Exploiting Multiple View Geometry in X-Ray Testing: Part II – Applications

Domingo Mery
Departamento de Ingeniería Informática
Universidad de Santiago de Chile
Av. Ecuador 3659, Santiago de Chile
dmery@ieee.org
http://www.diinf.usach.cl/∼dmery

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Abstract

In this paper we present four applications reported in the literature that use the theory of multiple view geometry in X-ray testing. Multiple view analysis offers advantages not only in 3D interpretation. Two or more views of the same object taken from different viewpoints can be used to confirm and improve the diagnostic done by analysing only one image. The key idea of the multiple view analysis is to gain more information about a test object by analysing multiple views taken at different viewpoints. The multiple view X-ray testing represents an economic alternative to CT for rapid internal feature analysis.

Keywords: X-Ray testing, automated inspection, computer vision, multiple view geometry.

1 Introduction

In some NDT & E applications, it is necessary to process multiple views in order to infer 3D information of the object under test. Multiple view information is required for example, for inspecting the internal and external geometry of a casting using CAD-models [1]; for locating features of a 3D object using stereoscopic techniques [2] and for finding flaws in a casting using correspondences of multiple views [3].

Multiple view analysis offers advantages not only in 3D interpretation. Two or more views of the same object taken from different viewpoints can be used to confirm and improve the diagnostic done by analysing only one image. This idea is also used by radiologists that analyse two different-view X-rays of the same breast to detect cancer in its early stages. Thus, the number of cancers flagged erroneously and missed cancers may be greatly reduced as shown for example in [4], where a novel method that automatically finds correspondences in two different views of the breast is presented. Additionally, there are other applications, developed in the past 15 years by the medical community, which also require 3D information. To cite a few: 3D reconstruction of tree structures from X-ray angiogram projections [5], in which 3D vessel reconstruction provides accurate anatomical measurements to diagnose coronary artery diseases; and image guided surgery [6, 7], where the placement of a biopsy needle or a sawing tool is guided by a computerised stereo X-ray imaging system (see for example *stereotactic* and *stereotaxy* techniques in [8]).

Another method to infer 3D information is computed tomography (CT) [9, 10]. In contrast to the multiple view X-ray testing, where the images are 2D projections of the object under test, CT reconstructs from several projections a 3D voxel array of the test piece, where each voxel represents an approximation of the X-ray absorption coefficient of the object material at that location. At present, the 3D reconstruction in CT is not a time consuming task. However, CT data acquisition is a very time intensive process requiring a minimum measurement time for adequate signal to noise ratios as well as a minimum number of projections for the desired local resolution. Typically, the whole CT process on objects up to 500mm in diameter can be performed in a few minutes.

However, in the applications mentioned in this paper, information about the distribution of the X-ray absorption coefficients is not required. In our case, an attempt is made to obtain a 3D reconstruction only in the sense of 3D location (and not in the sense of the 3D distribution of the X-ray absorption coefficients in the test object). Thus, tasks like 3D geometric measurement can be performed faster (on the order of seconds) by analysing few X-ray images using multiple view geometry. In addition, a CT system is significantly more expensive than a radioscopic inspection system. For example, in the inspection of aluminium wheels, the cost of a CT system and a radioscopic system are on the order of EUR 700.000 – 750.000 and EUR 200.000 – 250.000 respectively[1]. For these reasons, multiple view X-ray testing represents an economic alternative to CT for rapid internal feature analysis.

In this paper we present four applications reported in the literature that use the theory of the multiple view geometry in X-ray testing [11]: 3D measurement, 3D flaw simulation, flaw detection using an image sequence and stereoscopic X-ray imaging for the screening of passenger baggage. Finally, we give some concluding remarks.

2 3D measurement

3D industrial measurement is usually performed using techniques based on coordinate measurement machines (CMM) or computed tomography (CT). However, both are prohibitive for many industrial applications. For instance, CMM is typically limited since complicated structures like internal features, small holes or

[1]The prices do not include the software for automated defect detection.

highly curved concave surfaces, cannot be reached. On the other hand, CT is a very time intensive process requiring a minimum data acquisition time for adequate signal to noise ratios as well as a minimum number of projections for the desired local resolution. At present data acquisition and reconstruction based on CT can be performed in a few minutes. An alternative approach to the internal feature measurement of industrial parts, is proposed in [12, 13, 1], where the 3D geometry is measured by 3D reconstruction from few X-ray views of the test object (see Fig. 1). Since the 3D reconstruction is based on photogrammetric rather than tomographic methods, the 3D measurement can be achieved in a few seconds. A comparison between this method and CT, in terms of accuracy or measurement time, is not reported in the literature.

