Contents

1 ABSTRACT

250 words or less, concise summary of research conducted, results obtained, and conclusion reached
Background: Place the question addressed in a broad context and highlight the purpose of the study.

Aim:

Approach: Methods: Describe briefly the main methods or treatments applied;

Significance:Results: Summarize the article's main findings;

Conclusion: Indicate the main conclusions or interpretations. The abstract should be an objective representation of the article, it must not contain results which are not presented and substantiated in the main text and should not exaggerate the main conclusions.

Examples: from "2018 Path Planning of Industrial Robot - RRT"

With the development of modern manufacturing industry,the application scenarios of industrial robot are becoming more and more complex. Manual programming of industrial robot requires a great deal of effort and time. **Therefore**, an autonomous path planning is an important development direction of industrial robot.

Among the path planning methods, the rapidly-exploring random tree (RRT) algorithm based on random sampling has been widely applied for a high-dimensional robotic manipulator because of its probability completeness and outstanding expansion. **However**, especially in the complex scenario, the existing RRT planning algorithms still have a low planning efficiency and some are easily fall into a local minimum.

To tackle these problems, this paper proposes an autonomous path planning method for the robotic manipulator based on an improved RRT algorithm. The method introduces regression mechanism to prevent over-searching configuration space. **In addition**, it adopts an adaptive expansion mechanism to continuously improve reachable spatial information by refining the boundary nodes in joint space, avoiding repeatedly searching for extended nodes. **Furthermore**, it avoids the unnecessary iteration of the robotic manipulator forward kinematics solution and its time-consuming collision detection in Cartesian space. The method can rapidly plan a path to a target point and can be accelerated out of a local minimum area to improve path planning efficiency.

The improved RRT algorithm proposed in this paper is simulated in a complex environment. The results reveal that the proposed algorithm can significantly improve the success rate and efficiency of the planning without losing other performance.

2 INTRODUCTION

- Novelty: Literature review
- Goal: What question you're trying to answer
- Motivation: Why you're asking the question

Guide: *Goal: provide context and encourage reader to read the paper.*
1. Background and motivation (1 paragraph)
2. Overview of the paper and contributions (1-2 paragraphs)
3. More details and summary of the approach
4. Summary of the results and conclusions.
Overview: Q4. Why should the community care?
Related work: Q1. What did the community know before you did whatever you did?
Contribution: Q3. Why exactly did you do?
We focus on....
We propose ABC algorithm...
We prove that ....
We demonstrate the EFG problem through x case studies (Section 3.4). We evaluate the ... (Section 4,5).

In this paper, we present discrete path planning of platonic solids including cube, tetrahedron, octahedron, icosahedron, and dodecahedron. These are types of convex polyhedra with equivalent faces constituted to congruent convex regular polygons....

Not much work has been done in path planning under considering rolling contact. [1] and [2] proposed XYZ method. In their work, they did XYZ (how they did).... However, they did not perform ABC.... => mention Types of rolling contact, and the paper of Z.Li

Literature in the path planning domain describes obstacles avoiding of two general types - continuous and discrete. **Continuous path planning** ....[][] **Discrete path planning** ....[][]. However, bla bla bla ...

Bla bla ....

On the other hand, bla bla bla...

Therefore, in this study, we present three cases of platonic path planning in terms of path finding for the same position and different orientation of initial configuration and goal configuration, direct searching for the long distance between two configuration, and bidirect search within obstacles.

Or: This paper presents a methodology for path planning of platonic solids in known environment. Bla bla ... ref Introduction from "Path planning in multi-scale ocean flows..."

A second contribution of this paper is a technique to compute ....

We explain our algorithms in Section II. We go over experiments and results in simulation in Section III. We verify our algorithms by executing them on a 3D model of the Statue of David and confirming that collision-free trajectories are efficiently generated. Our primary evaluation metric is time taken for the search. We discuss the performance of each individual search, as well as the advantages and shortcomings. Finally, we discuss possible future steps for this work in Section IV.

3 PROBLEM FORMULATION

Five types of Platonic Solids: Platonic solids properties: The platonic solids are also called regular

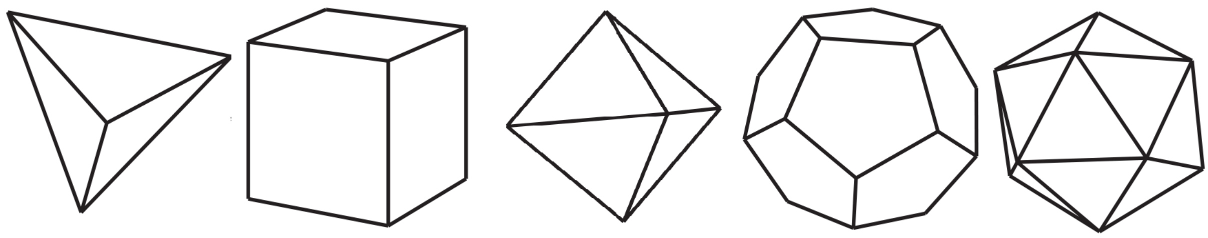


Figure 1: Platonic solids. From left to right: Tetrahedron, Cube, Octahedron, Dodecahedron, and Icosahedron

polyhedra have the convex polyhedra properties. There are only five solids namely cube, tetrahedron, octahedron, dodecahedron and icosahedron. Some of the equivalent statements are used to describe the platonic solids including all the vertices lie on a sphere, all the dihedral angle are equal, and all solid angles are equivalent.

