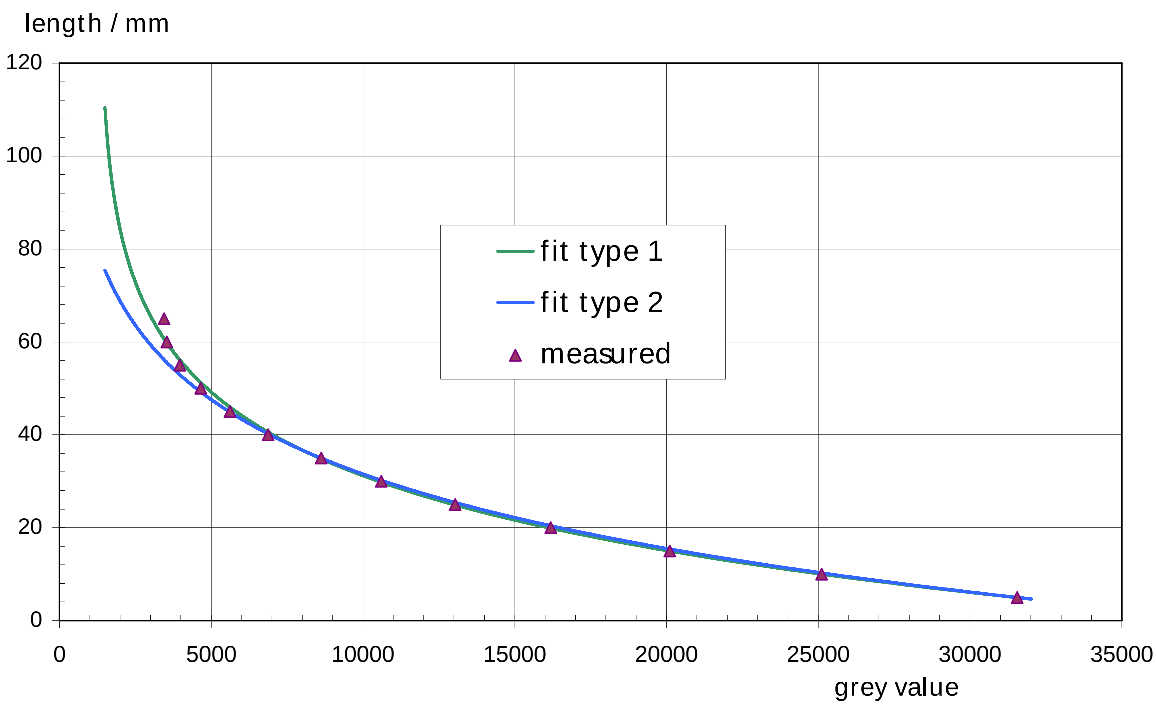

Figure 2: Grey value calibration curves with different fit functions
based on the measurements (triangles) with a aluminium step wedge.

Attention has to be paid to regions of high attenuation lengths where object- and detector-scatter radiation dominates the signal. Thus, the shape of the calibration object is crucial to the validity of the resulting look-up table for grey value calibration. By applying the look-up table, the length of the material along the direction of every pixel in the projection can be calculated in the current and the reference image (Fig. 3).

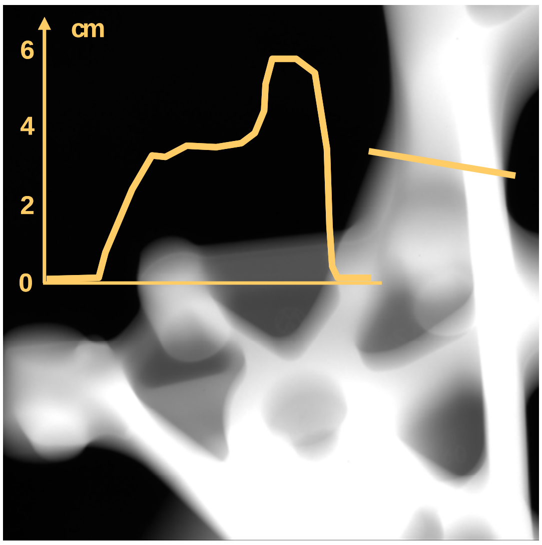

Figure 3: Material thickness image as resulting from the calibration step.