An additional application of 3D reconstruction is the location of a detected flaw in the test object [14] and the accurate measurement of the dimensions of a detected flaw. Usually, the 3D measurement is performed by multiplying the size in pixels of the flaw in the X-ray image by a scale factor that converts the pixels into millimetres [15]. However, this procedure suffers from inaccuracy because it does not take into account the depth information. Using a 3D reconstruction technique, as explained in [11], it is possible to avoid this problem. An example is illustrated in Fig. 2, where the size d of the flaw can be measured in a more precise way.

3 3D flaw simulation

In order to evaluate the sensitivity of defect inspection systems, it is convenient to examine simulated data. This gives the possibility to tune the parameters of the inspection method and to test the performance of the system in critical cases [16]. Among the non-destructive testing and evaluation community there are several approaches that produce this simulated data using a 3D model of the perspective projection.

One approach makes a simulation of the entire X-ray imaging process [17, 18], i.e., the characteristic of the X-ray source, the geometry, and material properties of objects and their defects, as well as the imaging process itself are modelled and simulated independently. Complex objects and defect shapes can be simulated using CAD models.

Another method simulates only the flaws (and not the whole X-ray image of the object under test) by superimposing projections of 3D models onto real X-ray images [19, 20]. Using the geometric model for a radioscopic imaging system outlined in [11], we are able to estimate the projections of a CAD model in every desired position. An example is illustrated in Fig. 3, where an ellipsoidal flaw is superimposed onto a real radioscopic image.

4 Automated flaw detection based on the tracking of potential defects

A method for the automated inspection of aluminium die cast pieces with the aid of monocular X-ray image sequences was developed in [21, 3]. The procedure is able to perform casting defect recognition in two stages: identification and tracking of potential flaws (see Fig. 4).

In the first step, the identification is performed automatically with a single filter and without a priori knowledge of the test piece structure. An edge detection procedure based on the Laplacian-of-Gaussian is employed to find abrupt changes in grey values (edges) in every X-ray image. Here, the zero crossings of the second derivative of the Gauss low-pass filtered image are detected [22]. These edges are then utilised to search for potential flaws defined as regions with a certain area and a high contrast level compared to their surroundings[2].

In the second step, the attempt is made to track the potential casting defects in the sequence of images. False detections can be eliminated successfully in this manner, since they do not appear in the following images and, thus, cannot be tracked. In contrast, the true casting defects in the image sequence can be tracked successfully because they are located in the position dictated by the geometric conditions. The tracking of the potential casting defects in the image sequence is performed according to the multiple focal constraints explained in [11]. Multi-focal tensors are applied to reduce the computation time. Following a 3D reconstruction of the position of the potential casting defect tracked in the image sequence, it is possible to eliminate those which do not lie within the boundaries of the test piece[3]. A schematic example is illustrated in Fig. 5.

5 Stereoscopic X-ray imaging for the screening of passenger baggage at airports

In [2, 24], a stereoscopic X-ray imaging system is presented for a security screening of passenger baggage at airports. The system is based on a single X-ray source and a pair of linear X-ray detector arrays. The images are acquired whilst the object under inspection is linearly translated past the X-ray detectors. The stereoscopic image pair of a suitcase is used to perform a 3D reconstruction in order to extract 3D coordinate information of the contents. Thus, the inspection task can be easily performed in complicated images where there are superposed structures. Preliminary studies indicate that the binocular stereoscopic X-ray images produced by this technique significantly aid X-ray machine operators in their ability to interpret complex 3D objects [24].

[2] Other methods for segmenting potential casting defects could be used in this first step [23].

[3] In `<http://www.diinf.usach.cl/~dmery/sequences.htm>`, a real example of this method is shown.

6 Summary

In this paper we present four applications reported in the literature that use the theory of the multiple view geometry in X-ray testing [11]: 3D measurement, 3D flaw simulation, flaw detection using an image sequence and stereoscopic X-ray imaging for the screening of passenger baggage. The key idea of the multiple view analysis is to gain more information about a test object by analysing multiple views taken at different viewpoints.

It is well known that "an image says more than thousand words". However, this is not always true if we have an intricate X-ray image with superposed structures. In this sense, multiple view analysis is a useful and powerful alternative for examining complex objects were uncertainty can lead to misinterpretation.

Multiple view analysis offers advantages not only in 3D interpretation. Two or more views of the same object taken from different viewpoints can be used to confirm and improve the diagnostic done by analysing only one image.

Due to the relatively low cost and the low number of images that must be taken and processed, the multiple view X-ray testing represents an economic alternative to CT for rapid internal feature analysis.