Here is your table 1

Table 1: Properties of polyhedron

	Faces	Edges	Vertices	Edges on each face	Edges meeting at each vertices
Tetrahedron	4	6	4	3	3
Cube	6	12	8	4	3
Octahedron	8	12	6	3	4
Dodecahedron	12	30	20	5	3
Icosahedron	20	30	12	3	5

Here is your table 2

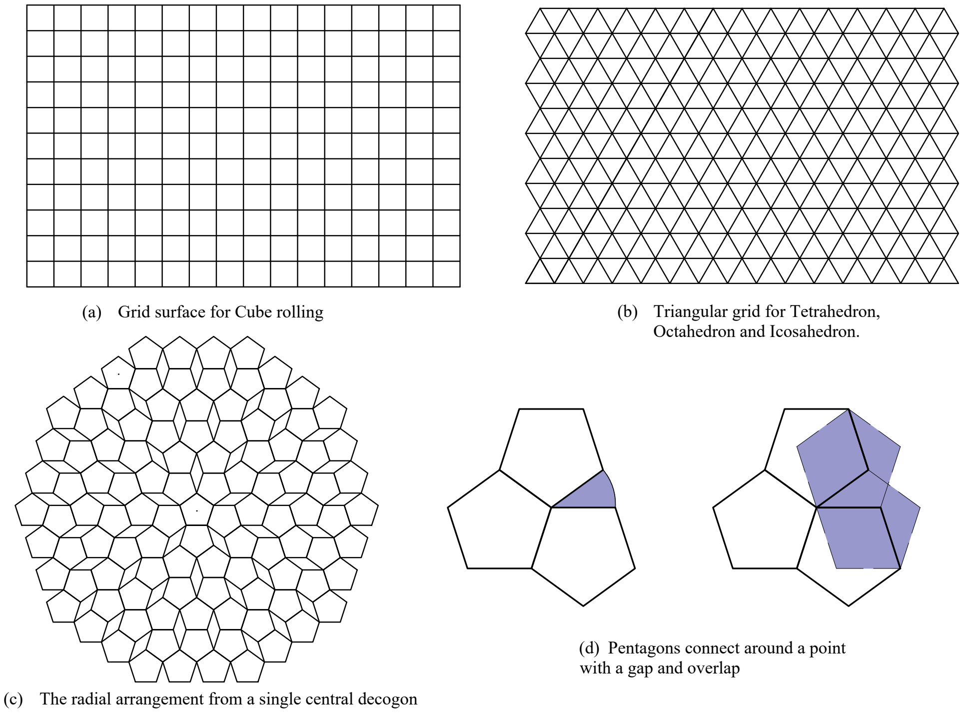
Table 2: Dimensional of platonic solids

	r_d	ρ	R	dihedral angles (β)
Tetrahedron	$\frac{1}{12}\sqrt{6}$	$\frac{1}{4}\sqrt{2}$	$\frac{1}{4}\sqrt{6}$	$\cos^{-1}(\frac{1}{3})$
Cube	$\frac{1}{2}$	$\frac{1}{2}\sqrt{2}$	$\frac{1}{2}\sqrt{3}$	$\frac{1}{2}\pi$
Octahedron	$\frac{1}{6}\sqrt{6}$	$\frac{1}{2}$	$\frac{1}{2}\sqrt{2}$	$\cos^{-1}(-\frac{1}{3})$
Dodecahedron	$\frac{1}{20}\sqrt{250+110\sqrt{5}}$	$\frac{1}{4}(3+\sqrt{5})$	$\frac{1}{4}(\sqrt{15}+\sqrt{3})$	$\cos^{-1}(-\frac{1}{5}\sqrt{5})$
Icosahedron	$\frac{1}{12}(3\sqrt{3}+\sqrt{15})$	$\frac{1}{4}(1+\sqrt{5})$	$\frac{1}{4}\sqrt{10+2\sqrt{5}}$	$\cos^{-1}(-\frac{1}{3}\sqrt{5})$

4 ALGORITHM\METHODOLOGY

4.1 Path Planning Based Rolling Contact

Rolling on discretized surfaces: The surface contacts between platonic solids and the plane can be categorized into three types as shown in Figure2 including square shape for cube, triangle shape for tetrahedron, octahedron, and dodecahedron, pentagon shape for dodecahedron. However, in the case of dodecahedron rolling contact, the Figure2d shows the two types of connections between pentagons where the first case has a gap (Figure2c) and the other has overlap pentagon connection. A regular pentagon has five interior angles of $108°$ which generate a gap between three pentagons surrounding because of $3 * 108° = 324°$, which is different $360°$ of the full circle. Another case of four overlap pentagons with $4 * 108° = 432°$ is greater than the circle of $360°$.



(a) Grid surface for Cube rolling

(b) Triangular grid for Tetrahedron, Octahedron and Icosahedron.

(c) The radial arrangement from a single central decogon

(d) Pentagons connect around a point with a gap and overlap

Figure 2: Grid of platonic solids

Algorithms: Due to the different surface contacts, there are three types of direction for the rolling of platonic solids. As shown in the Figure3, the cube has four directions with the square surface contact while tetrahedron, octahedron and icosahedron have three rolling directions with the triangular surface contact. The dodecahedron with pentagon surface contact has five rolling directions. In the case of rolling cube, the surface contact is surrounded by four edges which means there are four possible directions through the edges. In this work, the proposed path planning algorithm deals with rolling from initial configuration with position and orientation to the goal with the same position but different orientation. While rolling on the smooth plane, the platonic solid models will contact to the plane though their edges.

The Algorithm1 shows that path planning for cube rolling based on tree graph search has some important steps. The first step is to initial the coordinates and the orientations of the initial cube and the target cube. The same as tree expansion, cube will roll in four different directions including the right, left, up and down is the next step. From these new positions and orientations, the cubes will continue expand with only three directions to avoid return the previous positions. An example for this step is that from the initial coordinate the cube achieves a new position after doing rolling for right direction, the three new positions of the cube by rolling through right, up, and down direction.