2.3 Image Processing

Reference-less

Optionally, the material length representation of the current image is median-filtered. The filter adapts automatically to the local object structure by referring to the properties of the reference. Thereby, the self-adapting filter selects its size, direction and filter method optimally according to the local structure of the projection image of the part (Fig. 4).

The adaptively median-filtered image is subtracted from the non-filtered image. Thereby the filtered image serves as the reference, and pixel with high non-zero values are suspected to belong to some fault region. The advantage of this method is the fact, that it works without an actual reference image in contrary to the method described above. On the other hand, the result of the median filter strongly depends on the size of the kernel and is predominantly suitable to detect small local blow holes.

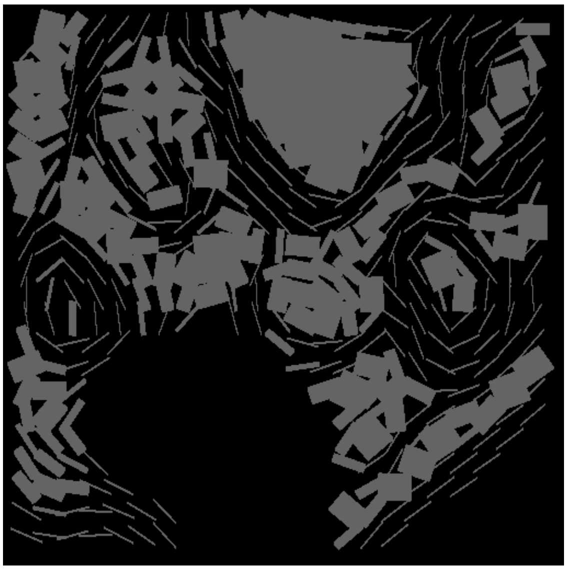

Figure 4: Size and orientation of the median filter kernel are determined adaptively.

Reference-based

The reference image, which was processed in exactly the same way, is subtracted from the current image. Thereby, all structures that do not appear within the fault-free reference part, will become clearly visible (Fig. 5). The resulting difference image is optionally median-filtered in just the same way as described in the previous paragraph.

In addition, special methods exist to extract large fault structures, which usually cannot be detected by local filter algorithms. Separate approaches are used to analyse large high contrast and low contrast fault structures. Both exploit the reference image information in great detail.

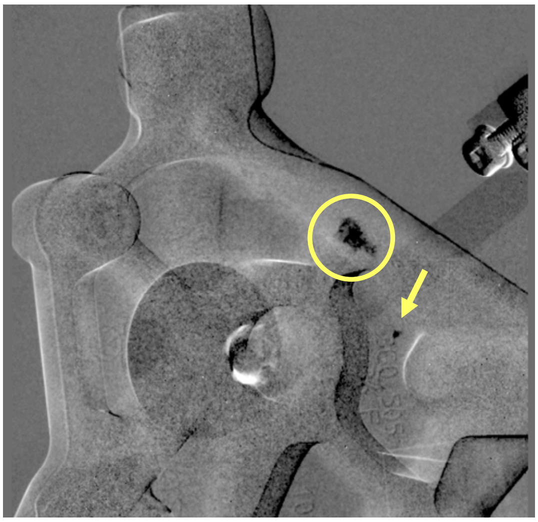

Figure 5: A typical subtraction image from the current and the fault-free reference.
A large defect is indicated by the circle, a small defect by an arrow.

2.4 Segmentation and Selection of Fault-regions

The next processing step is to assemble the single suspicious pixels into well defined fault regions appropriately. The analysis is based on the subtraction image. Thus, we are able to detect defect regions, that cover a large area and show a low contrast against the background of homogenous material. We can detect these defects independent of the size of a filter kernel.

