CAD-Enhanced Workspace Optimization for Parallel Manipulators: A Case Study

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Introduction

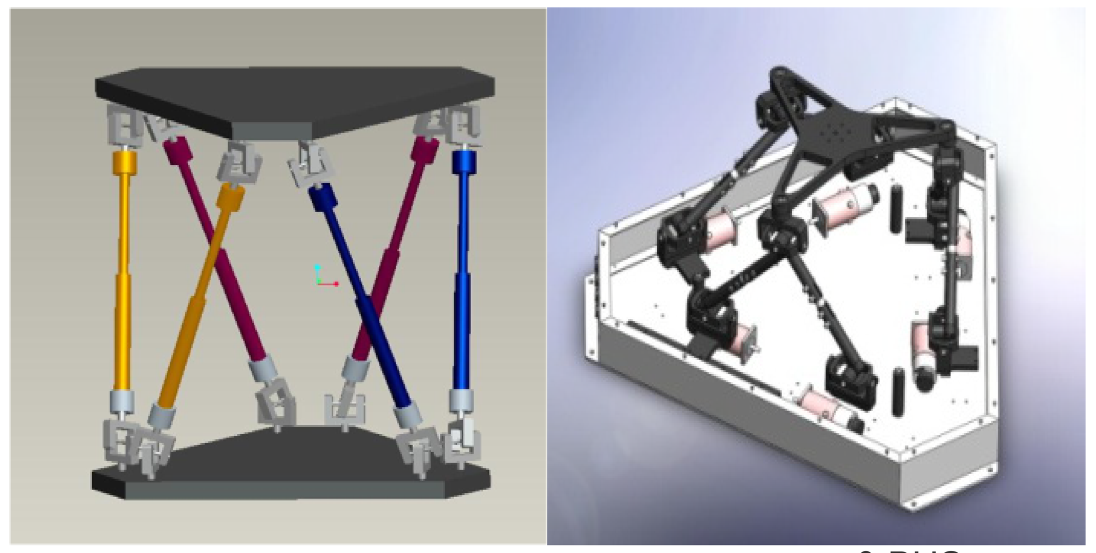
The challenges of computing the forward-kinematics of parallel manipulators (PMs) tend to be limited by the lack of analytical solutions. The alternative inverse-position kinematics based approach for determining workspace feasibility tends to be inefficient, time consuming and unsophisticated. In this paper, we present a geometry based method for accurate and computationally effective calculation of the workspace of a constrained PM. We illustrate how boolean geometric operations can simplify the process of finding the workspace and optimizing the designs. Comparative performance studies, in terms of accuracy and computational performance, are performed to benchmark the approach against more conventional methods. Finally, we examine ways to further automate the process using a CAD package.

Background

Representation of 6D workspace for 6-DOF parallel platform manipulators is challenging. So, we represent it as 3D subsets:

1. Constant position workspace (all orientations attainable with fixed position of center of central platform)
2. Constant orientation workspace (all positions attainable keeping central platform at constant orientation)

Many attempts on constant position workspace but very few on constant orientation workspace. We will focus on automating constant orientation workspace.