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Domingo Mery (1965) received his Diploma (MS) degree in Electrical Engineering from the Technical University of Karlsruhe, Germany, in 1992, and his PhD degree with distinction at the Technical University of Berlin, in 2000. During 1993–1996, he was a Research Assistant at the Department of Electrical Engineering at the Catholic University of Chile. From 1996 to 2000, he was a Research Scientist at the Institute for Measurement and Automation Technology at the Technical University of Berlin with the collaboration of Philips and YXLON X-Ray International. From 1989 to 1992 he was a recipient of a Scholarship from the Konrad-Adenauer-Foundation, and from 1996 to 2000 of a Scholarship from the German Academic Exchange Service (DAAD). Since 2001 he is an Assistant Professor at the Departamento de Ingeniería Informática of the Universidad de Santiago de Chile. His research interests include image processing for automated inspection, X-ray imaging, computer vision and non-destructive testing and evaluation.

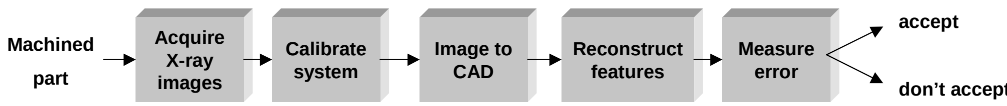

Figure 1: Schematic diagram of CAD-based inspection using X-ray images.

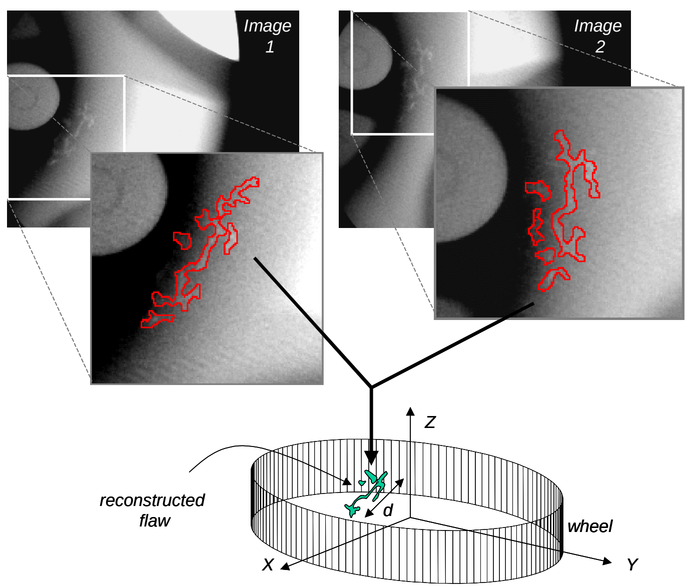

Figure 2: Schematic diagram of the 3D reconstruction of the location of a flaw in a wheel from two X-ray images.

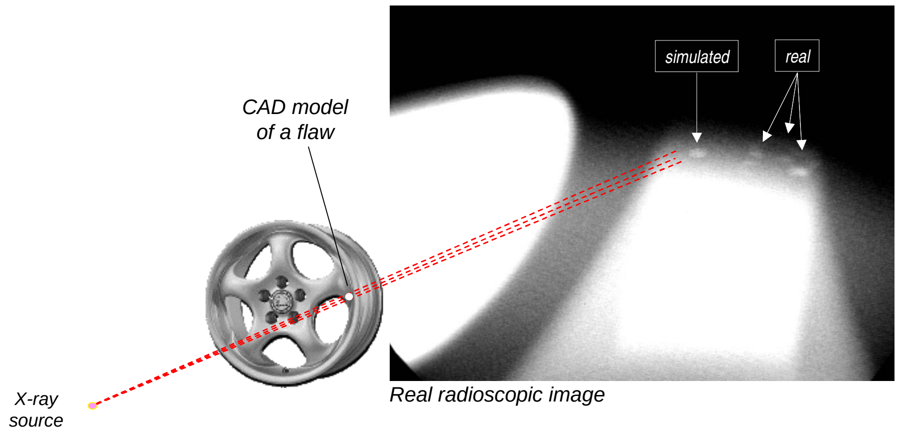

Figure 3: Flaw simulation process using a CAD model for an ellipsoidal flaw. The simulated defect is almost identical with the real flaws.