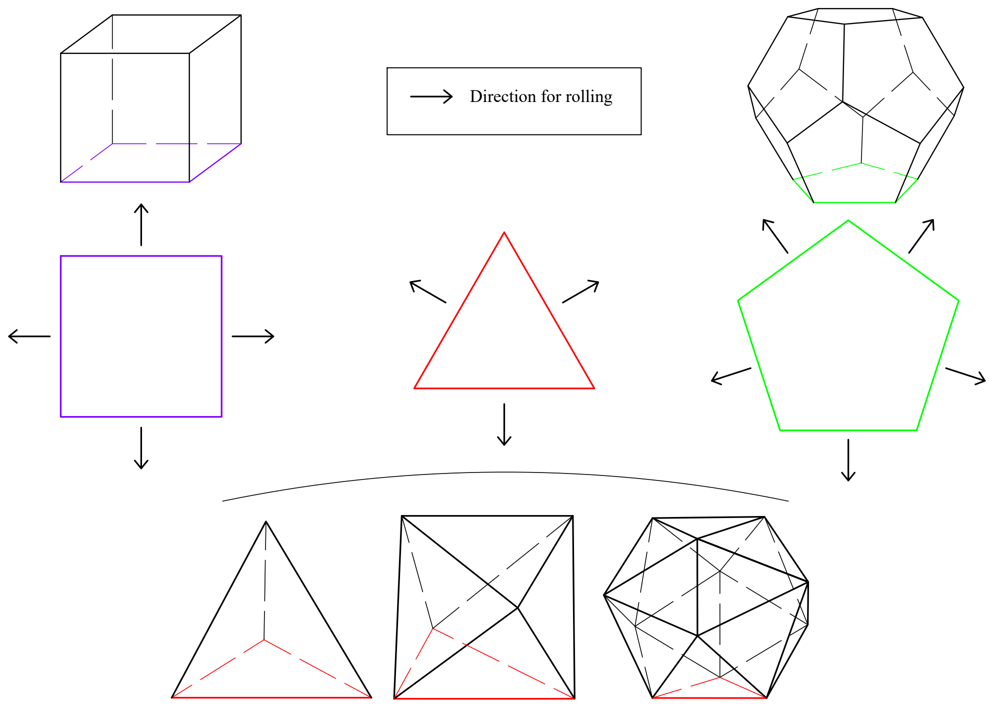


Figure 3: Rolling direction for each types of platonic solids

4.2 Tree Exploration Algorithm

The node tree exploration for searching algorithm described in Algorithm1 is similar to non-recursive depth-first-search algorithm. The graph search in the Figure4 shows the expansion from the *root* with node S to multi-level from $level^1 ... level^n$. Each nodes indicates the position of the cube's center and the orientation of the cube. The node S means Start-Point while R, L, U, D are labelled for four different directions including right, left, up and down respectively.

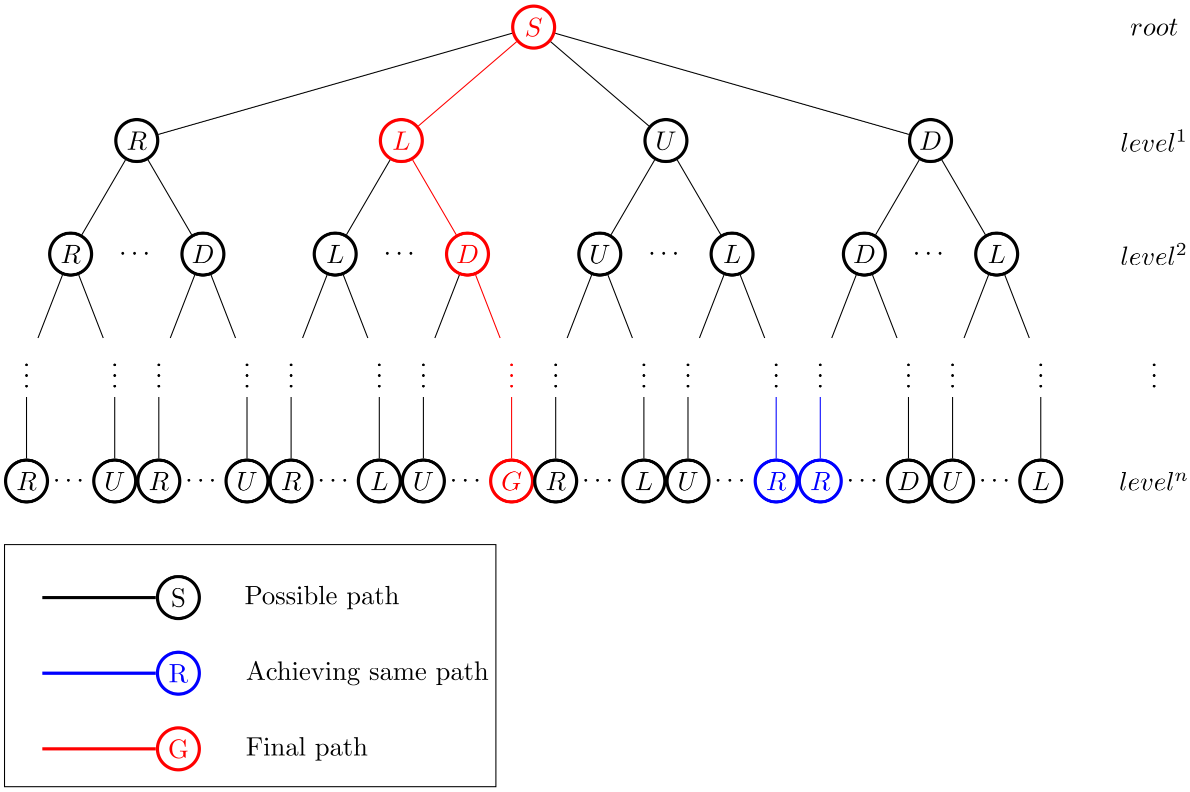


Figure 4: Tree Exploration of Cube Rolling

Starting form the root S, path planning based rolling of the cube model at the first level of expansion will generate to four different direction R, L, U, D. In the next level, the cube can only roll with three directions without rolling back to the previous position. An example of the second level is that node R will roll to right, up, and down directions.

Algorithm 1 Path planning based rolling contact for Cube model.