Stewart Platform 6-PUS

Fig 1: CASE STUDIES

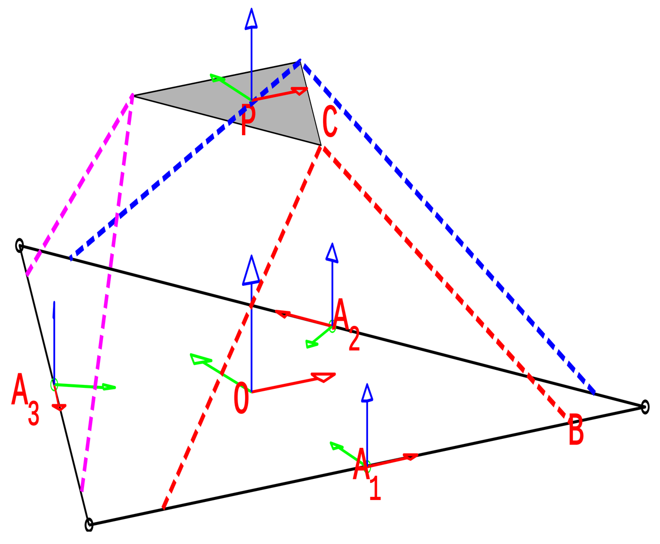


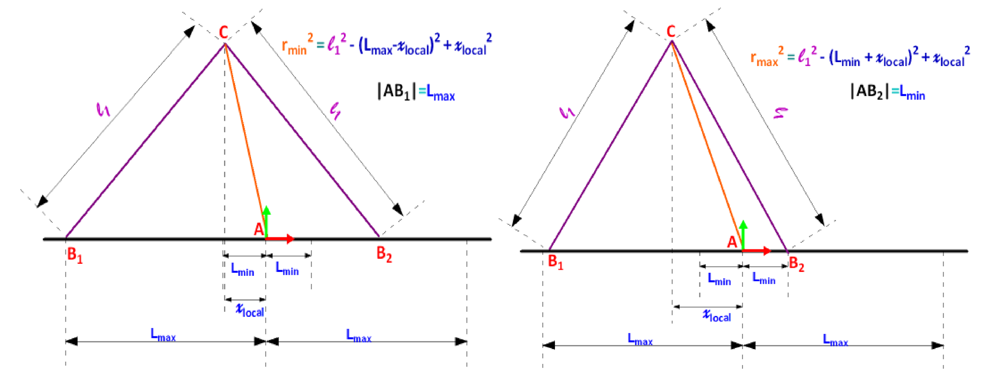
Fig 2: 6-PUS Articulated Representation
Ai → local reference frame, B→ Prismatic joint position, C→ Platform Endpoint, P→Platform Center .

Method A - Parameter Sweep , Inv. Pos. Kin.

Create 3D grid of points with initial guess
Check all points with Inverse Position Kinematics routine.
Very time consasuming.

Method B - Parameter Sweep , Geometric Check

Geometry used to find minimum and maximum values for vector and check for the range.



Equation for minimum value of |AC| Equation for maximum value of |AC|

Fig 3: Magnitude equations for Method B

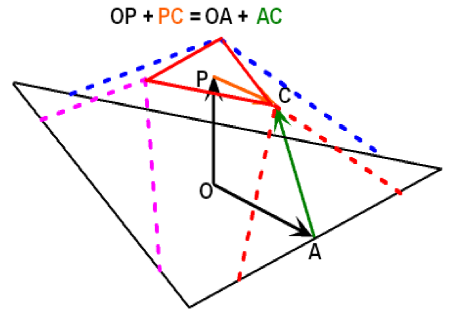


Fig 4: Main equation used in Method B

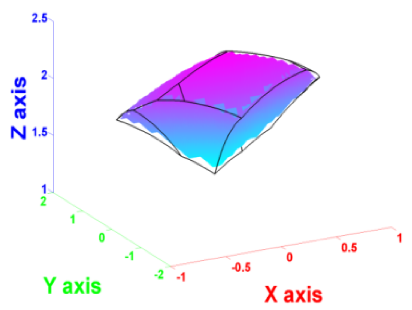
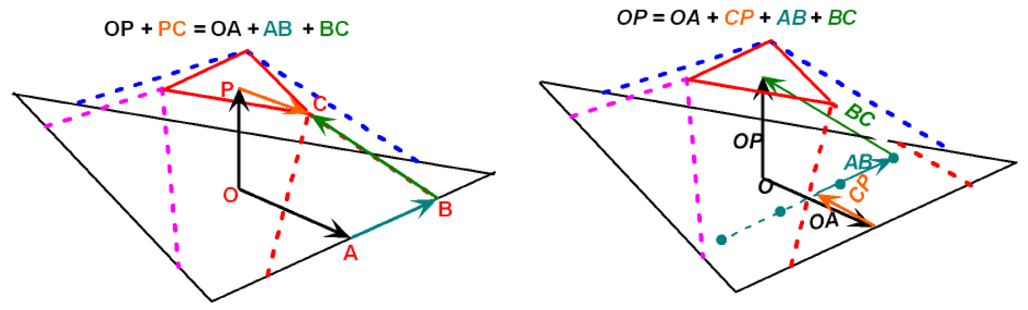


Fig 5: Overlay of Method A (Color Surface) with method C (Black Line)

