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Advanced Computer Vision and AI Techniques for Nano-Scale Quality Control in Manufacturing In the Space Industry

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Abstract

This paper examines the integration of advanced computer vision (CV) techniques and Artificial Intelligence (AI) algorithms to improve quality control (QC) for nano-scale manufacturing processes in the space industry. As nanotechnology is regularly used in the space industry for manufacturing electromechanical components such as NEMS (Nanoelectromechanical Systems), solar panels, and energy storage devices, it's becoming increasingly important to detect defects or imperfections in one of those systems to prevent the loss of life and a costly catastrophe. In order to help mediate this issue, this paper will discuss the methods and processes that can be implemented to capture and analyze nano-scale images and data in order to detect possible flaws in the components.

Keywords: artificial intelligence, manufacturing, aerospace, computer vision

Introduction

There have been massive leaps and improvements in technological development and manufacturing around the world and people are making even more advanced products by utilizing those improvements. However, due to past events such as the implosion of the Titan submersible, the massive Samsung Galaxy Note 7 recall in 2016, and the Challenger space shuttle disaster in 1986, quality control has been of utmost importance in various manufacturing industries. Now that these industries are finding ways to implement nanotechnology in their products, ensuring that the products are of high quality and meet the industry standard is of utmost importance. In the space industry, more specifically, a minute, nanoscale fracture in a part of a component can lead to a catastrophic failure that can lead to injuries or loss of life. To help remedy this problem, this paper will present a system that could help improve quality control at a nanoscale.

Methodology

Nanotechnology, a branch of science that deals with objects of less than 100 nanometers, is still in its early stages, and while it has promising application potential, there's still some work to be done. For this reason, nanoscale quality control has become increasingly important. The quality control system discussed in this research paper is to use Computer Vision (CV) and Artificial Intelligence (AI) to determine if there are defects in a manufacturing component. However, modern technology has its limits: the instruments that can examine objects at a nano/microscale have restrictions in sample size. In order to resolve this issue, a new system of Scanning Electrons and Fluorescence Microscope System (SEFMS) had to be conceptualized. SEFMS incorporates both aspects of a Scanning Electron Microscope (SEM) and a Fluorescence Microscope (FM) in order to increase the accuracy and preciseness of the QC. In this device, the SEM and FM will both be integrated into one robotic arm that can move freely along three dimensions (3D). Each robotic arm will have the crucial components that the SEM and FM need to function properly. These components include the electron gun anode, condenser lens, scan coils, objective lens, a secondary electron detector for SEM and the light source, excitation filter, emission filter, dichroic mirror, objective, and detector for the FM. This will solve the current constraints regarding SEM and FM scanning objects of large sizes and will increase QC. This process is enabled by AI software that analyzes the results of both SEM and FM and uses techniques found in Geographic Information System (GIS), which fuses data signals from the two microscopes and determines whether a part has an issue.

The full QC process that the SEFMS will undertake begins by putting the sample on a plate with varying dimensions. Then, after the user has entered the full measurements of the sample, the robotic arm will go around the sample, and every time it scans a part of the sample, it will send it to the AI program, which will determine whether the sample has imperfections or defects that need to be fixed. The results of the SEFMS will be displayed on an external monitor where the user will be given information on the location and severity of the defect (length and depth).

As all new ideas and new technology do, there has to be evidence that shows whether the SEFMS will function properly in the proper working environment. In a study conducted by Aditya Akundi and Mark Reyna, the authors state that, after testing numerous different testing models, there is a high likelihood of a device similar to the SEFMS to work.

Shape	Base	Tested	Likeness score
Cube	3 cm	3 cm	1.000
Cube	3 cm	2.8 cm	0.924
Cube	3 cm	2.9 cm	0.958
Cube	3 cm	3.1 cm	0.958
Cube	3 cm	3.2 cm	0.923

Note: Reprinted from A Machine Vision Based Automated Quality Control System for Product Dimensional Analysis (1st ed., p. 132) by Aditya Akundi, Mark Reyna, ScienceDirect, 2021. Copyright 2021 by Aditya Akundi, Mark Reyna

The table above shows how a device made by Akundi and Reyna differentiated a sample of different sizes, compared those samples with the base sample, and provided statistics on how different they (the samples with different sizes) were. This shows that the SEFMS can work, as there have been examples that showed that machine vision can differentiate two similar (yet different on a millimeter scale) objects and give a numerical value that shows the difference. The SEFMS is fundamentally a device that shows where a component has imperfections by comparing it to the original (how the component should look), and sources and studies like the one conducted by Akundi and Reyna show that this is possible. The SEFMS can, at least theoretically, function if manufactured and put in a working environment.

In addition, the SEFMS has applications outside of the aerospace industry. As this is a device for QC, it can be used not only in the aerospace industry but also in other industries in which components must be examined at a nanoscale. For example, the electronics industry could benefit from implementing the SEFMS, as the need for strict quality control is crucial in this industry. The electronics industry is greatly dependent on the Central Processing Unit (CPU), which acts as the brain of the device and undertakes most of the calculations and processing required to run an electronic device. As the CPU is such a small and delicate component, any microfracture or imperfection can lead to a truly catastrophic failure. Implementing the SEFMS in these industries will enable them to enjoy a much more reliable manufacturing system with significantly increased quality control.

However, similar to numerous electronic/robotic systems, there are limitations to this concept despite the proof of possible functionality. As implementing an electroscopic device in a robotic arm, or any robotic device, has never or very rarely been done before, there is little evidence that ensures that when the product is manufactured, it will function as hoped and to the accuracy that it should produce. Also, the amount of time the single robotic arm will take to go over large components cannot be ignored. It may take the system hours to scan an entire component which, despite its accuracy, can be a detracting factor in terms of performance. This is mainly due to the limitations of modern technology. Not all technologies have matured yet, and nanotechnology in particular is still in its infancy, requiring more research and exploration to resolve the limitations posed. Although these constraints can be troublesome for the SEFMS, if the system performs even anywhere near its promises, it would provide manufacturers with great improvements in QC.

Conclusion

This paper presented a new device of SEFMS capable of robust quality control of aerospace components with great application potential. The SEFMS incorporates AI, CV, microscopy, and robotics in order to increase QC, which will greatly benefit the aerospace industry and potentially save human lives as well as capital. As this is a new technology, there is room for improvement and work to be done to better the device. If such work is done, the SEFMS can greatly improve the quality of QC done in the aerospace industry.

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