During the segmentation of suspected defect regions several types of faults are distinguished as listed below:

- inclusions of foreign material (hyperdens),
- singular blow holes, i.e. well defined defects (hypodens),
- pore-nests, i.e. several small defects embedded in a common “halo”,
- large-area low-contrast defect objects (e.g. oxides), and
- cracks.

The information on the type of each fault region is stored and provided to the end-user as part of the test result. This detailed information on the kind of faults occurring during production enables the operators of the x-ray testing system to improve the casting process itself.

Unfortunately but inevitably, the evaluation of a subtraction image is error-prone at edges. There, even slight shifts or tilts may cause a signal in the difference image that maybe interpreted as a defect.

Thus, additional methods are applied to reduce pseudo i.e. false-positive detections at edges. Two methods are applied successively. First, local image features at suspicious positions are extracted. These features include the mean gradient within the fault region (“edgeness”), the mean depth, the size and the shape via the eccentricity (between “circular” and “linear”). The selection of the fault regions compares several local image features with respective threshold values. If several criteria are fulfilled independently the decision is made to reject the fault as a false-positive.

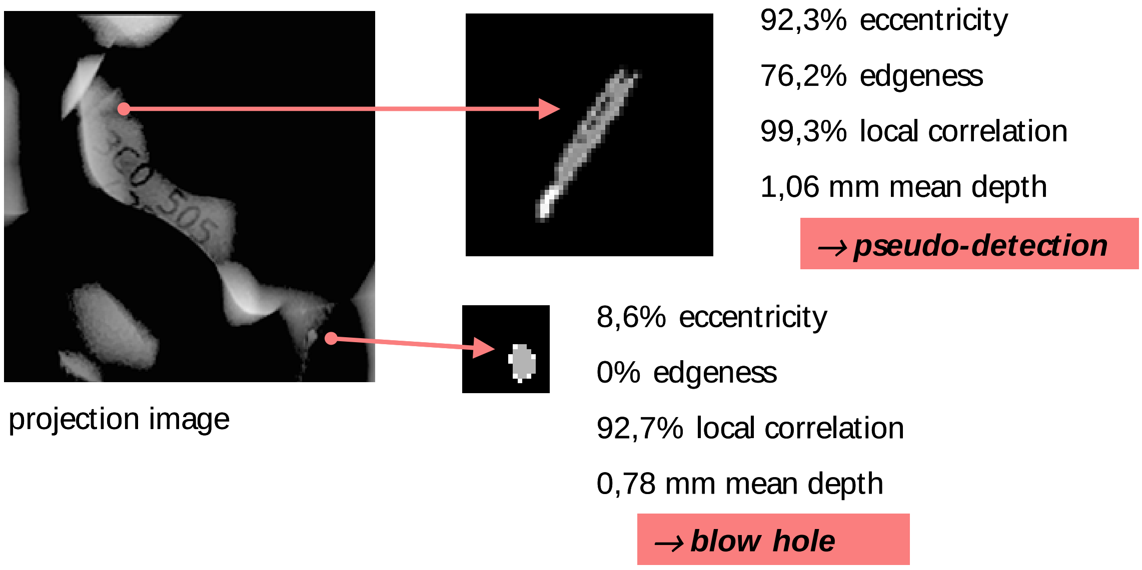

Figure 6: Two examples of faults, the upper one is identified as a false-positive detection, the lower one is a true fault.

Second, a classification is performed based on teachings independent of position and orientation of the faults. Regions, that are frequently identified erroneously as defects are selected by the operator and stored together with the other part-specific testing parameters. Each newly found fault is compared with the existing teachings and in case of a high similarity classified as pseudo-detection. Thereby, the classification algorithm is robust against rotations and shifts of the available templates with respect to the structures within the current image.

2.5 Quality Assessment

Last but not least quality criteria are applied which are defined by the engineers who designed the respective part. There is no absolute measure for “good” or “bad” in casting industry, too. The decision how serious a single fault of the current part is, must be based on the role the part plays in the complete system (e.g. the car) it was designed for.