Method C - Exact workspace using Geometry



Original Equation Modified Equation

Fig 6: Equation manipulation for Method C

ALGORITHM
Here, B is the prismatic limit ➔ End point is along workspace boundary and AB is known.
Constant Orientation ➔ PC (=-CP) is known
Thus, all vectors except BP known and |BP| = Link length.
Therefore, change order of addition of vectors ➔ problem changed to that of intersection of 6 spheres (because 6 Prismatic joints).
To solve it, start with points (intersection of 3 spheres).
Calculate all possible spherical intersection points and check feasibility for each. Reduces all points to feasible points.
Find curves between points (along intersection of two spheres)
Find surfaces between curves (along a single sphere)

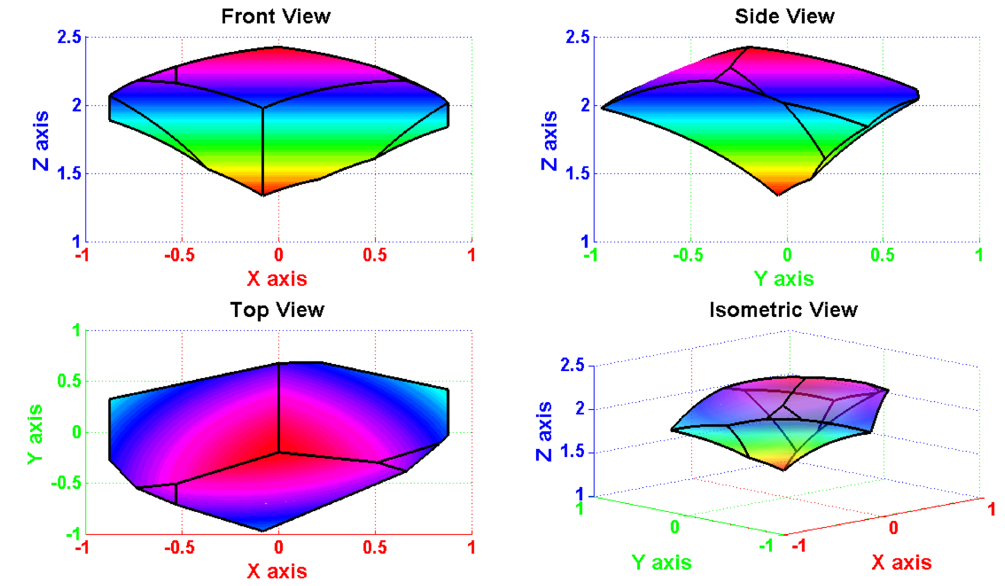


Fig 7: Method C Results for [0,0,0] orientation

Method D - CAD Model based Method C

All parameter relations fed into CAD Model (NOT a model of the actual system, just a model finding the intersection of individual serial workspaces).
Easy to set up, runs much faster. Provides accurate workspace and its volume.
Parameter sweeps, optimization studies and sensitivity analyses easily set up.
Can be run from within another program like Excel or MATLAB to create another level of automation.

