

Task 22

Design Concepts and Process Analysis for Transmuter Fuel Manufacturing

G. Mauer

BACKGROUND

The safe and effective manufacturing of actinide-bearing fuels for any transmutation strategy requires that the entire manufacturing process be contained within a shielded hot cell environment. To ensure that the fabrication process is feasible, the entire process must be designed for remote operation. The equipment must be reliable enough to perform over several decades, and also easy to maintain or repair remotely. The facility must also be designed to facilitate its own decontamination and decommissioning. In addition to these design factors, the potential viability of any fuel fabrication process will also be impacted by a number of variables, such as the current state of technology, potential problem areas, deployment scaling, facility safety, and cost.

RESEARCH OBJECTIVES AND METHODS

The goal of this project was to provide technical support to process designers working on the development of the fuel cycles for transmutation applications. Detailed process models were developed to better define the impact of fuel choice on the transmuter fuel cycle, including relative process losses, waste generation, and plant capital cost. These process models provide insight regarding required plant size and the number of plants needed to mesh with the fuel recycling line. They also determine requirements for automation.

Manufacturing models for large-scale production in a hot cell environment were also developed. Combined, these two models allow the assessment of plant layout, and provide the framework for estimation of plant capital and operating cost estimates, and for feasibility in general. The operations of robotic equipment and the sensor technology required for safe and reliable robot control have been evaluated through simulations in three-dimensional space. The manufacturing technology developed for hot cell applications is also applicable to other, more general uses, where occupational hazards prevent human presence near processes.

Simulations: This task modeled manufacturing processes to generate a realistic assessment of plant layout, size, feasibility, and technology development required for large-scale remote fabrication of fuel. Modeling of the candidate fuel manufacturing processes was performed using the MSC.visualNastran and ProEngineer simulation software tools. The modeling of dispersion and TRISO fuels were completed.

Cost, Feasibility, and Large Scale Deployment: This task developed the database necessary to provide cost estimates and differential cost for various fuel manufacturing options. Cost estimates regarding projected capital cost, reliability, and plant life were developed and should be refined as additional knowledge is developed.

Automated Vision-Based Image Acquisition and Robot Control: This task explored and demonstrated strategies for the reliable and



Robot grasping a cylindrical pellet

flexible control of the material handling robots inside the hot cell by means of automated vision systems. Since the cameras can be positioned outside the hot cell, such systems would have significant advantages over sensors inside the hot cell, resulting in potentially reduced system maintenance and increased system reliability.

RESEARCH ACCOMPLISHMENTS

Hot Cell robot control: Visual servoing was demonstrated. For this purpose, the stereo vision system was set up in a laboratory next to a Fanuc M-16iB industrial robot.

Sensor-Robot Integration: Driver software was written, tested and implemented for the transmission of sensor data, i.e., the target object's position and orientation, to the Fanuc robot controller.

Accelerated Object Extraction: The contour extraction algorithm can require long durations during image feature extraction (Canny Edge Detection, up to one second per image). Since the cylindrical targets each cover only a portion of the image, there is no need to apply the feature extraction to the whole image. By fragmenting each image into sub-images containing the desired objects, the duration of the feature extraction can be significantly reduced.

Targets are found by under sampling the image and testing the neighborhood of the respective pixels for their color. In application, black pellets were used for black pixels in the neighborhood. By merging all black neighboring locations, the rectangular boundaries of the pellets can be determined by ascertaining their respective contours.

To avoid the issue that corners of targets in certain angles are not collected by the sampling, and possibly eliminated, the search algorithm doubles the number of search points at each of the four sides. The duration of the edge detection process depends on the number of objects in the scene, but is usually a fraction of the amount a complete detailed search.

Steering and Rotation of the Robot End Effector, Gripping Operations: For gripping horizontal cylindrical targets, the orientation of the cylinder is required. The orientation can easily be computed as the angle between the two extracted surface points and the x-

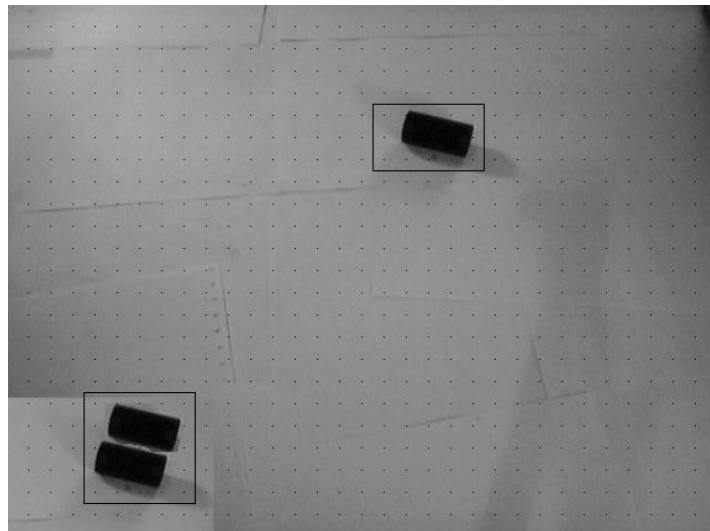
axis. To align the gripper with the target's orientation, the last joint of the robot has to be rotated. For this purpose, the orientation of the cylinder in the bin (in world coordinates) is transformed to robot-specific joint coordinates

