Title: COMPUTER MODEL AND SIMULATION OF A GLOVE BOX PROCESS

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Submitted to: American Nuclear Society 9th Topical Meeting on Robotics
and Remote Systems
Seattle, Washington
March 4-8, 2001

Los Alamos
National Laboratory

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ABSTRACT

The development of facilities to deal with the disposition of nuclear materials at an acceptable level of Occupational Radiation Exposure (ORE) is a significant issue facing the nuclear community. One solution is to minimize the worker's exposure though the use of automated systems. However, the adoption of automated systems for these tasks is hampered by the challenging requirements that these systems must meet in order to be cost effective solutions in the hazardous nuclear materials processing environment.

Retrofitting current glove box technologies with automation systems represents potential near-term technology that can be applied to reduce worker ORE associated with work in nuclear materials processing facilities. Successful deployment of automation systems for these applications requires the development of testing and deployment strategies to ensure the highest level of safety and effectiveness. Historically, safety tests are conducted with glove box mock-ups around the finished design. This late detection of problems leads to expensive redesigns and costly deployment delays. With widespread availability of computers and cost-effective simulation software it is possible to discover and fix problems early in the design stages.

Computer simulators can easily create a complete model of the system allowing a safe medium for testing potential failures and design shortcomings. The majority of design specification is now done on computer and moving that information to a model is relatively straightforward. With a complete model and results from a Failure Mode Effect Analysis (FMEA), redesigns can be worked early. Additional issues such as user accessibility, component replacement, and alignment problems can be tackled early in the virtual environment provided by computer simulation. In this case, a commercial simulation package is used to simulate a lathe process operation at the Los Alamos National Laboratory (LANL).

The Lathe process operation is indicative of most glove box operations and demonstrates the ability and advantages of advance computer based modeling. The three-dimensional model also enables better comprehension of problems to non-technical staff. There are many barriers to the seamless integration between the initial design specifications and a computer simulation. Problems include the lack of a standard model and inexact manufacturing of components used in the glove box. The benefits and drawbacks are discussed; however, the results are useful.
Working to reduce the ORE level should not come at an increased risk of system failure. Computer modeling and simulation allows the designer an early tool to combat potential problems before costly reworking is necessary. In addition to the cost savings, better comprehension of the system fosters intelligent decisions for the development of glove box processes.

1. INTRODUCTION

The objective of this investigation is to explore the operating characteristics of a gantry glove box robot in the ARIES processing line. The Lathe Glove Box (LGB) is one of several glove boxes in the ARIES processing line (see Figure 1). The ARIES pilot line currently consists of five glove boxes: Bisector, Hydride/Dehydride, Hydax, Canning and Electrodecontamination. The LGB is being developed to operate in parallel with the Bisector, and the Canning and Electrodecontamination glove boxes are being combined into a single glove box. The ARIES line receives Plutonium parts, and processes them into a form suitable for storage, inspection, reuse or disposal.

The bisector or the lathe initially sections the incoming Plutonium parts into smaller pieces called hemishells. These hemishells are processed by either the hydride/dehydride furnace into plutonium metal “pucks” or by the hydax reactor furnace into Plutonium Oxide (PuO₂) as shown in Figure 1. The scope of this effort is to examine in detail a design configuration for the LGB and to propose paths suitable to accomplish the process operations for the LGB.

Figure 1. ARIES Process Description.
It is well known that an option to reduce ORE is to use automated systems in glove boxes such as the in the LGB. Future trends indicate using modular robotics\textsuperscript{1-4} to reduce ORE in plutonium processing glove boxes. A gantry type robot has been designed using off-the-shelf technology in order to accomplish the immediate goal of reducing ORE to the operator. The LGB robot is operating in a critical facility and failures are potentially detrimental. An early analysis of the paths, collision scenarios, and robot envelopes can avoid costly late design changes.

2. COMPUTER MODEL OF LATHE GLOVE BOX

This model of the LGB is completed using the simulation features of Cimetrix\textsuperscript{5}. The Cimetrix simulation package is able to generate basic geometric primitives and use Boolean algebra to create more complex objects. After each component is built, the inverse kinematics feature of Cimetrix is used to determine the robot motion of the simulated robot. The features of the package can be extended to control the motion of the physical robot. Table 1 contains the listing of the components of the robot and glove box contained in the computer simulation model.