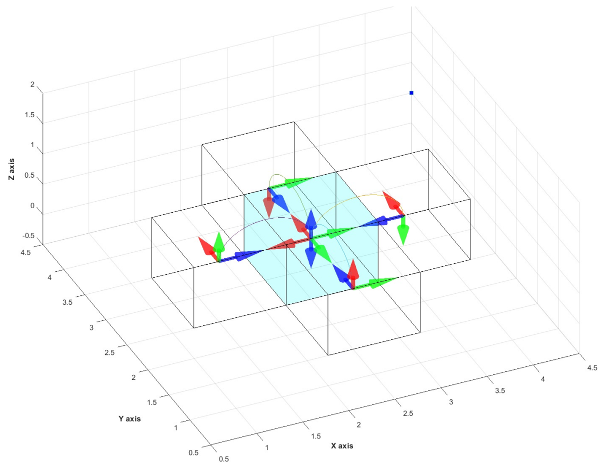
```
procedure CubePathPlanning(S_p, G_p)  ▷ Find the shortest path from start to goal position with different orientation
    flag ← false
    Path[S_p] ← S_p
    newPoints ← rolling4Directions(S_p)                    ▷ Generate first four updated points
    while newPoints != G_p do
        updatedPoints ← treeExploration(newPoints)   ▷ Update new three right rolling models
        n ← size(updatedPoints)
        for i ← 0, n do
            for j ← 1, n do
                if updatedPoints[i] = updatedPoints[j] then
                    remove(updatedPoints[i])
                end if
            end for
        end for
        flag ← checkingTargetPoint(updatedPoints)  ▷ Compare updated points with goal point
        if flag = true then
            return Path[S_p, G_p]                              ▷ Store new point to Path
        end if
        newPoints = updatedPoints
    end while
    return "no path found"
end procedure
procedure rolling4Directions(S_p)          ▷ Generate new points in different direction of rolling
    (newRightPoint, newLeftPoint, newUpPoint, newDownPoint) ← rollingContact(S_p)
    return newPoints ← (newRightPoint, newLeftPoint, newUpPoint, newDownPoint)
end procedure
procedure treeExploration(newPoints)
    if dir = right then
        updatedPoints ← (newRightPoint, newUpPoint, newDownPoint)
    else if dir = left then
        updatedPoints ← (newLeftPoint, newUpPoint, newDownPoint)
    else if dir = up then
        updatedPoints ← (newRightPoint, newLeftPoint, newUpPoint)
    else
        updatedPoints ← (newRightPoint, newLeftPoint, newDownPoint)
    end if
    return updatedPoints
end procedure
procedure checkingTargetPoints(updatedPoints, G_p)
    if updatedPoints = G_p then                    ▷ Consider both position and orientation
        flag ← true
    end if
    return flag
end procedure
```

5 EVALUATION

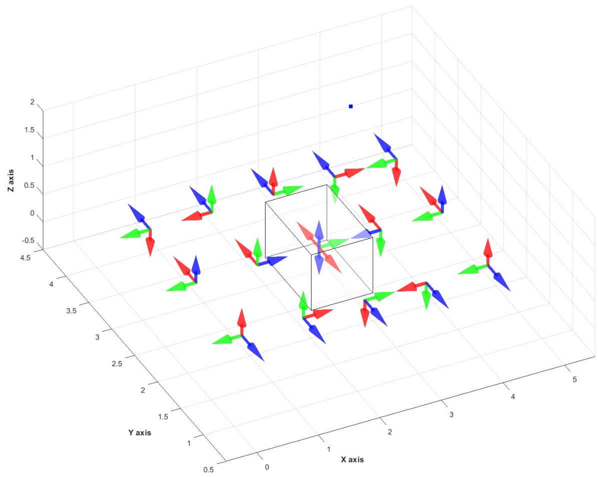
Simulations: Our algorithm was implemented in MATLAB. Three case studies of path planning are considered for validation: same location and different orientation between initial configuration and goal configuration, long distance between two configuration, and bi-direction path finding.

Cube solid: Writing about cube solid properties

Case study 1: Dennis also went his own way and divided the sides of the triangles into equal-angles (as measured from the center of the geodesic), instead of equal-length pieces. This technique is slightly more effective at evenly distributing the triangles across the surface of the sphere. For example, compare an octahedron subdivided with frequency 20, using the linear technique (as outlined by the quiz) versus the angular technique Dennis used in this picture. Note how the linear technique has the triangles piling up along the edges of the original face of the octahedron, where the radial technique does a better job of spacing them out.



(a) The initial configuration is the same position but different orientation with goal configuration



(b) First four paths of the cube rolling

Figure 5: Blah Blah

Result:

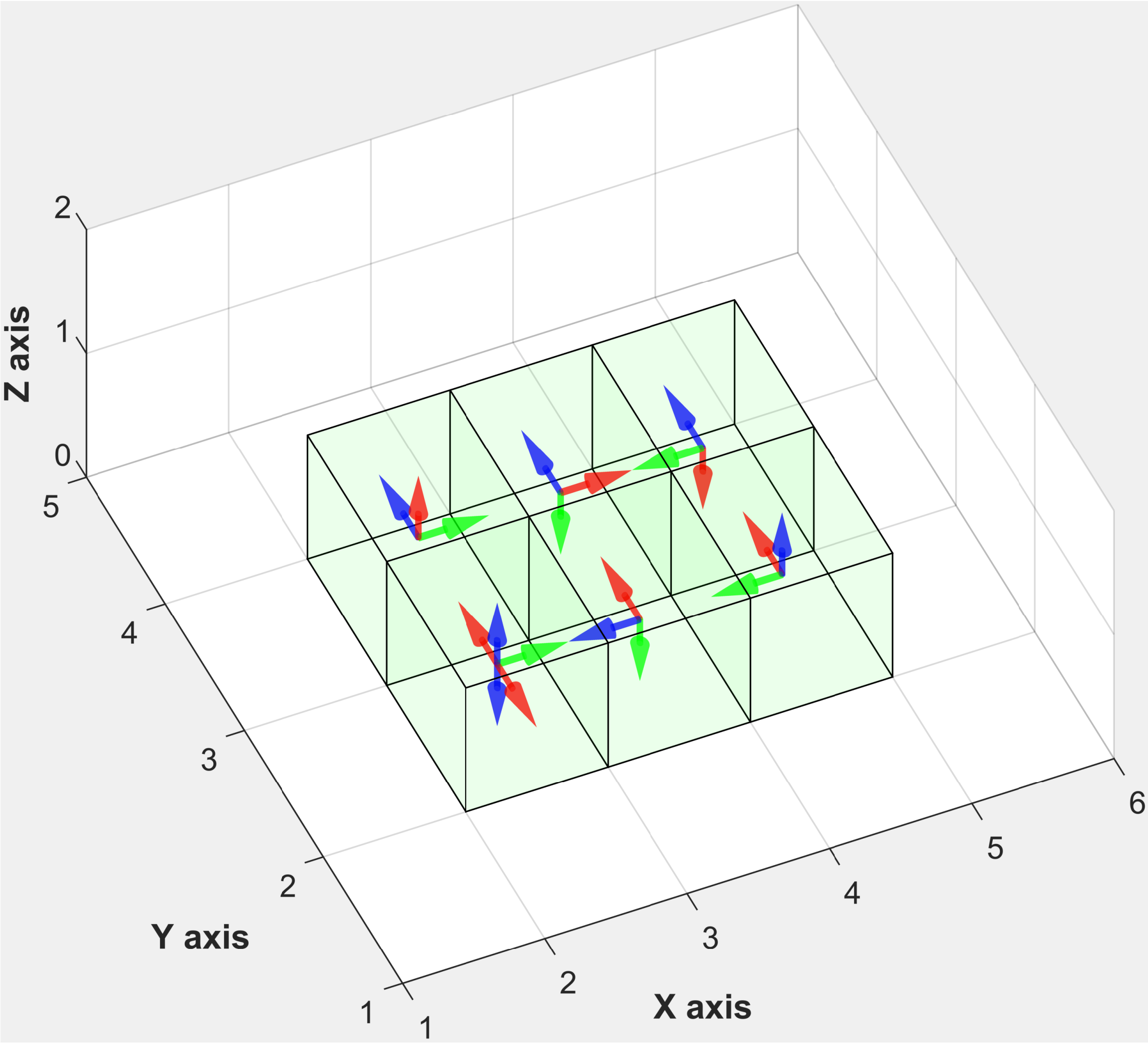
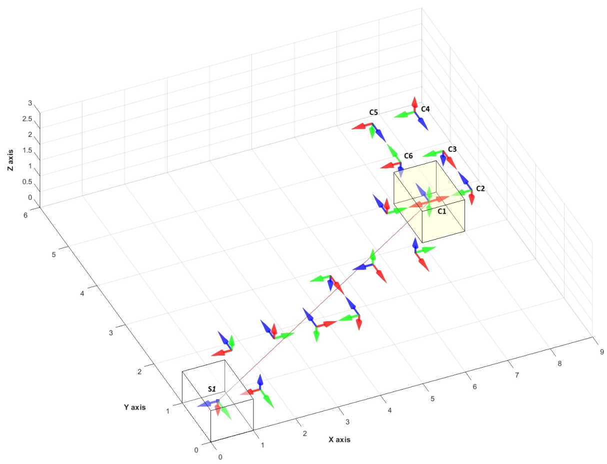
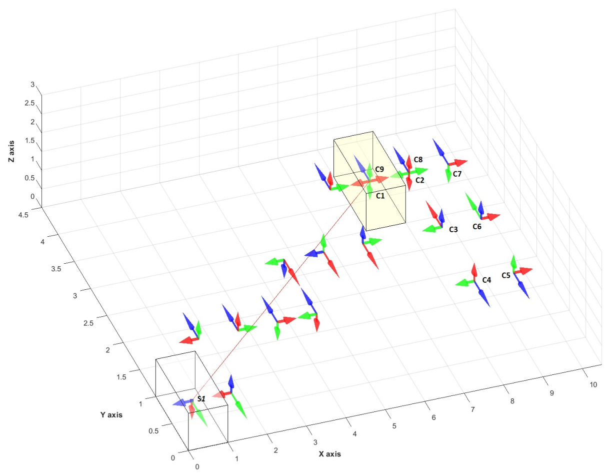


Figure 6: Shortest path of cube rolling



(a) Path1

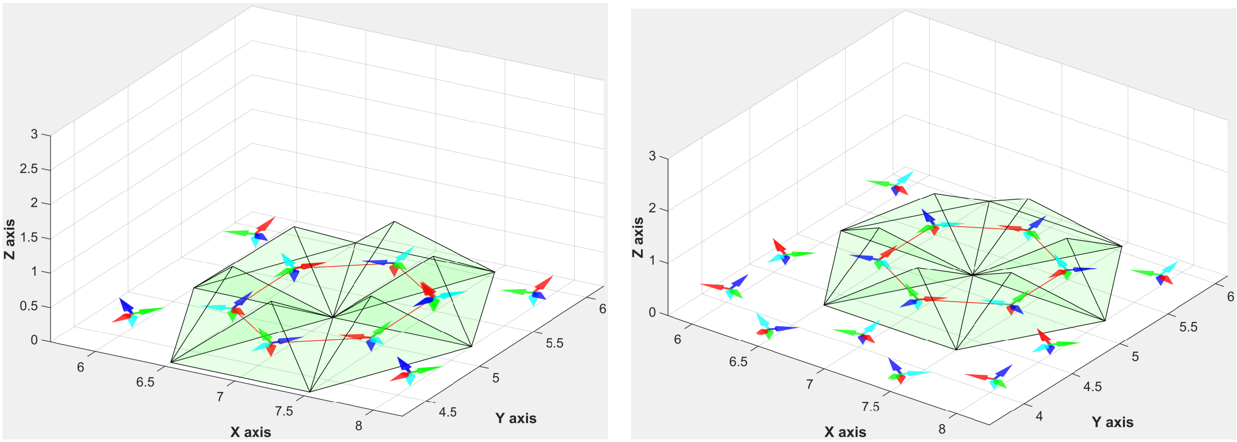


(b) Path2

Figure 7: Blah Blah 3

Tetrahedron solid: Writing about cube solid properties

Case study 1: Dennis also went his own way and divided the sides of the triangles into equal-angles (as measured from the center of the geodesic), instead of equal-length pieces. This technique is slightly more effective at evenly distributing the triangles across the surface of the sphere. For example, compare an octahedron subdivided with frequency 20, using the linear technique (as outlined by the quiz) versus the angular technique Dennis used in this picture. Note how the linear technique has the triangles piling up along the edges of the original face of the octahedron, where the radial technique does a better job of spacing them out.

