SIMPLE GEOMETRIC ALGORITHMS TO AID IN CLEARANCE MANAGEMENT
FOR ROBOTIC MECHANISMS

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ABSTRACT

For Robotic Mechanisms which are required to operate in quarters limited by external structures, the problem of clearance is often of considerable interest. In such cases it is possible to distinguish between "contact prediction" and "minimum safe clearance management."

The advantage of the distinction is principally in the fact that the latter may be quite simple and well suited to real-time calculation, whereas the former may require more precision, sophistication, and computational overhead.

This paper deals with the selection of global geometric shapes such as lines, planes, circles, spheres, cylinders, etc., and the associated computational algorithms which provide relatively inexpensive estimates of minimum spatial clearance for safe operations. The Space Shuttle, Remote Manipulator System, and the Power Extension Package are used as an example.
<table>
<thead>
<tr>
<th>CONTACT PREDICTION (HIGH RESOLUTION)</th>
<th>MINIMUM SAFE CLEARANCE MANAGEMENT</th>
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<tbody>
<tr>
<td>o Requires accurate, detailed geometric modeling</td>
<td>o Allows the use of global geometric shapes for the enclosure of large pieces of structure</td>
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<td>o Requires accurate motion modeling</td>
<td>o Allows more tolerance in motion modeling</td>
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<td>o Comparatively high computational time and large program size</td>
<td>o Comparatively low computational time and small program size</td>
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<td>o Usually involves basic geometries (points, spheres, cubes)</td>
<td>o Usually involves more complex geometries (circles, cylinders, cones, spatial trajectories, surfaces of revolution)</td>
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$U_D = \text{UNIT}(U_1 \times U_2)$

$R_{21} + \theta_2 U_2 = \theta_1 U_1 - \rho U_D$

$U_1 \cdot U_D = 0$

$U_2 \cdot U_D = 0$

**TO DETERMINE MINIMUM CLEARANCE**

$d = 1 - r_1 - r_2$

$d > 0$

$0 < \theta_1 < c_1$

$0 < \theta_2 < c_2$

**FIGURE 1.- CYLINDRICAL-SHELL-TO-CYLINDRICAL-SHELL CLEARANCE.**

$U_{R1} = U_2 \times (\text{UNIT}(U_1 \times U_2))$

$R_{21} + r_1 U_{R1} + \rho u_1 = P$

$U_1 \cdot P = 0$

$p = \text{LENGTH}(P)$

**TO DETERMINE MINIMUM CLEARANCE**

$d > 0$

$p < r_1$

**FIGURE 2.- CIRCLE-TO-PLANE CIRCULAR AREA CLEARANCE.**
\[ R_{21} + r_2 u_{2r} + d u_0 = u_1 u_1 \]
\[ u_0 \cdot \frac{d}{d\phi} u_{2r} = 0 \]
\[ u_0 \cdot u_1 = 0 \]

Adjust \( \phi \) to minimize \( d \)

To determine minimum clearance
\[ d > r_1 \]
\[ 0 < u_1 < c_1 \]

\textbf{FIGURE 3.- CIRCLE-TO-CYLINDRICAL-SHELL CLEARANCE.}

\[ R_{21} + r_2 u_{2r} + d = u_1 u_{1r} \]
\[ d \cdot \frac{d}{d\phi_1} u_{1r} = 0 \]
\[ d \cdot \frac{d}{d\phi_2} u_{2r} = 0 \]
\[ d = \text{LENGTH (D)} \]

Adjust \( \phi_1, \phi_2 \) to minimize \( d \)

To determine minimum clearance
\[ d \cdot u_1 > 0 \]

\textbf{FIGURE 4.- CIRCLE-TO-CIRCLE CLEARANCE.}
CLEARANCE MANAGEMENT MODEL APPLICATION TO SHUTTLE/
REMOTE MANIPULATOR/POWER EXTENSION PACKAGE (PEP)

○ PEP CONTROL SYSTEM EXECUTES TWO-AXIS MOTION SWEEPING OUT DISK-LIKE CYLINDER

○ RMS SECTIONS CYLINDRICAL

○ SHUTTLE SECTIONED AND MODELED AS CYLINDERS AND LINES

○ THE ALGORITHMS AND AN EXECUTIVE LOGIC WERE USED TO AID IN DESIGNING
OPERATIONAL TRAJECTORIES AND CONFIGURATIONS FOR THE POWER EXTENSION PACKAGE
AS WELL AS OTHER SHUTTLE PAYLOADS
FIGURE 5.- CYLINDRICAL VOLUME SHEET BY POWER EXTENSION PACKAGE DEPLOYED.

FIGURE 6.- CLEARANCE MANAGEMENT MODEL CYLINDRICAL ENCLOSURE OF SHUTTLE ORBITER.
CONTROL SHOULD BE INVESTIGATED

EVALUATION AND SELECTION OF SUITABLE DISPLAYS AND CUES FOR MANUAL

APPLICATIONS

SURFACES OF REVOLUTION AND CONES, ETC., FOR MORE COMPLICATED

THE CIRCLE AND CYLINDER DEMONSTRATION HEREFIN MAY BE GENERALIZED TO

CYLINDERS

INTEGRATED INTO AN ALGORITHM TO MANAGE THE OVERALL CLEARANCE BETWEEN

THE FOUR SIMPLE GEOMETRIC COMBINATIONS DISCUSSED HEREFIN HAVE BEEN

TIME AND COMPLEXITY FOR THIS APPLICATION

CLEARANCE MANAGEMENT LED TO A SIGNIFICANT SAVINGS IN COMPUTATIONAL

THE DISTINCTION BETWEEN "CONTACT PREDICTION" AND "MINIMUM SAFE

CONCLUSIONS AND EXTENSIONS