<table>
<thead>
<tr>
<th>Table 1. Components Modeled in the Simulation</th>
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<tbody>
<tr>
<td><strong>Robot Components</strong></td>
</tr>
<tr>
<td>o Dual X-Axis Rails</td>
</tr>
<tr>
<td>o Dual Y-Axis Rails</td>
</tr>
<tr>
<td>o Single Z-Axis Rail</td>
</tr>
<tr>
<td>o Force Torque Sensor</td>
</tr>
<tr>
<td>o Quick Connect</td>
</tr>
<tr>
<td>o Tool Gripper</td>
</tr>
<tr>
<td>o Pot Chuck Gripper</td>
</tr>
<tr>
<td>o Part Gripper</td>
</tr>
</tbody>
</table>

Mechanical drawings of the elements for the components in the form of ProEngineer and SolidWorks models were made available by LANL. Each component is modeled from the available ProEngineer and SolidWorks drawings with the design specifications. Cimetrix models accept simple shapes only, thus the general geometry was modeled omitting minute details. For example the headstock has a number of cooling indentations, however the headstock was modeled as a solid cylinder.

Once the component models are created, path plans can be investigated. A series of linear path segments is generated for the robot to follow for each respective path. The Cimetrix package is used to perform joint level interpolation for the motion between end points for each path segment. The LGB Robot is intended to be slow-moving robot, therefore, the speed variations associated with joint level interpolations are deemed acceptable. Time-optimal trajectories are considered unimportant in this application. The scope of the simulation is to propose acceptable paths and confirm that collisions are avoided.
A critical safety requirement of the design is that the LGB Robot must not come into contact with the glove box at any time. Mechanical hardstops are used to enforce this constraint. The allowable motion of the robot attachment point was calculated as a rectangle according to the constraint of not allowing contact to the side of glove box at any location. The closest that the robot is allowed to come is 7.5 cm at the shuttle side. This proximity is warranted because of the necessity to interact with the shuttle. The range of motion of the LGB Robot is 240 cm in the x direction along the length of the LGB, 91.5 cm in the y direction along the width of the LGB, and 38.0 cm in the vertical z direction. The workspace envelope for the LGB Robot is shown in Figure 2.

![Figure 2. Robot Workspace Envelope.](image)

Internal collisions within the robot workspace envelope must also be considered. Possible internal collisions include the headstock, tailstock, and anything on the shuttle. The robot changes end-effectors throughout the process operations for the LGB. Furthermore, the objects processed in this glove box are geometrically altered. In Figures 3 through 5, the workspace envelopes for the various tools that the LGB Robot manipulates are shown. The tools are the Part Gripper, the Pot Chuck Gripper, and the Tool Gripper.

Figure 3 shows the part gripper workspace envelope. This is the largest tool and its gripper arms protrude into the false floor by 4.45 cm. It is placed in the floor this depth so as not to protrude into the robot’s workspace when not in use. The center point of the Part Gripper has collision potential with every object in the glove box including the false floor (by 0.27 cm).

The Pot Chuck Gripper Envelope is shown in Figure 4. It is slightly shorter than the Part Gripper and its gripper arms extend into the false floor by 4.15 cm. The collision potential for the center point of the Pot Chuck Gripper includes everything in the glove box except for the false floor.
Figure 3. Part Gripper Workspace Envelope.

Figure 4. Pot Chuck Gripper Workspace Envelope.

Figure 5 shows the Tool Gripper Workspace Envelope. The Tool Gripper is used to change the tools from the tool post, and to remove the cutting bowl. The Tool Gripper floats over the false floor by 4.0 cm. The envelope for this tool does not contact the false floor, because the tool gripper was modeled as a center point pickup. Actually the tool has a greater range if the
lower extents of the arms are used to grab tools. The center point of the tool gripper has collision potential with everything in the glove box except the false floor.