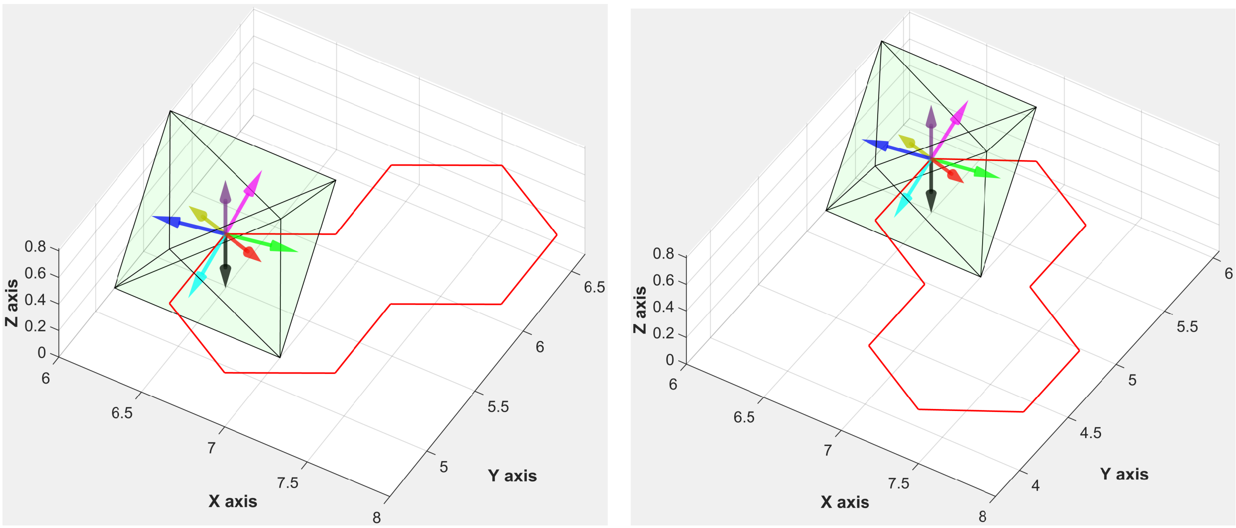


(a) The initial configuration is the same position but different orientation with goal configuration

(b) First four paths of the cube rolling

Figure 8: Blah Blah Tetra

<u>Octahedron solid</u>: Dennis also went his own way and divided the sides of the triangles into equal-angles (as measured from the center of the geodesic), instead of equal-length pieces. This technique is slightly more effective at evenly distributing the triangles across the surface of the sphere. For example, compare an octahedron subdivided with frequency 20, using the linear technique (as outlined by the quiz) versus the angular technique Dennis used in this picture. Note how the linear technique has the triangles piling up along the edges of the original face of the octahedron, where the radial technique does a better job of spacing them out.

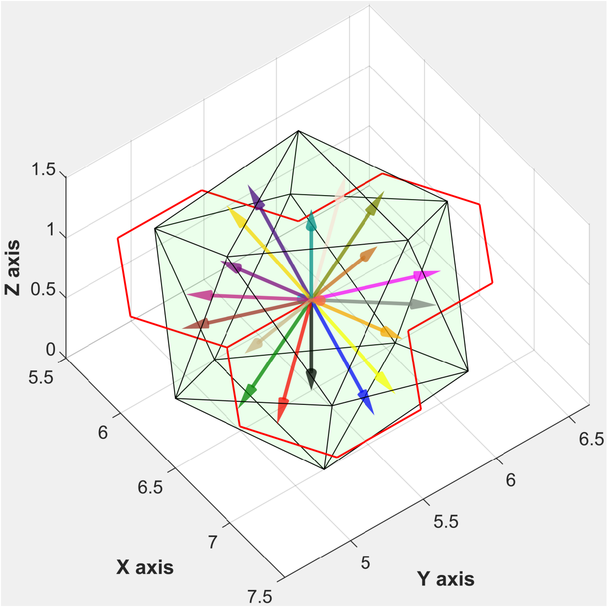


(a) The first shortest path of Octahedron path rolling

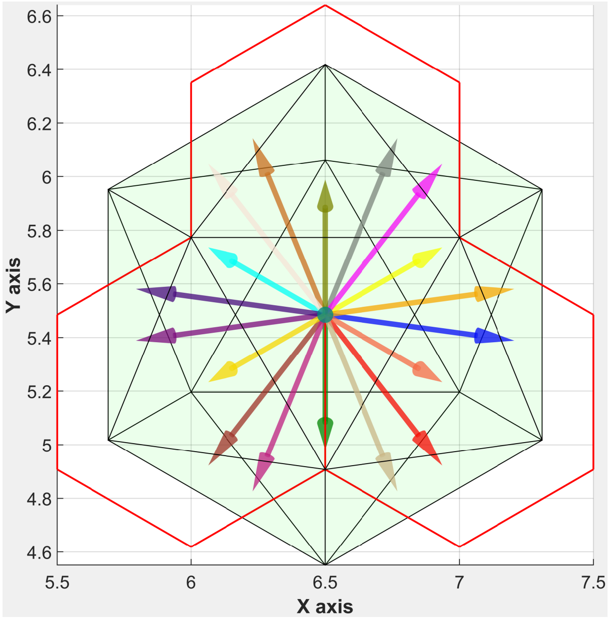
(b) The second shortest path of Octahedron path rolling

Figure 9: Blah Blah Octa

<u>Icosahedron solid</u>: Writing about cube solid properties
This is the rolling path of icosahedron type 10.



(a) The first shortest path of Icosahedron path rolling

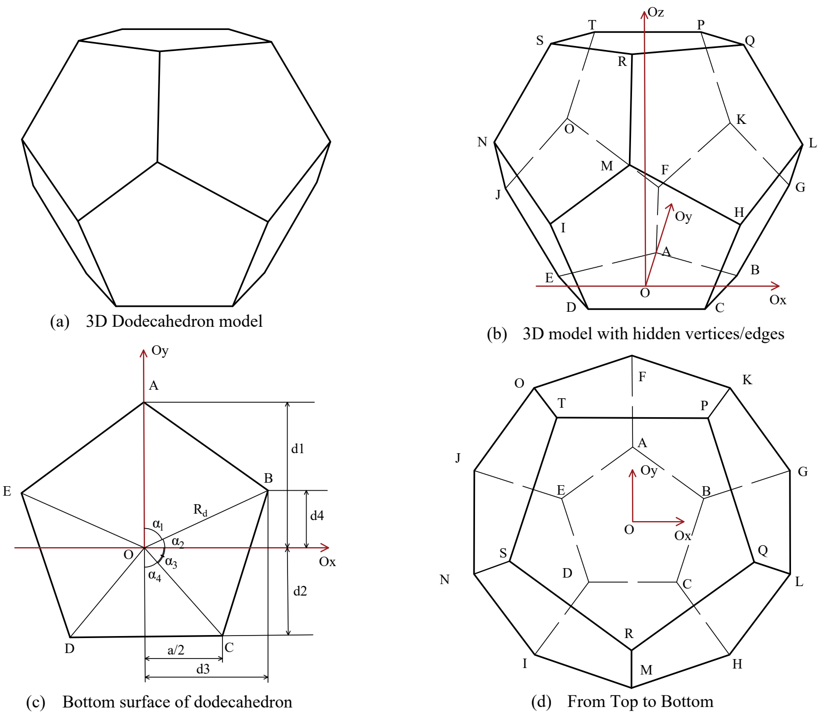


(b) The top view of path planning for Icosahedron

Figure 10: Blah Blah Octa

Dodecahedron:

Properties: An dodecahedron has 12 faces and 20 vertices of which generates a pentagon as shown in Figure 11. It will be assumed that the coordinates $Oxyz$ lie on $ABCDE$ surface within Oy through A and Oz perpendicular to $ABCDE$. The 30 edges have the same length as a. It should be determined all the vertices' coordinates in the three dimensional system. The Figure 11 indicates the lengths of each vertices from d_1 to d_4 and the angles α_1 to α_4 which correspond to the five sides of a pentagon.



(a) 3D Dodecahedron model

(b) 3D model with hidden vertices/edges

(c) Bottom surface of dodecahedron

(d) From Top to Bottom

Figure 11: Dodecahedron's vertices.

The path planning will implement on a surface but it will be considered in $3D$ spaces. Then, each of vertices will be determined on $3D$ coordinates such as the vertices A has coordinate with $[A_x A_y A_z]$. Based on the properties of pentagon, the angle $\alpha_1 = \frac{2\pi}{5}$ and $\alpha_4 = \frac{\pi}{5}$. Because the angle between Ox and Oy is $\frac{\pi}{2}$, the sum of α_1 and α_2 is $\alpha_1 + \alpha_2 = \frac{\pi}{2}$. Then the other two angles α_2 and α_3 can be determined by $\alpha_2 = \frac{\pi}{2} - \alpha_1 = \frac{\pi}{2} - \frac{2\pi}{5} = \frac{\pi}{10}$ and $\alpha_3 = \alpha_1 - \alpha_2 = \frac{2\pi}{5} - \frac{pi}{10} = \frac{3\pi}{10}$.

From the Figure 11(c), these labelled dimensions can be calculated as $d_1 = R_d = \frac{a}{2\sin\alpha_4}$ with R_d is the circumradius of dodecahedron, $d_2 = d_1 \cos\alpha_4$, $d_3 = d_1 \cos\alpha_2$, and $d_4 = d_1 \sin\alpha_2$. Referencing to the properties of a dodecahedron with length a, the radius of an inscribed sphere is $r_i = \frac{a}{20}\sqrt{10(25 + 11\sqrt{5})}$ and the circumscribed sphere radius is $r = a\frac{\sqrt{3}}{2}\frac{1+\sqrt{5}}{2}$.

There are total 20 vertices of a dodecahedron. This article focuses on the rolling contact to $2D$ surface, the bottom surface of the dodecahedron integrated to the Oxy which contact to the $2D$ surface. This condition express the Oz dimension of the vertices $ABCDE$ equal to 0 or $A_z = B_z = C_z = D_z = E_z = 0$. Then $P_z = Q_z = R_z = S_z = T_z = 2.r_i = \frac{a}{10}\sqrt{10(25 + 11\sqrt{5})}$.

It can be seen that the distance $|AF|$ is a and the distance $|BF|$ is $2d_3$. Using the distance properties and squaring the results give:

$$
\begin{aligned}
AF^2 &= a^2 = (A_x - F_x)^2 + (A_y - F_y)^2 + (A_z - F_z)^2 \\
BF^2 &= (2d_3)^2 = (B_x - F_x)^2 + (B_y - F_y)^2 + (B_z - F_z)^2
\end{aligned}
\tag{1}
$$

Figure 11(d) shows that $A_x = F_x = 0$, $A_y = d_1$, $B_y = d_4$, $B_x = d_3$, $A_z = B_z$. Define $d_5 = A_z - F_z$, the relations of these equations are:

$$\begin{aligned} a^2 &= (F_y - d_1)^2 + d_5^2 \\ (2d_3)^2 &= (F_y - d_4)^2 + d_5^2 + d_3^2 \end{aligned} \tag{2}$$

Solving F_y and d_5 gives:

$$\begin{aligned} F_y &= \frac{a^2 - (2d_3)^2 - (d_1^2 - d_3^2 - d_4^2)}{2(d_4 - d_1)} \\ d_5 &= \frac{1}{\sqrt{2}}\sqrt{a^2 + (2d_3)^2 - (F_y - d_1)^2 - (F_y - d_4)^2 - d_3^2} \end{aligned} \tag{3}$$

From these equations 1,2,3, all the vertices will be founded in the three-dimensional space. Path planning based on rolling is the motion of all these vertices through edges' contact.

Experiments: Writing about cube solid properties

Discussion: Q2 & Q3
- Q2: What are the new things you learned after you did whatever you did?
- Q3: What exactly did you do?

- **Discussion**
- *What your results mean*
- *Why it makes a difference*
- **Conclusion**
- *Broader implications*
- *Areas for further study*

6 CONCLUSION AND FUTURE PROSPECTS

Questions: Q4. Why should the community care?
Should do: - Overview of Q1, Q2, and Q3; plus
- What does the community still not know?

Examples: - We have introduced a method of ....
- Most of our effort has focused on .... The results of our method often contain .... We believe that there is significant room for improvement by applying ABC methods to the XYZ problem.
- What do we not do?

In this study, we established a method for ... Although we focused on discrete path planning of platonic solid - regular convex polyhedra in known environment, as illustrated using ABC model and EFG example, the developed method/algorithm can be easily implemented to the complex convex polyhedra such as elipsoil ???. The contributions of this study can be summarized as follows:

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Authors
Figures
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Citations
Keywords
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SECTION IX.
CONCLUDING REMARKS

In this paper, we have introduced Bayesian optimization from a modeling perspective. Beginning with the beta-Bernoulli and linear models, and extending them to nonparametric models, we recover a wide range of approaches to Bayesian optimization that have been introduced in the literature. There has been a great deal of work that has focused heavily on designing acquisition functions; however, we have taken the perspective that the importance of this plays a secondary role to the choice of the underlying surrogate model.

