Augmentation of Camera based Non-Destructive Testing using Robotics and Motion Tracking

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by

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Abstract

The usage of Camera based Non-Destructive Testing (NDT) methods such as Thermography and Laser Shearography in Aerospace applications such as the inspection of large composite panels for defects presents some challenges. Even though they are area based methods, they still capture only a small fraction of the surface to be inspected at a time. Moreover, the surfaces which they are supposed to inspect can be curved or complex in shape, while the image that is captured by the camera is rectangular in shape according to how the camera frustum intersects the surface. Hence it can be challenging to achieve a complete coverage of the surface from multiple viewpoints and also relate the data from images gathered to the actual location of the defects in the panel.

Computer Aided Inspection (CAI) involves the use of hardwares like robotic and motion tracking systems, and associated algorithms for path planning, motion tracking and image stitching. While the CAI solutions for Ultrasonic NDT and Radiography (X-ray) have been available for a long time in the form of C-scan machines and Computed Tomography systems respectively, the same cannot be said for lesser known NDT methods such as Thermography and Laser Shearography. While some solutions are known to exist at research centres such as NASA, the know-how related to this is not shared in the public domain. Augmentation of the camera based NDT processes is therefore much needed as these processes are gaining more acceptance due to their non-contact, non-hazardous and area based nature of inspection.

This thesis presents algorithms and techniques to augment the camera based NDT Systems using Motion Tracking, Viewpoint Planning, Image Stitching and Coverage Path Planning. The working of these algorithms is demonstrated using theoretical simulations on a 'Digital Model' of the system and also on prototype robotic and motion tracking hardware. The development of these prototype hardware and their operation, as well as their limitations is also explored.

The first chapter gives an introduction to the problem being solved and the motivation behind the present approach. Several case studies of existing solutions in the field of NDT Augmentation using Robotics, Drones and Motion tracking systems are presented. The NDT systems being augmented are using Camera based techniques like Thermography and Laser shearography, though in some cases ultrasonic NDT is also given as examples.

These case studies are primarily deductions from studying videos and conference papers. The exact methodology as to how the solution is reached is not disclosed.

The second chapter gives the details about the construction and operation of the prototype 5-axis cartesian robot used for the inspection of a panel. The accuracy and repeatability of the robot are analyzed using metrological methods and its limitations are documented.

The third chapter details the development of the prototype motion tracking systems and characterizes the performance of the optical hardware to give some insights about the limitations of the different cameras and optical systems. The algorithms for motion tracking using April Tags and integrating it with the 3D model of the panel being scanned are detailed. The stereo and monocular tracking pipelines, through which the image data captured by the camera are converted into pose information for the motion tracking integration are fully described.

Viewpoint planning and Image Stitching using the virtual 3D model of the panel is the subject of the fourth chapter. A user friendly 3D viewer is developed to accept input from the user and manually plan the viewpoints on the 3D model of the panel. The G-code for positioning the robot is generated from the viewpoints chosen by the user and the robot is moved using this code to record the corresponding images. The image obtained are stitched onto the 3D model of the panel by using a 3D stitching algorithm as presented, which is based on mapping points in the pointcloud to the images taken. Blending is done at the overlapping areas covered by more than one viewpoint, using the Grassfire algorithm. The 3D image thus formed is presented to the user. For verifying the technical correctness of the method, simulated data taken from the virtual camera model is also used in the image stitching process. Evaluation of the stitching result is done by comparing it with data from the actual panel.

The Fifth chapter improves on the manual viewpoint planning approach presented in the previous chapter by addressing the problem of coverage path planning. While in the literature much study has been done on optimization based methods and geometric methods utilizing the slicing approach, the method present here relies on geodesic path generation and mapping a grid of viewpoints onto the surface. Nodes corresponding to viewpoints are generated automatically and the node generation is stopped based on certain criteria. This approach is semi automated and relies on the user to give good starting conditions for the node propagation. A large number of examples are presented to show the strengths and weaknesses of the method.

The Last chapter details the conclusions from the study. The algorithms for the augmentation of camera based NDT Systems, including the development of virtual 3D models, motion tracking system integration with NDT, path planning including automated coverage path planning, 3D image stitching and visualization are fully detailed and documented. Prototype hardware for cartesian robot and motion tracking have been developed for the demonstration of these algorithms and also their limitations are noted. Simulation models for verifying coverage path planning and image stitching techniques have also been extensively explored. It is hoped that the presented work will lead to a unified common model for the augmentation of camera based NDT systems to be used in industrial applications.