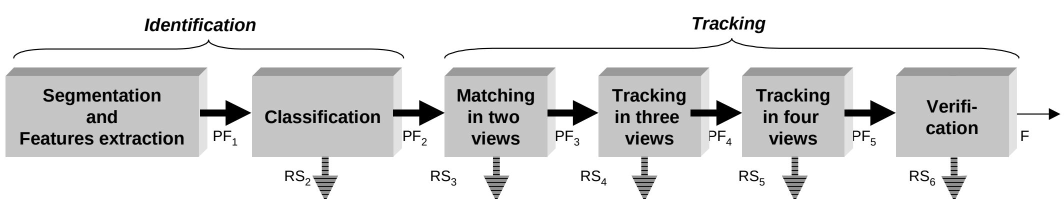

Figure 4: Automated flaw detection in aluminum castings based on the tracking of potential defects in a radioscopic image sequence: PF = potential flaws, RS = potential flaws classified as regular structures, F = detected flaws.

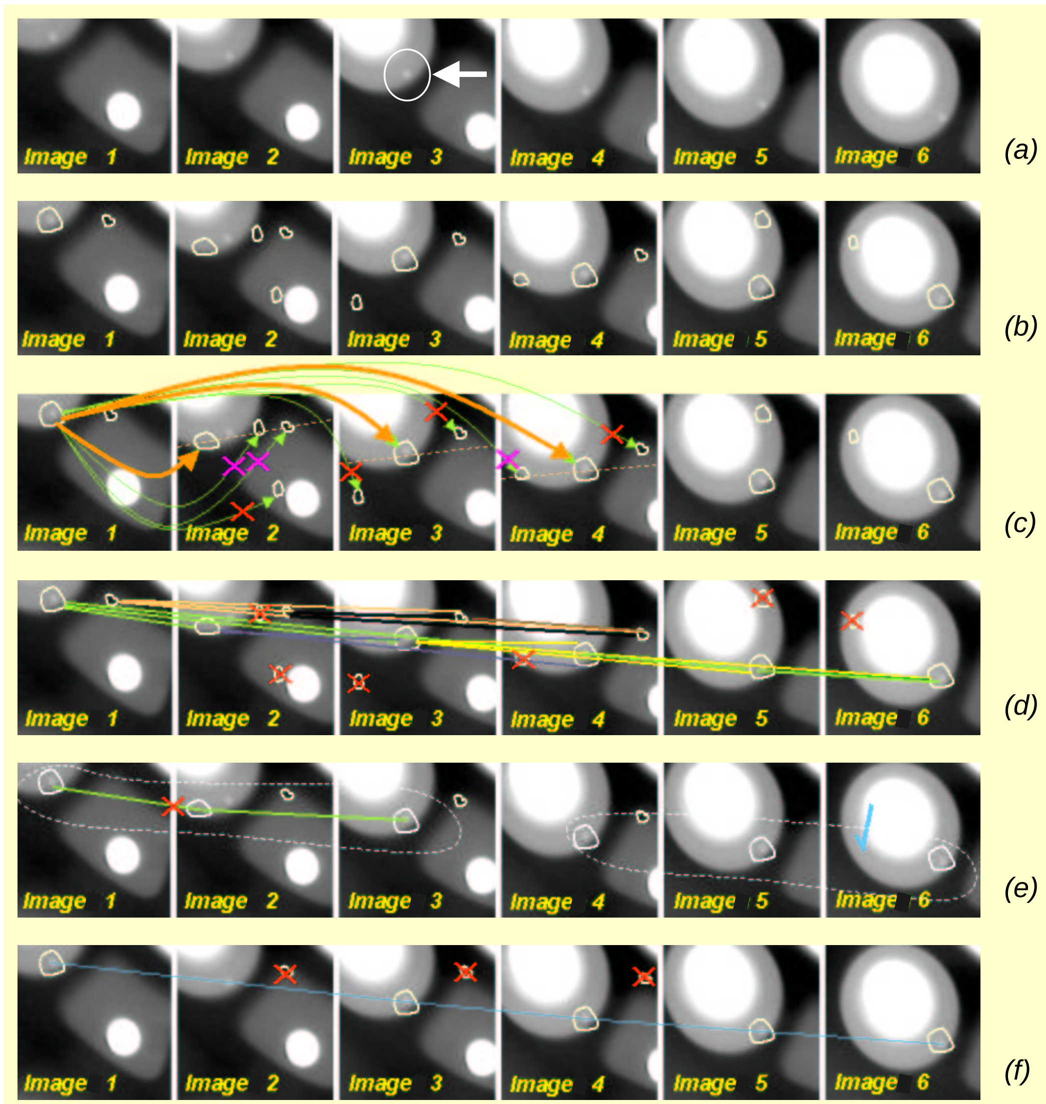

Figure 5: Flaw detection based on tracking of potential flaws in a sequence: a) image sequence with a small flaw (see arrow), b) detection of potential flaws, c) search of matching in two views, d) remaining potential flaws after matching in two views, e) search of triplets, f) tracking in more views, and final detection, the false alarms are eliminated without discriminating the real flaws.