In addition to outlining different modeling choices, we have considered many of the design decisions that are used to build Bayesian optimization systems. We further highlighted relevant theory as well as practical considerations that are used when applying these techniques to real-world problems. We provided a history of Bayesian optimization and related fields and surveyed some of the many successful applications of these methods. We finally discussed extensions of the basic framework to new problem domains, which often require new kinds of surrogate models.

Although the underpinnings of Bayesian optimization are quite old, the field itself is undergoing a resurgence, aided by new problems, models, theory, and software implementations. In this paper, we have attempted to summarize the current state of Bayesian optimization methods; however, it is clear that the field itself has only scratched the surface and that there will surely be many new problems, discoveries, and insights in the future.

Figure 12: First four paths of the cube rolling

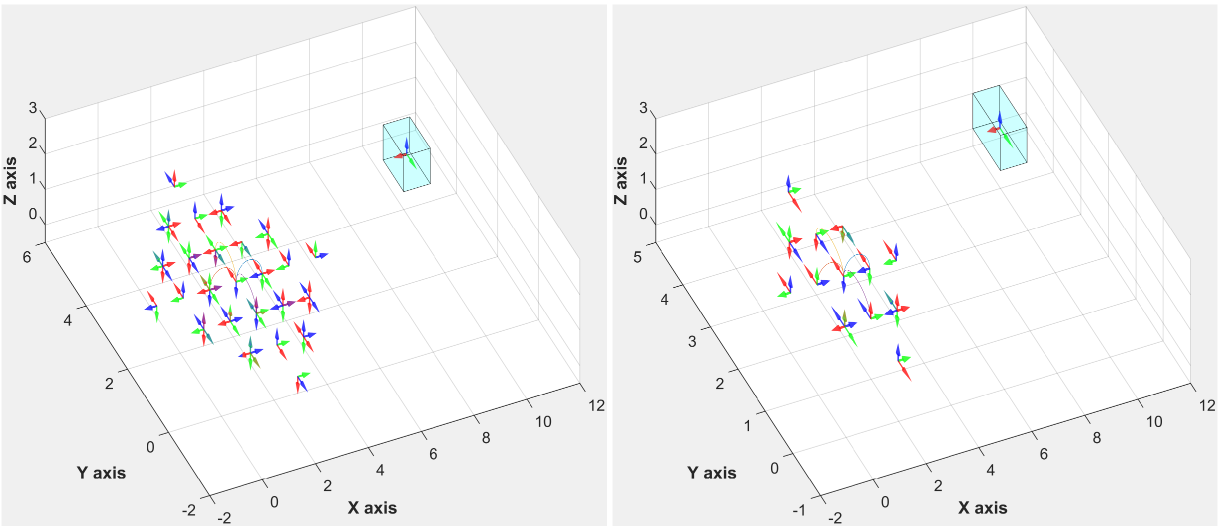
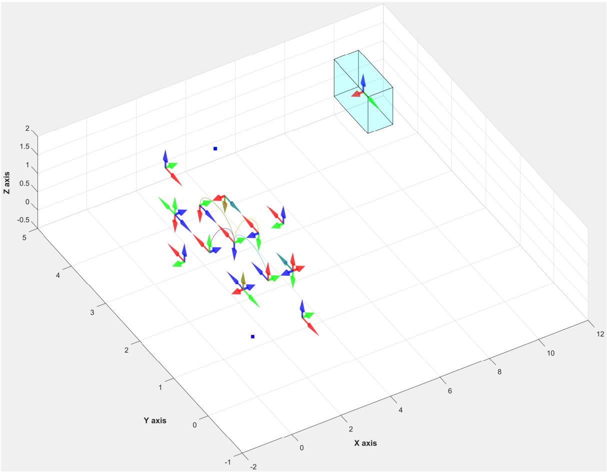
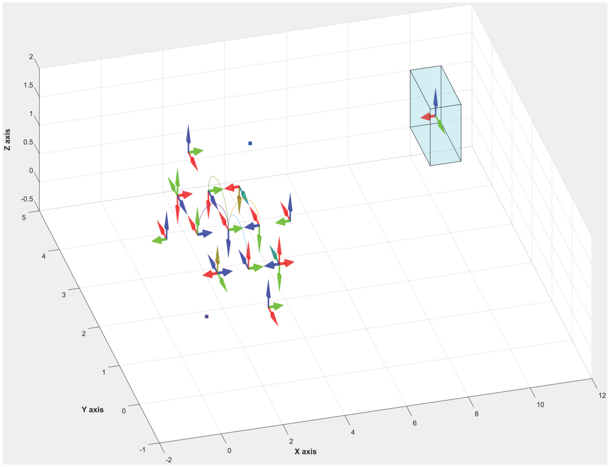


Figure 13: Test



(a) Cube1



(b) First four paths of the cube rolling

Figure 14: Blah Blah

Refer to the Data Management Plan in Appendix A.
[1]

7 Reviews from Prof. Jonathan Paxman for PhD Candidacy Proposal

• Include a discussion of the motivation and advantages for rolling contact for in-hand manipulation
• Reduce the length of the discussion on modelling the kinematics of rolling motion
• Add a brief review of path planning for two general objects under nonholonomic constraints
• Simply the aims: remove specific techniques and algorithms, and describe the broad aim of the project general terms, and in one or two sentences. Ensure that specific objectives are framed so that the aim can be achieved.
• Include a section which describes how a discretised model will be produced such that the discrete planning algorithms described can be applied. How is this discrete model to be obtained from the continuous-time models discussed?
• If optimal planning is discussed, ensure you are specific about in what sense the solution is optimal. In some cases, optimality is not required, only a satisfactory or satisficing solution in the sense of a cost function being below some bound. In such cases, sampling-based solutions (such as RRT) are appropriate.
• Please also review the writing for grammatical correctness (seek some assistance on this if needed).
• Note Robot Operating System (not Software) in Table 1.

[2], [3],[4],[5], [6].

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A APPENDIX