SANDIA REPORT

SAND2001-1843
Unlimited Release
Printed June 2001

Scripting For Video Inspections

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Albuquerque, New Mexico 87185 and Livermore, California 94550

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Scripting For Video Inspections

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Abstract

The purpose of this study was to enhance the reliability of deployed components for nuclear weapons by improving the quality and consistency of the final visual inspection before deployment of the weapon. Currently, most of these parts are subjected to manual visual inspection, a process subject to errors related to consistency and accuracy. Furthermore, there is no method for documentation of the inspection. Even state-of-the-art commercial visual inspection systems are inadequate because they require skilled engineers to artfully adjust camera parameters, lens settings, lighting, and processing for each new inspection, part or defect. In this project, we developed technology to automate much of the setup for visual inspection. We implemented graphical simulations and CAD models of the camera, positioning system and parts to be inspected. Using these tools, the system automatically generates camera locations and settings for the camera lens and illumination to produce optimal images for inspection. We refer to this combination of imaging parameters as a "script". The "script" contains all the instructions necessary to perform the inspection when run on the actual inspection system. In addition, we developed a cataloging system to allow storage and retrieval of the video images gathered during an actual inspection of real parts. We developed several feature extraction algorithms that were able to detect defects in the actual parts but were unable to achieve comparable results using the CAD based parts. A version of this system has been implemented at the neutron generator facility as a key element of implementing the process-based quality manufacturing.

Acknowledgements

The author would like to acknowledge the contributions of John Krumm who conceived this project; John Feddema for laying out the original approach and performing the initial investigation; Charles Little, Jeff Carlson, and Brian Kast for investigating algorithms for defect detection; Jill Rivera for developing CAD models of the components, workcell, and lighting and beginning the photo-realistic rendering process; Dan Schmitt for his work in generating the motion planner; and Ken Jensen for guidance and integration efforts. Lou Malizia, NG Inspection liaison, and Ross Burchard, NG Robotics liaison, contributed significantly to the development of the inspection workcell and software interface.

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Introduction

The purpose of this study was to enhance the reliability of deployed components for nuclear weapons by improving the quality and consistency of the final visual inspection before deployment of the weapon. Currently, most of these parts are subjected to manual visual inspection, a process subject to errors related to consistency and accuracy. Furthermore, there is no method for documentation of the inspection. Even state-of-the-art commercial visual inspection systems are inadequate because they require skilled engineers to artfully adjust camera parameters, lens settings, lighting, and processing for each new inspection, part or defect. In this project, we developed technology to automate much of the setup for visual inspection. We implemented graphical simulations and CAD models of the camera, positioning system and parts to be inspected. Using these tools, the system automatically generates camera locations and settings for the camera lens and illumination to produce optimal images for inspection. We refer to this combination of imaging parameters as a "script". The "script" contains all the instructions necessary to perform the inspection when run on the actual inspection system. In addition, we developed a cataloging system to allow storage and retrieval of the video images gathered during an actual inspection of real parts. We developed several feature extraction algorithms that were able to detect defects in the actual parts but were unable to achieve comparable results using the CAD based parts. A version of this system has been implemented at the neutron generator facility as a key element of implementing the process-based quality manufacturing.

The goals of this project were achieved by accomplishing the following milestones:

1. Develop a robotic inspection workcell with camera / part positioning and control of lens and lighting.
2. Incorporate capacity to capture images and store images to disk (data collection system).
3. Automate image comparison of good and bad parts.
4. Develop CAD-model based visualization of inspection process.
5. Integrate the CAD-model based graphical interface with physical system.
6. Test with post braze inspection system.

As will be discussed, we found the ability to automate comparisons between the CAD model and the actual parts is limited by the complexity of the interplay between light and shadows on the part which we were not able to reproduce in the CAD environment. Thus, algorithms to do this need to be incredibly robust – subject of a future fertile research effort. An approach which is more in line with current technologies entails taking a known good part, run it through the inspection process, and then compare the unknown images to those taken of the good part under equivalent lighting condition.