The following properties of regions that were identified as faults are evaluated:

- area within projection plane (fault size),
- longitudinal depth in ray-direction (fault depth),
- density, i.e. fault area per total area in %, and
- distance between two defects within projection.

The limiting value of each property is given by the operator according to the manufacturers requirements (Fig. 7).

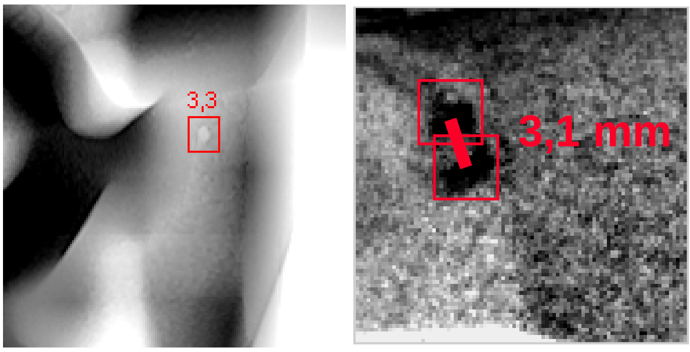

Figure 7: Two kinds of quality violations; left: fault size, right: fault distance.

3. Prototype Implementation

The described system was implemented as a new version of the Intelligent System for Automated Radioscopy: *ISAR* V5. Every algorithm used within the whole data processing system was optimized with respect to processing time, such that a cycle time of less than 2 s per image was achieved (512 by 512 pixel). In practice this means that a pair of parts e.g. a left and a right wheel-mount can be tested both within less than 30 s (each part with 7 projections).

ISAR V5 has been realized in a first production plant of castings. It's effectiveness in testing automobile parts has been proved in industrial routine. The installation of *ISAR* V5 in additional casting facilities is currently prepared.

Besides of quality assessment of castings several applications were examined. It was found that the *ISAR* V5 system shows excellent performance also with testing of wheels and ball bearings. A system dedicated to weld-seam inspection has been ordered and installed meanwhile [5].

4. Summary and Outlook

Yet, several issues will be examined in the future. A further analysis of radiation scattered by the object is needed. Then the correction of afterglow signal is to be improved.

Within the registration procedure there is still room for improvement, too. The handling of the mould specific reference part is somewhat difficult and cumbersome. In addition, the registration up to now accounts for translations and rotations within the projection plane. Any tilt or change in magnification between the actual acquisition and the reference measurement can not be corrected for. A registration which is based on a local similarity transformation may overcome these problems.

In general, we found the presented *ISAR* V5 automatic inspection system provides a low pseudo-fault rate as well as a very high degree of reliability in detecting casting failures. This high performance is achieved by optimizing and improving the whole chain of data processing, beginning with the actual acquisition and correction of the projections and ending with an intelligent selection and classification of the suspicious fault regions.

References

[1] D. Mery, T. Jaeger, D. Filbert, „Automatische Gussfehlererkennung: Stand der Technik“, tm - Technische Messen, Oldenburg Verlag, 68 (7 - 8), 2001

[2] T. Fuchs, R. Hanke, U. Hassler, U. Hütten, F. Schmolla, T. Wenzel, M. Jelinek „Fortschritte in der automatischen Durchstrahlungsprüfung von Gussteilen mittels digitaler Flachbildwandler“, Jahrestagung der DGZfP in Rostock 2.-5. Mai 2005

[3] D. Mery „Automated Radioscopic Testing of Aluminum Die Castings“, Materials Evaluation, February 2006

[4] F. Herold, R.-R. Grigat, K. Bavendiek „A New Analysis and Classification Method for Automatic Defect Recognition in X-Ray Images of Castings“, NDT.net, Vol. 7, No. 10, October 2002

[5] T. Wenzel, T. Fuchs, U. Hütten, P. Schmitt, R. Behrendt, G. Kostka “Fully Automated Inspection of Welded Seams with a New High Resolution Durable X-ray Camera System”, ECNDT Berlin, 25.-29. September 2006