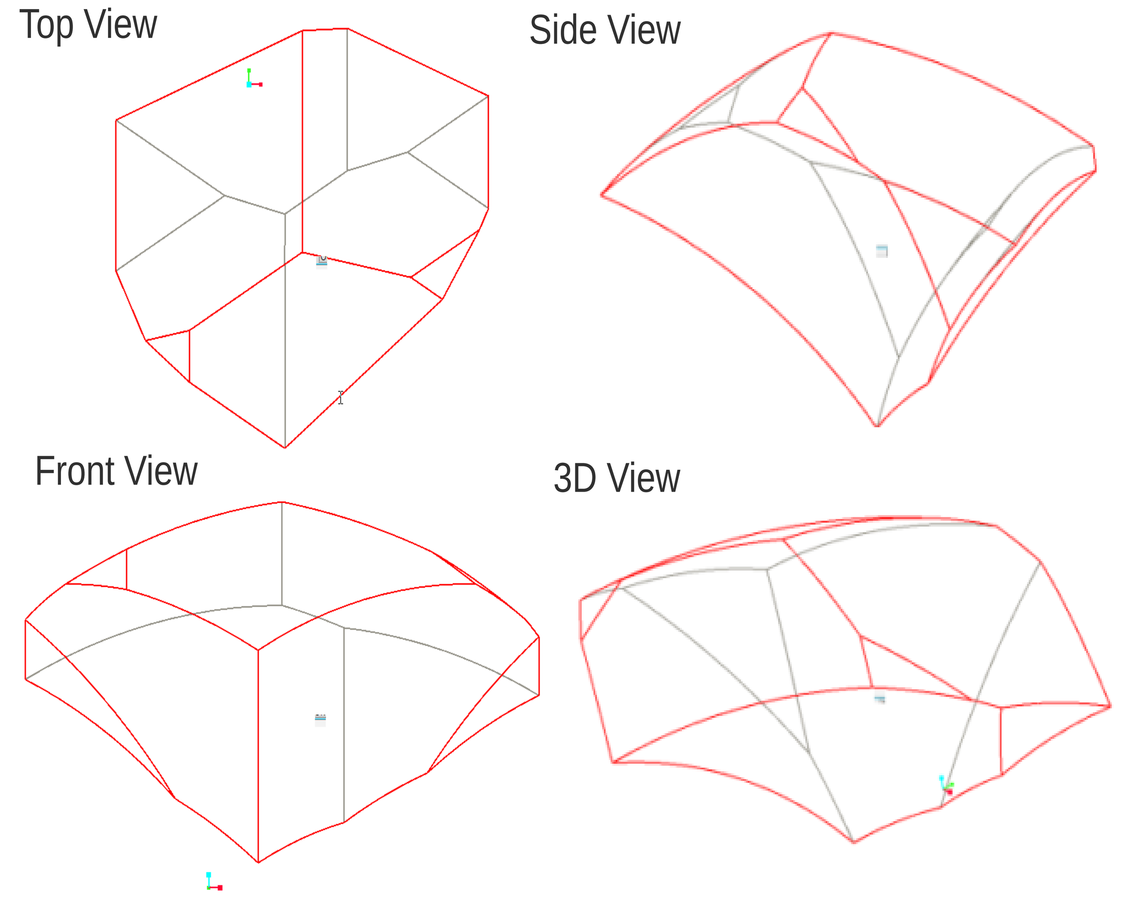


Fig 8: Method D Results for [0,0,0] orientation

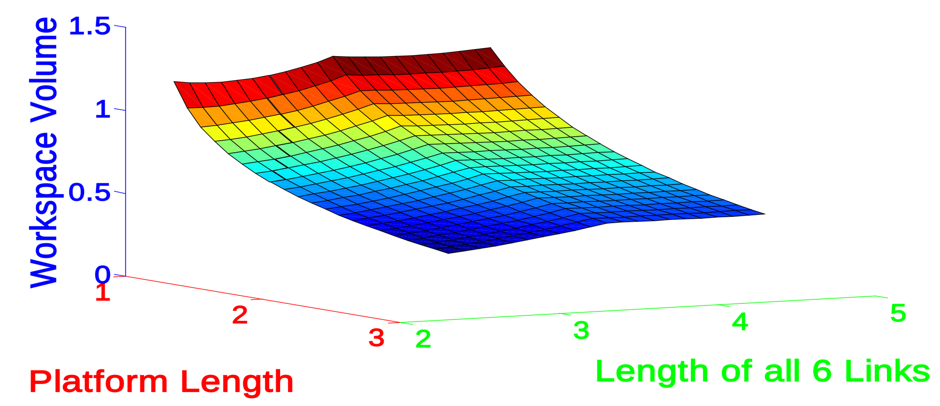


Fig 9: Parameter Sweep results from CAD Model
Parameter 1 : Length of each link
Parameter 2 : Central Platform Length
Function : Workspace Volume

