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Sandia National Laboratories
Weapons Systems Engineering Assessment Technology (WSEAT) Subprogram

Advanced Radiographic Diagnostics

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Recent advances in computed tomography (CT) have revolutionized the ability to nondestructively visualize objects of interest in three-dimensions (3D). The CT data acquisition process, however, takes anywhere from minutes to hours depending on material composition and complexity. During the CT process, the object of interest needs to remain completely still. The resulting data is a volumetric stack of images that provide the ability to measure the exact location of features within an object. At Sandia National Laboratories (SNL), Department 1522 (Experimental Mechanics/NDE and Model Validation) has teamed with Department 1535 (Sensing and Imaging Technologies) to develop a new diagnostic tool that will allow precise quantitative characterization of the displacement/movement of non-visible features during highly dynamic experiments. Because of the mismatch in the time it takes to acquire a CT data set and the time it takes to conduct these experiments, a new approach was developed. Using multiple view computer vision techniques, this stereo x-ray system will provide more precise data during dynamic testing, particularly in the area of fragmentation characterization which is of great interest to modelers at SNL.

Stereo x-ray is not a new concept in radiography. Traditional stereo x-ray was typically used to empirically determine the depth of flaws, and its' applications were limited and very specialized. The two images relied on an angular shift of the x-ray machine between exposures that represents the angle between the human eyes. The images are then viewed on a special table replicating the human vision system, allowing for a 3D view of the flaw location.

The new system consists of two x-ray machines and two detectors. The detectors utilized for the initial bench-top test are composed of reconfigurable enclosures containing an x-ray scintillator, a 45° degree turning mirror, and a scientific grade cooled charge coupled device (CCD) camera with a lens focused on the back of the scintillator via the turning mirror. The scintillator converts the x-ray photons into visible light photons. The 45° turning mirror is used to direct these photons towards the camera, while keeping the camera out of the direct x-ray beam.

The first challenge was calibrating the system. The calibration algorithm needed to provide a transformation that would take the two-dimensional (2D) coordinate systems from each x-ray image and map them into a 3D world coordinate system. The calibration device developed was a small cube with 16 ball bearings evenly spaced on three of the six faces of the cube. Computed tomography data was acquired for the cube in order to obtain precise locations of each ball bearing. The CT locations are used to acquire the calibration parameters and also provide the basis for the stereo x-ray coordinate system. The cube was then imaged by the stereo x-ray system and processed by the calibration routine. The output of the calibration routine is a set of intrinsic and extrinsic parameters of the system. The intrinsic properties provide a transformation that maps an image point from camera to pixel coordinates in each camera. The extrinsic properties are the physical relative positions and orientations of the two cameras and x-ray machines.

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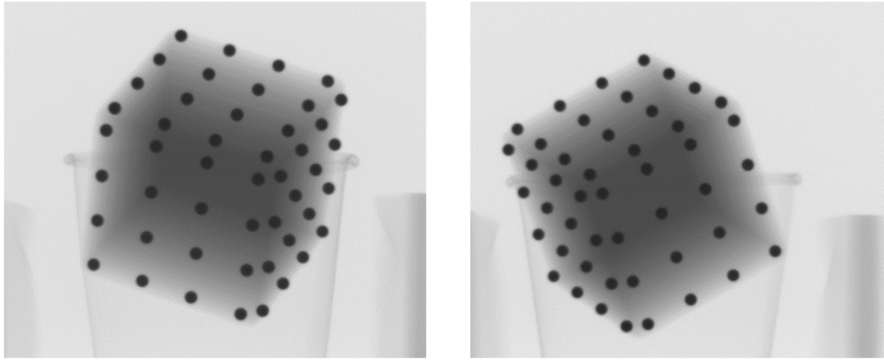

Figure 1: Left and Right Images of the Calibration Cube Acquired with the Stereo X-ray System

With a calibration in place, it is now possible to acquire data of a moving target and attempt to accurately track that target in 3D space. For the initial test, a simple plastic tube with a ball bearing on either side was used. The test item was placed on a rotational table at a slight angle and rotated through 360°, acquiring images every 15°. The acquired data looked just as expected; two sets of x-ray images with no concept of depth or location of the ball bearings at each location. Utilizing a triangulation algorithm and the calibration parameters however, each ball bearing location is plotted into the world coordinate system and in turn can be visualized in three dimensions. It is also now possible to accurately measure the distance the ball bearing moved, along a chord corresponding to a 15° rotation, as well as the distance between the ball bearings.

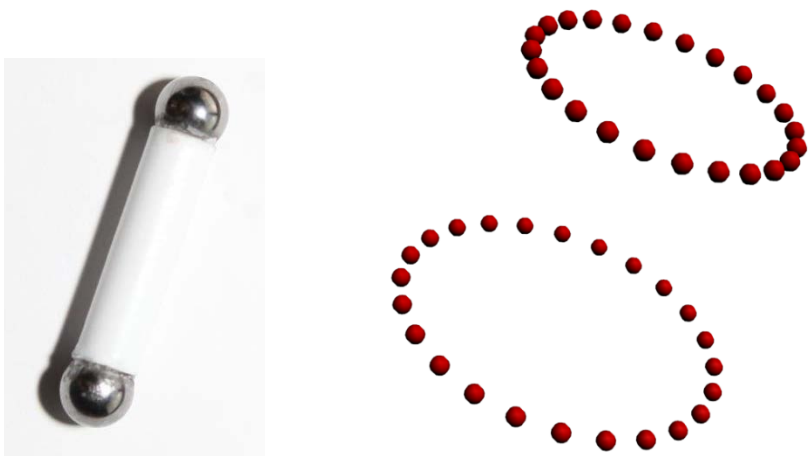

Figure 2: Optical Image of Ball Bearing Target (left) and 3D Plot of Ball Bearings Rotated through 360° (right)
(If this file is being viewed electronically, click the image on the next page of this document to interact with the 3D data)

As a sanity check, the distance between the ball bearings was measured with a caliper and compared to the measurements made with the stereo x-ray system. The caliper measurement was 36.91 mm. The stereo x-ray system mean measured distance was 36.90 mm; a difference of less than 1%.

While the stereo x-ray system still has limited applications and is very specialized, it has the potential to provide unprecedented data during dynamic experiments (e.g., (a) relative motion between internal weapon components during impact (or other) environments, (b) a projectile path within solid materials or liquids, (c) 3D guided surgical operations, etc.). The success of this diagnostic relies on the ability to track unique markers (uniquely identifiable using x-ray imaging) in consecutive x-ray images. The next step is to apply this technique on more complex and higher speed experiments. The ultimate goal would be to supplement an ultra-high speed stereo x-ray imaging LDRD with the advances made in this WSEAT project.

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