Development of the Robotic Inspection Workcell

This project was developed in conjunction with the Post-Braze Feedback Project. The latter project concentrates on inspection of the neutron generator header. The prototype Robotic Workcell was therefore tailored to accommodate this particular part.

Initially, a workcell based on an Adept I robot carrying a video camera was developed. In this system the part was fixed and the robot positioned the camera to obtain the desired views. This approach allows a great deal of flexibility in selecting views and is very similar to the free-floating camera implemented in our first CAD simulations. However, it presented some difficulties with lighting and was not precise enough for a second part we were asked to consider. We ultimately designed a workcell with a fixed camera and a set of stages to position the part for inspection. A sketch of this workcell showing the motions provided by the stages is presented in Figure 1. The actual hardware is shown in Figure 2. The system provides two translational and two rotaional degrees of freedom. Newport manufactures the stages and drive electronics. The microscope optics are provided by Navitar. The zoom and focus of the microscope are motorized. A Fostec ring light attached to the last element of the microscope provides illumination. The stage drives, lens motors and the light source can all be controlled via RS-232 serial commands from the host computer.

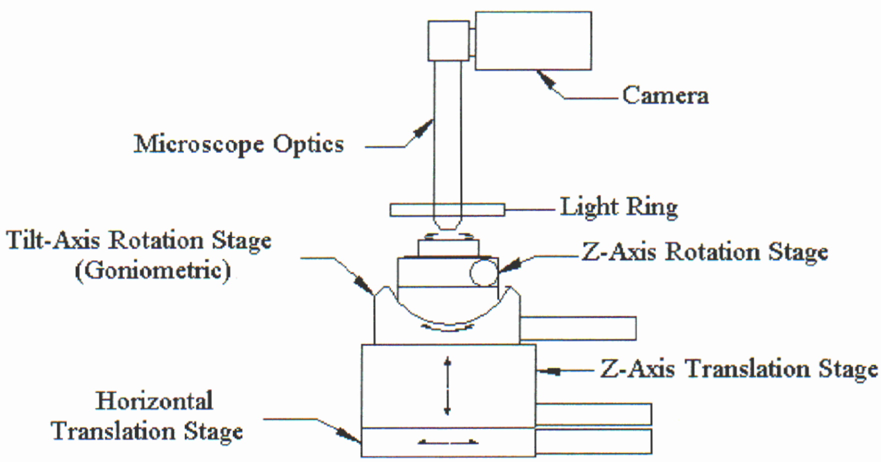


Figure 1. Inspection Workcell Sketch

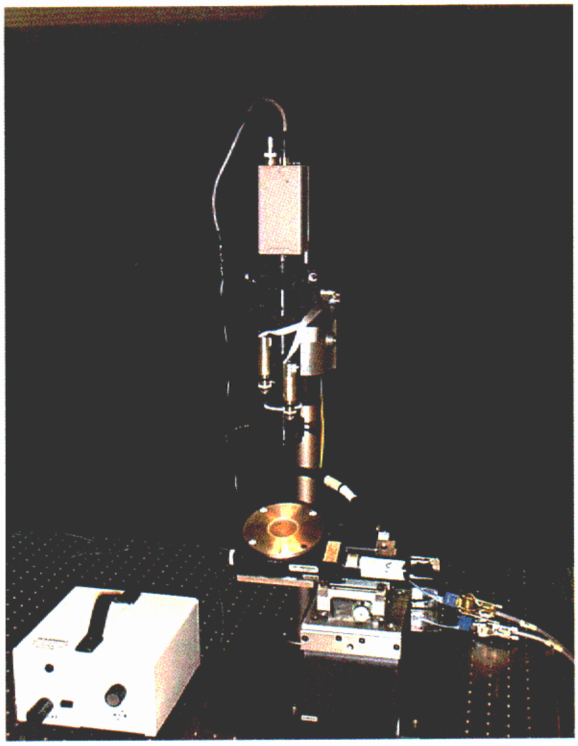


Figure 2. Inspection Workcell Hardware

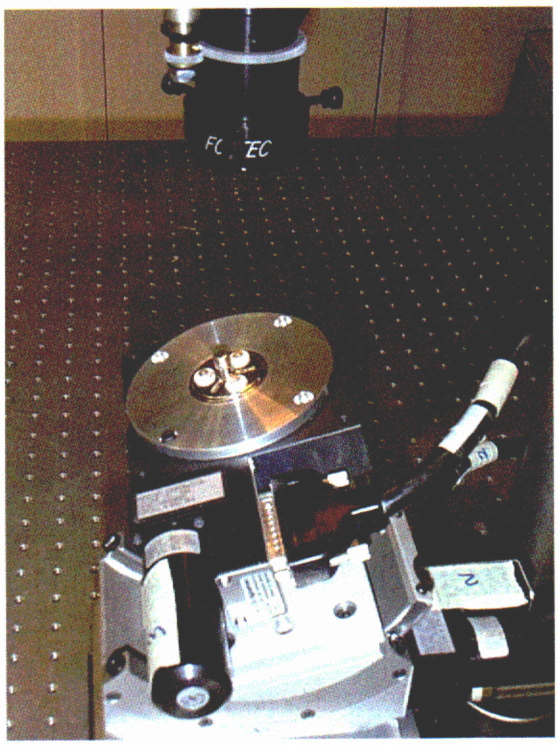


Figure 3. Header on Positioning Stages

Image Capture and Storage

The prototype software for the neutron generator header inspections allows the electronic images of the subassemblies as well as the image inspection results to be archived for future comparison when the parts are tested.

Images are captured and digitized by an Imagenation PCX-200 frame grabber on the host computer. We tried both monochrome and color frame capture modes. Most of the image processing work was conducted on 8-bit monochrome images. For archive purposes, we typically captured 24-bit RGB color images. All images were captured at 640 by 480 pixel resolution. The images were stored on the host's hard disk. Adequate space was available on the hard drive to store hundreds of uncompressed RGB images. When hard drive space became limited, the archived images could be transferred to a writable CD to make room for new images.

