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Design and Evaluation of Processes for Fuel Fabrication: Quarterly Progress Report #10

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Design and Evaluation of Processes for Fuel Fabrication

QUARTERLY PROGRESS REPORT #10

UNLV AAA University Participation Program

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Design and Evaluation of Processes for Fuel Fabrication

Summary

The tenth quarter of the project covered the following:

- Mr. Richard Silva continued the development of a simulation model with a Waelischmiller hot cell robot, and is close to completing his M.Sc. thesis project. Rich will likely defend his thesis in April 2004.
- A project review meeting with Dr. Mitch Meyer and other ANL scientists was held in December 2003 at ANL West, Idaho Falls, ID. Dr. Meyer described ANL long term research objectives with regard to transmuter fuel manufacturing.
- Further refinements on Concepts and Methods for Vision-Based Hot Cell Supervision and control, focusing on rule-based object recognition (Ph.D. Graduate Jae-Kyu Lee)
- Graduate student Jamil Renno refined and detailed his simulations of more complex fuel manufacturing and fuel pin assembly scenarios using hot cell robots. Jamil also created a new, exact robot dynamics model.
- A paper submitted to ANS for 10th International Conference on Robotics & Remote Systems (in March 2004) in Gainesville, FL was accepted for presentation and publication.

1. Hot Cell Robot Dynamics Analysis

1.1 Robot Control and Kinematics:

Robot dynamic equation can be derived using the Lagrangian Dynamics. The equations of motion are usually lengthy and highly coupled. An n joints manipulator can be described by the following equations:

$$M(q)\ddot{q} + V(q, \dot{q})\dot{q} + G(q) = \tau$$

where M is the nxn mass matrix

V is the nxn velocity matrix

G is the nx1 gravity vector

τ is the nx1 generalized force vector

One of the control schemes used for manipulator control is the computed torque method. The computed torque method used feedback as a means to establish an asymptotically stable control system. The computed torque method suggest a force vector τ , such that

$$\tau = \alpha \tau' + \beta$$

where $\alpha = M(q)$

$$\beta = V(q, \dot{q}) \dot{q} + G(q)$$

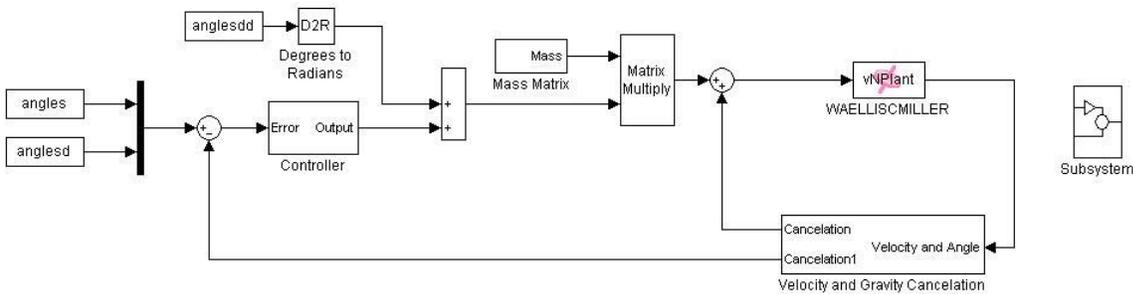
The manipulator dynamics hence reduce to the following equations

$$\ddot{E} + K_V \dot{E} + K_P E = 0$$

where $E = q_d - q$

K_V and K_P are the derivative and proportional gains respectively

The controller is implemented using MATLAB Simulink (see Fig 1). The block labeled (“Waelischmiller”) connects the MATLAB[®] environment with the MSC.visualNastran[®] environment. The dynamic environments of MSC.visualNastran[®] feeds back the joint angles and joint angular velocities to Simulink, where the control algorithm is implemented.