After accomplishing the process of picking up targets with a given position and orientation, the first autonomous tests were conducted. In these tests, a single target was randomly placed in the scene, picked up by the robot, and dropped in a box. In later test scenarios, the robot placed the target at randomly generated positions and picked it up again. This procedure was tested iteratively.

Multiple Objects: To extract multiple objects, the existing algorithm, which so far extracted only the coordinates of one object, was extended. The extended algorithm returns a list of points representing the two cylinder surface points for each identified target in the corresponding image. When these lists are created for each of the stereo image pairs, the correspondence matching between targets in both lists is performed using epipolar geometry.

To organize the search for correspondences uniquely, additional information may have to be included. These could be the locations of the image edges, for example, the bottom of the first image matches with the top of the second image.

Upright and Horizontal Targets: In general, there is no need to differentiate between upright and horizontal objects during the target extraction phase. The objects' orientations have no bearing on the appearance of the cylinder in the image (usually the mantle and one end surface). The determination of a cylinder's orienta-



Finding the regions containing the targets by undersampling: The black spots represent the sample points, the black rectangles are associated with the extracted regions.

tion is made after the two surface end points of each detected object have been triangulated. If the resulting 3D points are located at the same vertical elevation, the object is horizontal. Otherwise a standing object is assumed.

Graphical User Interface: After the completion of the basic operations for cylinder grasping, a demonstration application was developed. The program offers a graphical map of the scene contents (such as position and orientation of the objects), and tracks the manipulation of single objects. To perform picking and placing of targets, the user selects a specific target by mouse click in order to have the robot execute a set of user-defined operations.

TASK 22 PROFILE

Start Date: July 2004

Completion Date: November 2007

Theses Generated:

Jamil Renno, "Virtual Design and Modeling of Various Manufacturing Processes for Remote Fuel Fabrication of Transmuter Fuel," M.S. Thesis, Department of Mechanical Engineering, UNLV, March, 2005.

Andreas Roderburg, "Design Optimization Of Robotic Manufacturing Work Cell For Transmuter Fuel – Analysis And Simulation Of Robotic Manufacturing In A Hot Cell Environment," Diploma Thesis, Department of Mechanical Engineering, RWTH, Aachen, Germany. January 2006.

Conference Proceedings:

G.F. Mauer, and J. Renno, "Conceptual Workcell Design and Throughput Analysis for Robotic Transmuter Fuel Fabrication," *Proceedings*, ANS Winter Annual Meeting, November 2004.

G.F. Mauer, "Design Concepts and Process Analysis for Transmuter Fuel Manufacturing," *Proceedings*, 8th Partitioning and Transmutation Information Exchange Meeting, OECD Nuclear Energy Agency, Las Vegas, NV, November 2004.

G.F. Mauer and J. Renno, "Reliability Analysis of a Robotic Workcell for Transmuter Fuel Fabrication," *Proceedings*, ANS Winter Annual Meeting, November 2005.

G.F. Mauer, "Equipment Redundancy and Plant Reliability in Robotic Hot Cells for Fuel Fabrication," *Proceedings*, American Nuclear Society Winter Annual Meeting, November 2006.

G. Mauer, "Design Concepts and Process Analysis for Reliable, Automated Transmuter Fuel Manufacture," AccApp'07, Pocatello, Idaho, July 2007.

G. Mauer, "Accuracy Analysis of a Robotic Radionuclide Inspection and Mapping System for Surface Contamination," American Nuclear Society Topical Meeting on Decommissioning, Decontamination and Reutilization, September 2007.

Research Staff

Georg Mauer, Principal Investigator, Professor, Mechanical Engineering Department

Students

Jamil Renno, Graduate Student, Department of Mechanical Engineering

Koushik Damera, Kamalakur Aluri, and Prathima Sajja, Graduate Students, Department of Computer Science

Kyle Gohres, Undergraduate Student, Department of Computer Science

Tobias Kotthäuser, Undergraduate Student, Mechanical Engineering Department, University of Duisburg, Germany

Andreas Rodderburg, Undergraduate Student, Mechanical Engineering Department, Technical University of Aachen, Germany

Collaborators

Mitchell K. Meyer, Group Leader, Fabrication Development Group, Nuclear Technology Division, Argonne National Laboratory