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Sub-minute measurement times in inline-CT: development of a fast data acquisition pipeline

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Abstract

As the healthcare and life sciences sector plays an essential role in driving the rapidly expanding micro injection molding market, companies are faced with the challenge of maintaining rigorous quality control standards. Despite available non-destructive testing technologies permitting the precise measurement of internal defects, they are severely limited by their speed. A novel and scalable fast data acquisition pipeline for non-destructive testing is presented, enabling a 100 % inline-inspection of injection molded parts. The pipeline includes a robot-based radiographic measurement system and an AI model for defect detection. With only 6 to 14 required projections, measurement times of 30 s ± 3 s were achieved. Defect detection is performed by an AI model directly on the 2D projections. Initial performance of the AI model is promising with further development focused on eliminating false positives.

Projection analysis, Inline-CT, Acceleration of measurement, Neural networks

1. Introduction

Despite recent advancements, prolonged measurement times remain a significant barrier to widespread adoption of non-destructive testing (NDT) technologies for the 100% inline-inspection of injection molded parts. Current quality control systems primarily focus on monitoring weight, surface geometry, and surface quality, thus limiting defect detection to externally observable factors and necessitating destructive testing for internal defect identification [1, 2, 3]. To address this challenge, a novel data acquisition pipeline was developed, integrating a custom robot-based x-ray computed tomography system and a specialized AI model for defect detection.

While existing research emphasizes the development of faster sensors and algorithms to expedite individual projection acquisition and image reconstruction, these approaches still require several hundreds to thousands of projections, posing limitations for inline inspection in micro injection molding [4, 5, 6]. For instance, Murtaza et al. implemented a radiographic system capable of rapidly scanning additively manufactured components, capturing 720 radiographs in 36 seconds. However, the system's reliance on high frame rates and moderate resolutions limits its suitability for defect detection in larger components requiring higher spatial resolution [7].

The subsequent chapters detail the experimental setup, the data acquisition pipeline, and methodology for data acquisition and defect detection. Furthermore, the reduction in the number of required projections and resulting measurement times are presented, along with an initial assessment of the AI model's performance. The paper concludes with an overview of the findings significane for injection molding.

2. Methodology

Conventional x-ray based non-destructive testing methods need at minimum several minutes to capture the required measurement data. The following chapter present a scalable, fast data acquisition pipeline which performs everything from image capture to defect detection in less than a minute.

2.1. Setup

The radiographic measurement system, depicted in Figure 1, integrates a 6-axis robotic manipulator at its core. This industrial robot maneuvers a bespoke C-arm, housing both an X-ray source and detector, facilitating projections from diverse angles and positions in 3D space. All pre-computation steps, encompassing trajectory planning to data acquisition, are centralized on a control PC, serving as a Single Point of Control (SPOC).

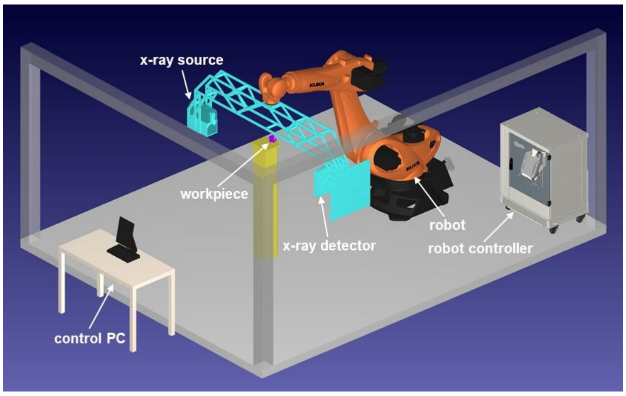

Figure 1. Setup of the radiographic measurement system for the measurement of arbitrary projection poses

The system is capable of inspecting components as small as 5 mm, achieving magnifications in the range of x1.36 to x61.44.

It is possible to scale the system for the non-destructive testing of smaller or larger components up to 225 mm but the maximum available magnification decreases with increasing object size.

2.2. Pipeline

The presented pipeline is based on the hypothesis, that each projection contains information on the location, shape and size of all defects present in a workpiece. Since all information is contained within the projection data, no 3D reconstruction is necessary for defect detection. Thus, it is possible to perform defect detection with an arbitrary number of projections, with each additional projection providing diminishing information. Consequently, by using a small number of projections data acquisition can be reduced by multiple magnitudes. A pipeline was implemented on this basis, as can be seen in Figure 2.