Automate Image Comparison of Good and Bad Parts

During the first year, we assessed the feasibility of the inspection routines for the neutron generator header and frame. Using image differencing, we have successfully shown that we can find voids in the braze fillets as well as braze splatter on the ceramic insulators.

The neutron generator header is inspected for:

1. Good appearing braze surface
2. Complete fillet
3. No braze splatter on other surfaces
4. Damaged rivets/lead insertion
5. Handling marks.

We used image differencing and auto-correlation techniques to identify these defects. Using image differencing, we have successfully shown that we can find voids in the braze fillets as well as braze splatter on the ceramic insulators. Figures 4 and 5 show the processed images of a neutron generator tube with complete and incomplete fillets. Figures 6 and 7 show the processed images of a neutron generator tube with a clean ceramic insulator and a ceramic insulator, which has braze splatter on it. The void and the splatter show up as light colored regions in the image. We are building up statistical models, which we can then use to classify parts using Bayesian hypothesis testing. The results of the statistical decision along with electronic images of the subassemblies are transferred to a project database. These image inspection results can be combined with other information of the brazing process (e.g., the furnace termperature profiles) to aid the engineers in design and manufacturing process. The stored images will be archived for future comparison when the parts are tested. If a failure is found when a neutron generator tube is exploded during test, the engineers would like to look at a historical archive of the subassemblies to try to determine the cause of failure.

Similar techniques were successfully applied to the inspection of the neutron generator screen. In this case we were looking for breaks, over and under etching, pits, holes, and contamination. While the processing techniques were very similar, the positioning, magnification and lighting required were all very different.