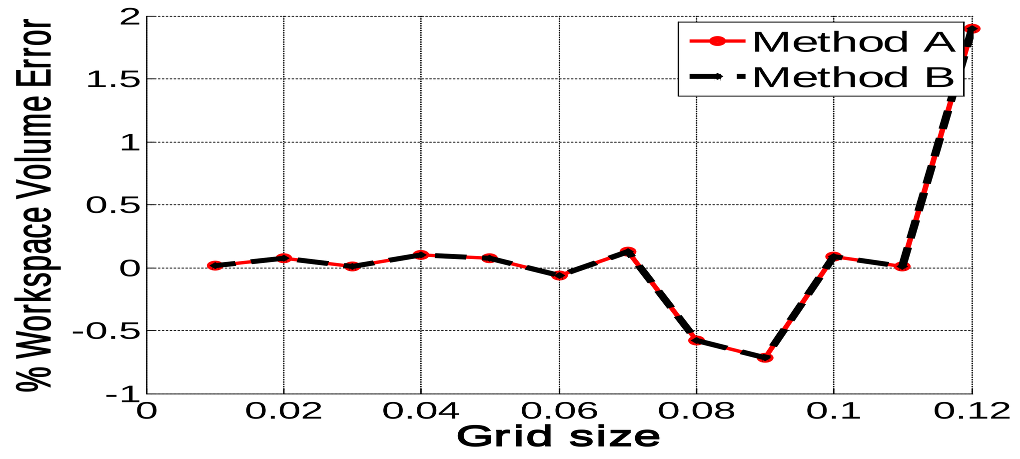


Fig 10: % Error of Methods A,B with respect to Method D

CAD Model can be easily modified to incorporate Stewart Platform.

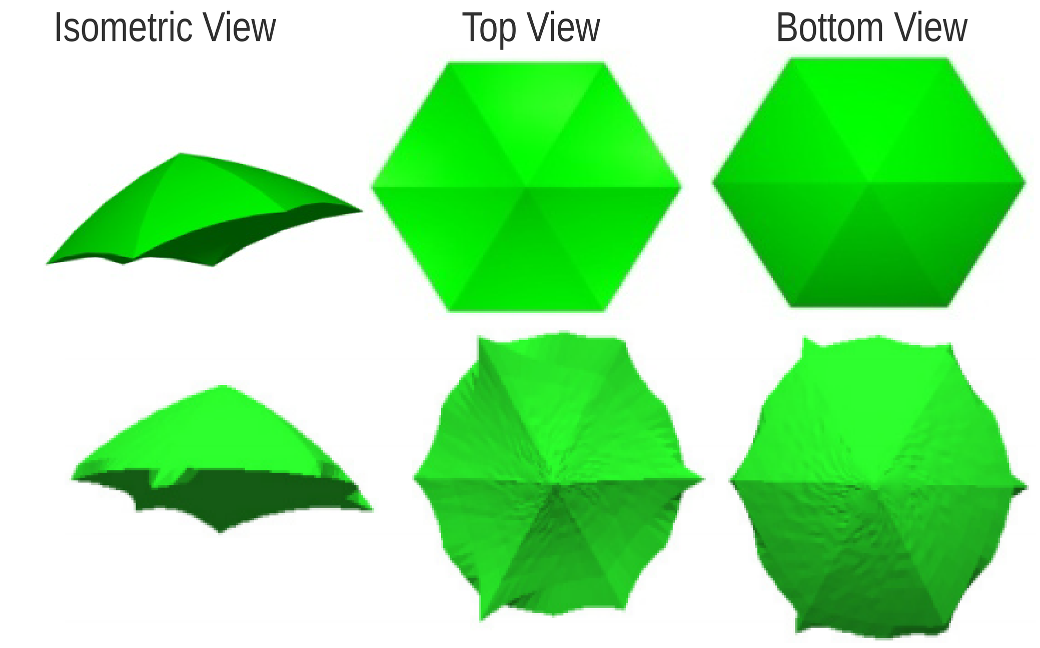


Fig 11: Method D(top) for Stewart Platform compared with previous work[2] (bottom)

Computation Time

Intel Pentium 4 – Core 2 Duo, 4GB RAM, Windows 7 Home

TABLE 1: METHODS COMPARISON (CPU TIMES)

Method	CPU Time (s)	Improvement (%)
Method A(0.05)	29.241(total)/ 20.373(computation)	0
Method B (0.05)	0.878(total/computation)	95.69 (Met. A)
Method C (exact)	0.731(total/computation)	16.74 (Met. B) 96.41 (Met. A)
Method D (exact)	0.0963(total/computation)	86.82 (Met. C) 89.03 (Met. B) 99.52 (Met. A)

Conclusion

An alternate and flexible method of workspace evaluation using CAD modeling software.
Such methods could potentially be much more insightful, efficient and accurate than conventional parameter sweep methods
Benchmarked results against standard example and previous work.

References

[1] Hrishi Shah, Sumit Tripathi, Madusudanan Sathia Narayanan and Venkat Krovi, "CAD-Enhanced Workspace Optimization for Parallel Manipulators: A Case Study," in Conference on Automation Science and Engineering, 2010.*[In Review]*
[2] Y. Yoshito Tanaka, J. Ishii, M. Wakiyama, "Evaluation of workspace in parallel machines," 1999