![Figure 5. Tool Gripper Workspace Envelope.](image)

3. COMPONENT PLACEMENT

The LGB robot’s end effectors are stored away from the motion of the robot when not in use. The first choice for this location was on the shuttle port side of the tool post. This location was changed to the shuttle port side (left side of the Figure 5) of the tailstock. This change was made because it gave equal access to the space between the headstock and tailstock from both sides of the lathe. The frequent use of this space made access from both sides a priority. This move increased the travel of the Pot Chuck Gripper in pick up the pot chuck and placing it in the lathe. However, because of the greater ease with which the pot chucks are placed in position it was considered acceptable. The location of the Part Gripper is ideal for easy access to the shuttle port and the Tool Gripper is located as near to the tool post as possible. The frequent use of this tool during operation made a long distance between it and the tool post less than desirable.

Only one chuck was simulated in this computer model. Because of the infrequent use of this tool the simulation simulated the placement of the pot chuck on the headstock side of the tool post. The glove box design places a significant amount of equipment in this area, and so this simulation represents the most difficult pot chuck installation. Any additional equipment placed in this area may further restrict movements of the robot. Furthermore, the path to remove the cuttings bowl passes through this side of the tool post.

A limited number of tools were modeled. However, a denesting tool was included near the Part Gripper location. The size of this tool and potential path planning problems determined the location of this tool. The cutting tools are located very near or are attached to the tool post. As long as these tools do not protrude significantly, parts will still be able to be transported through this region of the glove box.
4. PATH GENERATION

Three critical paths are proposed and analyzed in this section. These paths include:

1. Pot Chuck Paths,
2. Part Movement Paths,
3. Tool Paths.

The first task analyzed is the Pot Chuck Path. The goal is to place a pot chuck onto the headstock after placement of a pot chuck onto the tailstock of the lathe. Figure 6 shows a line for the path to place the pot chucks onto the lathe. The Tool Gripper is picked up, moved to the tool post, and then moved down to the pot chuck. The gripper then picks up the pot chuck and passes between the headstock and tool post into the work area of the lathe. The Tool Gripper then places the pot chuck onto the tailstock. This path was chosen as the easiest and safest because it maximizes the distance between other objects. The sequence in which the pot chucks are placed is important. The tailstock pot chuck should be attached before the headstock pot chuck. The biggest collision problem for this path is the pot chuck placement on the headstock. In this case, the gripper actuator has zero clearance between the gripper and the headstock, as modeled in the computer simulation. The actual design of the headstock has some tapering and a small standoff and thus a collision is not expected, despite the simulation results. However, this portion of the path does represent a collision hazard that will be examined closely in the final system. This collision potential does not exist in the case of the tailstock.

Figure 6. Pot Chuck Path.
The second path analyzed is the material handling of incoming plutonium parts and subsequent part movements within the glove box. An incoming part is received from the shuttle, weighed and transported to the lathe where the headstock and tailstocks are engaged. The part is machined in the lathe and sectioned into smaller pieces. These pieces are individually removed, and then denested using the denesting tool. The resulting parts are again weighed and removed from the glove box. The placement of a part is shown in Figure 7, and the removal of a piece is shown in Figure 8. The nearest collision locations between the part and other objects are when passing near the side of the tailstock (1.9 cm) and after the part is placed in the cutting location and the Part Gripper is removed (1.22 cm). These potential collisions occur when both when a part is initially loaded into the lathe, and when pieces are removed from the lathe.

Figure 7. Part Placement Path.

Figure 8. Piece Removal Path.
The Tool Change Path includes the removal of the cuttings bowl as shown in Figure 9. In the computer simulation, an imaginary tool is changed (no process tools were modeled in the simulation) to examine the motion of the path. Then the cuttings bowl is removed and is taken to the scale to be weighed and then delivered to the shuttle port. The cuttings bowl is removed from the glove box, emptied, and returned through the shuttle port. The robot returns the empty cuttings bowl to the tool post where it is reattached. The nearest collision with the part was 23.0 cm, plenty of room to remove the cutting bowl. If there were multiple pot chucks in the pot chuck storage area it would still be possible to remove the cutting bowl by first moving towards the lathe workspace (reducing the 23.0 cm clearance between the cuttings bowl and the part in the lathe).