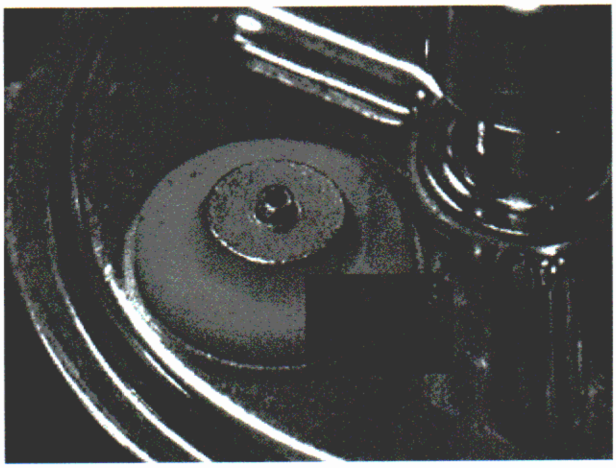


Figure 4. Processed image without fillet void.

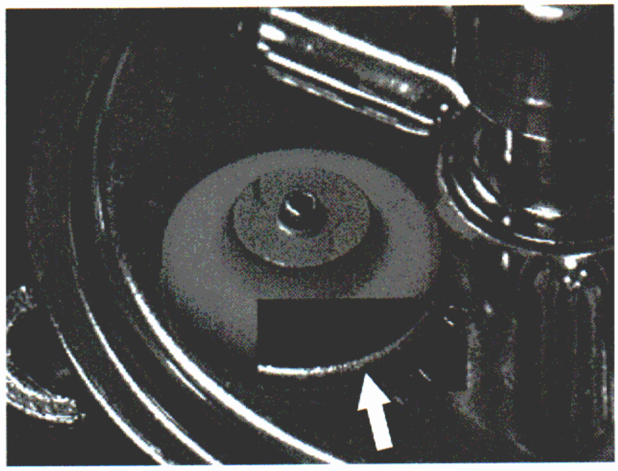


Figure 5. Processed image with fillet void.

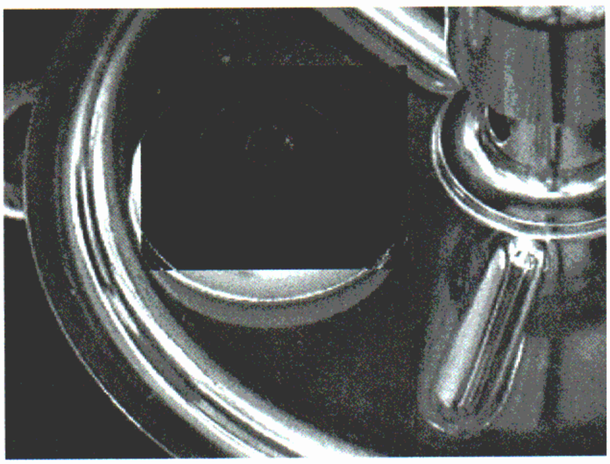


Figure 6. Processed image without braze splatter.

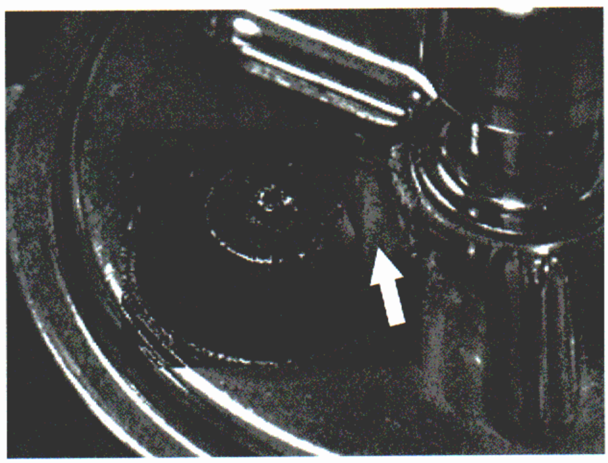


Figure 7. Processed image with braze splatter.

CAD-model Based Visualization of Inspection Process

Our next step was to build a CAD-based photo-realistic representation of the parts to be inspected and the inspection workcell. This virtual representation would be needed to determine the views, illumination, and processing required to achieve the desired inspection.