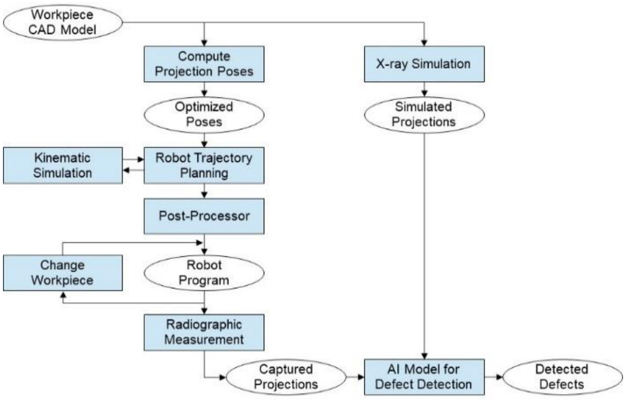

Figure 2. Sub-minute data acquisition pipeline

The Fraunhofer developed FLUX framework is used to conduct an x-ray simulation using 3D CAD models of the specimen with varied defect populations to generate synthetic projection data for a large number of projection poses and defect variations. These are used to train the AI model prior to data acquisition.

The inspection process starts by computing the optimal projection poses for a predefined number of projections. To evaluate the information contained in a specific set of projection poses, the 3D CAD model without defects is evaluated with two metrics. The first metric measures the standard deviation of the model thickness for every projection angle in 3D space. The second metric measures measures the geometric independency of projection poses. An optimal projection pose is the combination of a high standard deviation of the model thickness and high geometric independency.

Subsequently the trajectory planning for the robot is conducted with the help of a collision simulation using RoboDK. Robot program code is generated from the found trajectory and loaded onto the robot. After placing a workpiece in the system, a completely automatic inspection cycle is perforemd. Following the measurement program, the acquired projection data is automatically evaluated by the AI model and all identified and localized defects returned via the graphical user interface (GUI).

3. Results

The number of required projections was successfully reduced to 6 to 14 images in 3D space, signifying a reduction in projection data by a factor of 90 to 160 compared to conventional systems. The entire radiographic measurement of a component can be completed within less than a minute. When using 8 projection poses, a complete measurement cycle was completed within 30 s ± 3 s, excluding workpiece handling.

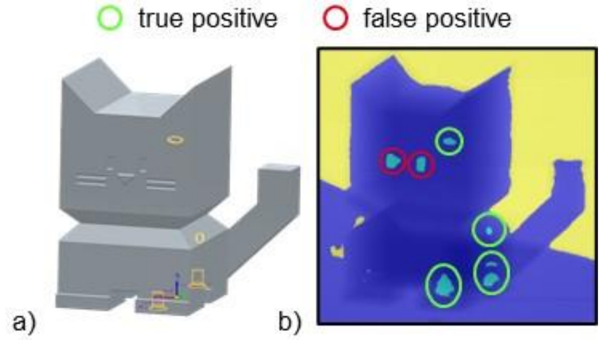

Figure 4. Example of AI-based defect detection using raw 2D projection data from an uncalibrated detector **a)** CAD model of the specimen with defects outlined in orange **b)** Identified defects with correct identifications marked in green and false identifications marked in red

Both internal and external defects in components are identified and localized by the defect detection AI model. The model finds all four of the existing defects in the specimen, for every of the four preliminary defect variations. From the seven small-scale geometry features, two are misclassified as false positives. While the model finds all of the existing defects in the specimen, individual geometry features, s.a. the eyes, tend to be misclassified as false positives, as seen in figure 4. Given the state of AI development this falls within expectations and current efforts are focused on remedying this problem.

		Actual	
		Positive	Negative
Predicted	Positive	**TP** 4	**FP** 2
	Negative	**FN** 0	**TN** 5

Table 1. Confusion matrix for the defect detection seen in Figure 4

4. Conclusion

In conclusion, the presented fast data acquisition pipeline represents a significant advancement in non-destructive testing for injection molding. By shortening measurement times, this approach enables a 100% inline inspection of injection molded parts with a radiographic measurement system for the first time. Through the adaptation of projection reduction and AI defect detection, measurement times were reduced to 30 s ± 3 s. While initial results are promising, ongoing efforts are aimed at further optimizing the system and improving defect detection capabilities. These advancements possess the potential to transform quality control across the injection molding sector.

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