**Figure 9. Tool Change Path.**

5. RESULTS AND RECOMMENDATIONS

Physical motion limits on the LGB Robot are provided by mechanical hard stops. The proximity of the three paths discussed in section 4 to these motion limits is summarized in Table 2. The Pot Chuck Path for changing the pot chucks is within 12.5 cm of the y motion limit, 0.0 cm of the x motion limit, and 0.0 cm of the z motion limit. To manipulate the part to and from the lathe the nearest envelope limit is 8.7 cm for the y motion, 0.0 cm for the x motion, and 0.0 cm for the z motion. Moving the part pieces has a proximity to the envelope of 8.7 cm for the y motion, 0.0 cm for the x motion, and 0.0 cm for the z motion. The Tool Change path has a proximity to the envelope of 9.4 cm for the y, 6.2 cm for the x, and 0.0 cm for the z. Note that in Table 2, the +/- indicates whether it is top/bottom, headstock/airlock, or tool post/lathe respectively.
Table 2. *Path Proximity to Motion Limits*

<table>
<thead>
<tr>
<th>Path</th>
<th>X Proximity</th>
<th>Y Proximity</th>
<th>Z Proximity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pot Chuck Change</td>
<td>+12.5cm / -115.0cm</td>
<td>+8.4cm / 0.0cm</td>
<td>0.0cm / -0.5cm</td>
</tr>
<tr>
<td>Move Part</td>
<td>+29.8cm / -8.7cm</td>
<td>+2.8cm / 0.0cm</td>
<td>0.0cm / -0.5cm</td>
</tr>
<tr>
<td>Move Part Pieces</td>
<td>+23.4cm / -8.7cm</td>
<td>+2.8cm / 0.0cm</td>
<td>0.0cm / -0.5cm</td>
</tr>
<tr>
<td>Tool Change</td>
<td>-22.1cm / -9.4cm</td>
<td>+6.2cm / -24.8cm</td>
<td>0.0cm / 0.0cm</td>
</tr>
</tbody>
</table>

As discussed in Section 4, each individual path was analyzed in detail. The nearest collisions are as summarized below (with the closest region). The Pot Chuck Path and Part Movement Paths contain caution regions as indicated in Table 3. Note that the Pot Chuck (at Pot Attachment) has unmodeled clearances, however, this remains a cautionary region.

Table 3. *Clearance for Nearest Collisions*

<table>
<thead>
<tr>
<th>Path (closest region)</th>
<th>Clearance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pot Chuck (at Pot Attachment)</td>
<td>0.0 cm</td>
</tr>
<tr>
<td>Tool-Post Tool Change and Cutting Bowl Removal (At Bowl Removal)</td>
<td>23.0 cm</td>
</tr>
<tr>
<td>Move Part / Halves (Above Part in Lathe)</td>
<td>1.22 cm</td>
</tr>
</tbody>
</table>

The emphasis of this effort has been study for the motion of a gantry robot in a glove box, the LGB Robot, as it performs process steps in the Lathe Glove Box. Recommendations for placement of components and appropriate paths have been analyzed and simulated. The most appropriate position for the grippers was found to be on the shuttle side of the tailstock. All of the required paths were found to be feasible and three indicatory paths were identified. For each of these paths the proximity to potential internal collision problems was identified. Each path was found feasible and the distances calculated with cautionary regions identified.

The primary recommendation is that the layout meets the manipulation requirements for the process steps and that for the design to progress as intended. There are no identified catastrophic failures, and necessary paths are feasible. The nearest internal collisions for each path have been determined, evaluated and discussed. Further research will focus in detail on collision and recovery scenarios. These recovery scenarios will include both potential collision recovery and joint failure recovery scenarios for the LGB robot. The calculation of the failure scenarios for each of the actuators is difficult and there are many potentially immobilizing situations. For example, a failure in the z-axis when both the x and y motions are constrained poses a challenging recovery scenario. It will be important to indicate how to avoid these problems and to determine recovery procedures.

ACKNOWLEDGEMENTS

This work was conducted under contract #1557-00-23 with the Los Alamos National Laboratory (LANL). The authors gratefully acknowledge both their funding and support. Furthermore, this work would not have been possible without the assistance of Dr. Pete Pittman, Dr. Chris James and Dr. Robert Hollen of LANL. Appreciation of the assistance of Cameron Turner in assisting with the collecting and reviewing the information in this paper is also gratefully acknowledged.
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