Three commercial packages were evaluated for generating photorealistic images from CAD data. Two of the products, Breault's ASAP and Optical Research Associates' Light Tools did not provide photorealistic images in a useable format. Kinetix's 3D Studio MAX was selected as the product to generate photo-realistic images.

Within 3D Studio MAX, we were able to bring in Pro-Engineer CAD drawings of neutron generator parts such as the header as shown in Figure 8. The operator can position the virtual camera and lighting relative to the parts and view a photo-realistic image of the part as would be seen by the camera. We can bring in positioning devices such as the stages shown in Figure 1. These positioning stages place the camera or microscope in the correct position relative to the part. The kinematics of the stages limit the possible camera or microscope views. We used the inverse kinematics of the stages to generate set points that can be directly downloaded to physical hardware. Thereby, the virtual image created by the CAD software is reproduced in the actual part. Both images can be stored on disk.

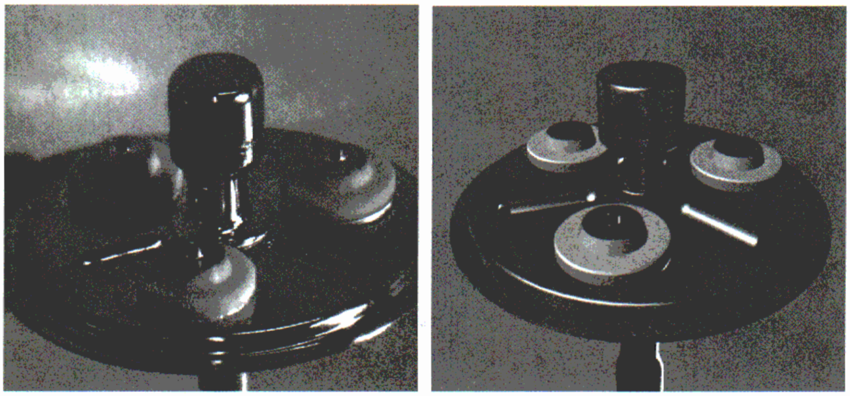


Figure 8. Actual and simulated images of neutron generator header assembly.

Integrating the CAD-model Graphical Interface with Physical System

Using the CAD model of the part, our system now determines camera locations, lens settings, and illumination to make good images. We refer to this combination of imaging parameters as a "script", and it can be used to drive a real system to perform the desired inspections.

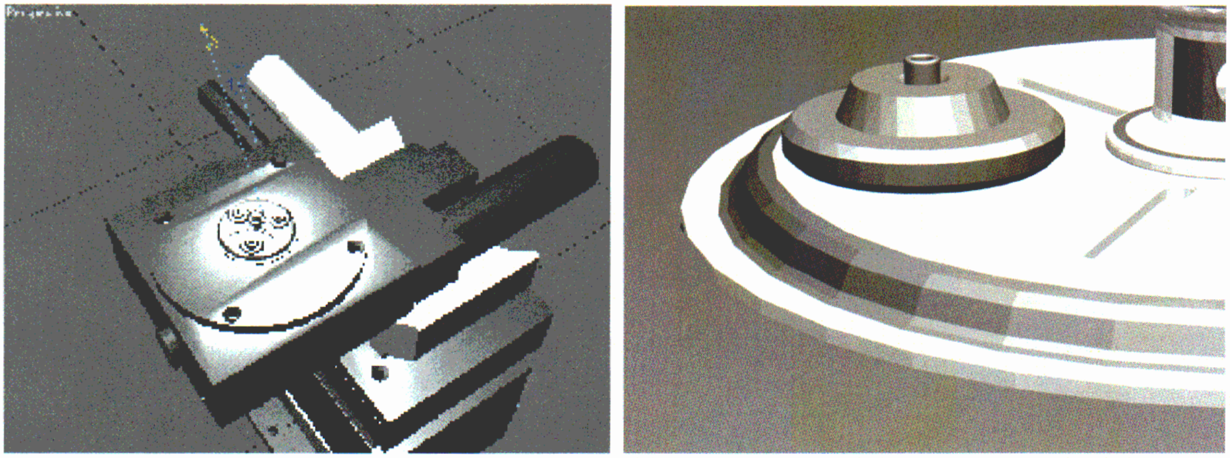
The graphical user interface allows the part movies to be used by human inspectors to direct their attention to the correct points, enhancing their consistency. The scripting system serves as the basis for human-assisted specification of specialized inspection routines.