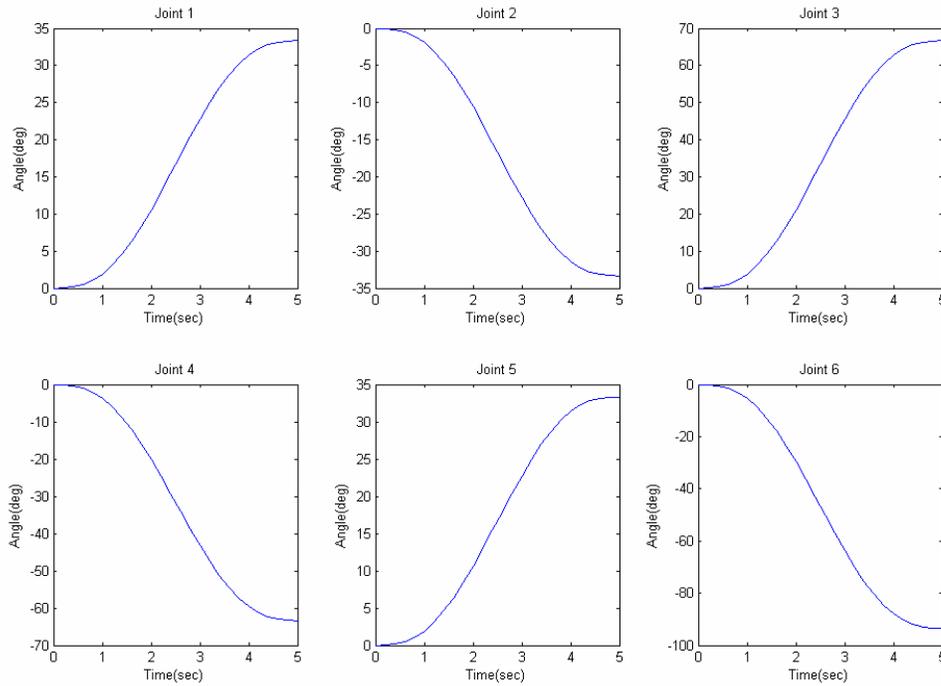
1 Computed Torque method implemented in MATLAB

Figure

a) Control Results

The more exact (compared to the usual linearization approach) robot model adds realism to the simulations. Being able to compute the exact torques needed to drive the robotic manipulators inside the hot cell would help in the decision making process of purchasing those manipulators.

Some typical results follow below:



Figure

2 Joint angle responses after implementing the controller

b) Robot Kinematics:

The robot kinematics were analyzed further. The trajectories of robotic manipulators can be planned in two ways: joint space, and operational space.

The joint space guarantees a smooth path for the joint angles, but does not guarantee a smooth profile of the end effector. For both planning methods, a 7th order polynomial is used to generate the paths. Figure 3 shows a schematic of the trajectories used in the hot cell simulation:

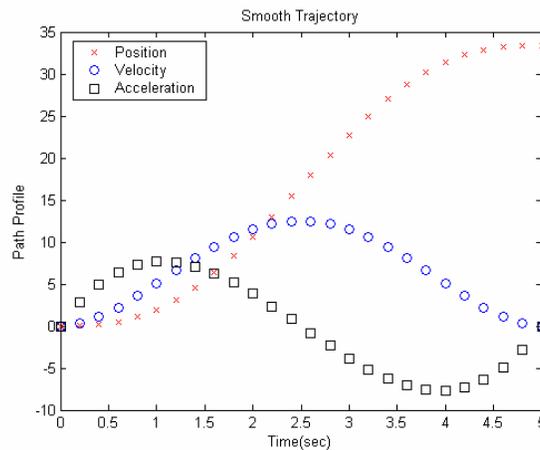


Figure 3 Smooth trajectories for joint angles and operational variables

Currently, a blend of joint space planning and operational space planning is used:

- i) Joint space planning methods are used when the manipulator is not holding any pellet. Trajectories produced by this method are easier to handle with the controller.
- ii) Operational space methods are used whenever the pellets are being held by the manipulator. The scheme used is the famous pick-place scheme, where the end effector approaches the pellet, lifts up to some safety margin in order to avoid obstacles, then moves the object finally dropping it. This path planning method insures that the smooth motion profile of the end effector, and consequently of the pellet. The inverse kinematics is performed at a selected number of points of the path, and the joint angles found are used in the control scheme described above.