The semi-automated inspection system allows the CAD model to be used by a master inspector to indicate which points and regions need to be inspected. The master inspector specifies these areas by pointing at the CAD model with a mouse on a computer screen. These points are saved and then used by path planning software to automatically develop a path for a robot-held camera to move around the part and make images of each of the indicated points. This software also automatically generates lens parameters (zoom, focus, and aperture) and lighting directions to get the best sequence of images. This automatically generated plan is like a videographers script to specify a smooth sequence of camera moves, lens settings, and illumination to produce a movie showing all the regions of the part that need to be inspected.

The movie will also serve as a video record of the part, which will be useful for diagnosing any subsequent failures. By asking the system to image every visible point on the part, the part's "inspectability" can be assessed by noting those areas that cannot be easily imaged or illuminated.

Testing with Post Braze Inspection System

The last stage of this project was to drive the physical inspection system using the script produced by the CAD-based simulation. To do this, we developed the control software for the robotic inspection workcell that read a file containing the inspection script and performed the specified sequence of tasks. Figure 9. shows the CAD simulation of our inspection hardware as well as the desired image of the header. Our system was able to take the script and generate an inspection view identical to the one specified in the script.



(a) (b)

Figure 9. (a)Neutron generator header placed in visual inspection workcell. (b)Photo-realistic image as seen by camera.

Future Enhancements

Enhancements of the system would allow the automatic comparison of actual and simulated images to automatically find certain defects without manual intervention. The proposed part could be evaluated using its CAD model. The technical challenge of this development would be to develop an algorithm to compensate for the complexities introduced by actual lighting as compared to the relatively simple structure of a CAD drawing.

Since the camera position, lens parameters, and lighting will be known from the script, the CAD model can be used to make accurate renderings of how the part should appear. To account for ranges of acceptable tolerances, the CAD model will embody tolerances on sizes, positions, and angles in a kinematic hierarchy. The CAD model and tolerances will be used to produce simulated images of all possible acceptable instantiations of the part. Alternatively, the system could take a number of images from a large sample of parts and develop acceptance criteria from the actual images. These images could be compared using principal component eigenvectors based on research we have done on object recognition[1]. This technique is sensitive to any difference between the CAD model, or image database, and the part, including cracks, blemishes, missing components and broken traces. Once developed, such a system could delineate allowable tolerance and consistently identify unacceptable deviations from specifications. This evaluation would also indicate which sections cannot be adequately imaged and could be fed back to the designers. In addition, having a movie of the part will assist in diagnosing future failures.

Additional enhancements of the project could concentrate on more specific visual inspection tasks that are beyond the capability of the current image comparison method. Examples of such specific tasks are checking the consistency of texture on rough ceramic, assessing the uniformity of a laser weld, and measuring the penetration of a diffused material. These characteristics cannot be represented easily by a CAD model; so more specific modules will be required.

Summary and Conclusions

We have created an automatic scripting system that will make a movie of a part showing the regions that need to be inspected. It automatically adjusts the camera position, lens parameters, and lighting. Our system automates the acquisition and storage of good images, and could be enhanced to constrain the inspection process by predicting all possible appearances of a good part, including acceptable tolerances

References

[1] Krumm, "Eigenfeatures for Planar Pose Measurement of Partially Occluded Objects", *IEEE Conference on Computer Vision and Pattern Recognition*, June 1996, 55-60.

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