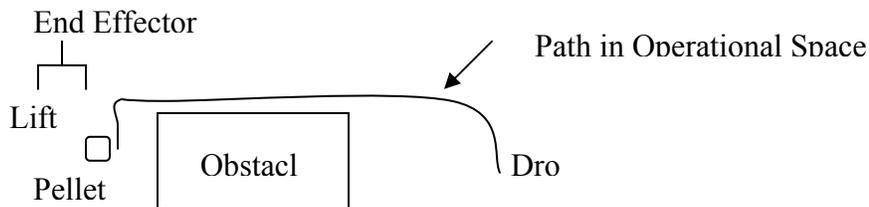


Figure 4 Schematic of operational space path planning

1.2 Hot Cell Design:

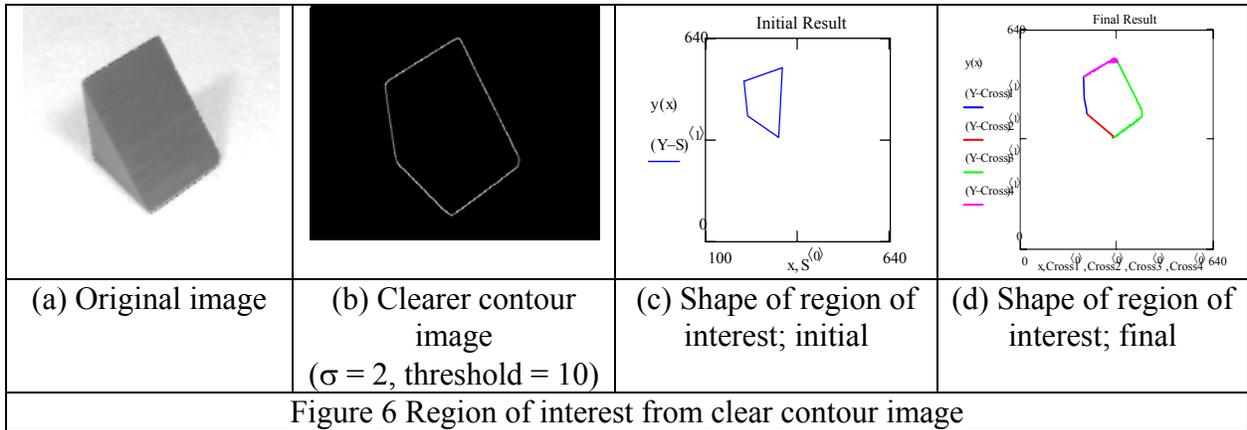
A grinder was added to the hot cell. The grinder is basically a sloped trough, with two grinding wheels rotating on the sides. The whole trough vibrates, to assist the pellets in dropping into a tray. A schematic of the grinder is shown in Figure 4. After the pellets are grinded, they are dropped into an output tray, from where they are loaded onto the V-tray for insertion into the cladding tube.



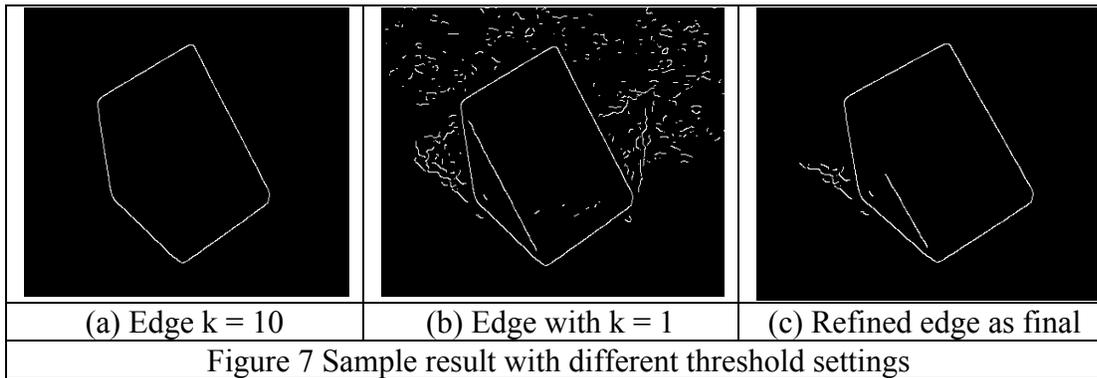
Figure 5 Grinder Schematic

2. Object Recognition

Further refinements were made to the object recognition tools developed by Dr. J.K. Lee. The focus was on improved segmentation and adaptive filtering for contour detection in CCD images. Fig. 6 shows an object and its initial edges, which do not contain contour lines within the object.



The adaptive thresholding algorithm is able to detect contours inside the object as seen in Fig. 7.



3. Summary of ANL west Planning meeting with Dr. Mitch Meyer and other ANL West Personnel

Objectives for 2004/2005 research:

- Transmuter fuels manufacturing simulation demonstrations for powder and metallic fuel processes.
- Compare both processes in terms of
 - (a) Throughput
 - (b) Equipment cost
 - (c) Plant layoutand document benefits/tradeoffs for the respective technologies. Production goals should be approx. 100 metric tons per year.

Other R&D needs/interests expressed during the discussion:

- Fuel modeling and chemistry
- Rad. Damage
- Fuel corrosion
- Metallic casting furnace: design and modeling

Simulation Work Plan for March 2004 through May 2004

Parametric analysis of manufacturing simulations.

The loading, unloading, and insertion processes required for powder fuel manufacturing will be simulated and analyzed with regard to time requirements, throughput, robot dynamics, and accident scenarios and recovery from accidents. After completion of the powder process analyses, we plan to begin simulation of the metallic fuel manufacturing.