Reviewer #1:

Comment 1:

While the analyses provided in this paper is intriguing, the end results are not very exciting as the proposed method is essentially a brute force method and has the same time complexity as integer programming.

Answer 1:

We consider that a discrete algorithm like integer programming cannot be applied to original NCPP problem on continuous surface. If the reviewer means that a better algorithm can be utilized for decomposed NCPP, we agree that it may exist. We argue that transforming the problem from continuous domain to discrete domain by disregarding those equivalent cellular decompositions is the key step, which makes the problem solvable and guarantees the existence of solution. This is the central contribution of this paper. For the proposed algorithm, it is the first method to solve the problem. As $n$ is usually less than 10, this method is applicable in practice.

The proposed algorithm is guaranteed to find all optimal solutions. We show that an exhaustive searching is necessary if all optimal solutions are requested. Hence, no algorithm achieving all optimal solutions can perform faster than exponential complexity. We think that the important part of this contribution lies on the insight for further improvement in the community: There may exist faster algorithm that can find one optimal solution with lower time complexity, but it is beyond the scope of this paper.

Comment 2:

The cutting paths connecting the "holes" to the outer boundary do not seem to play any important role in these examples. The holes seem to be simply removed because they are covered by other sets.

Answer 2:

The reviewer may misunderstand the definition of "topological edges" in (6). The "hole" that the reviewer mentioned is a "simple hole" which only has one edge (its circular boundary). No other cells lie in the inner part. However, refer to Fig.5(b), Fig.6 and Fig.7-8 for the illustration of 2-edge, 5-edge and 3-edge inner parts, respectively. In these cases, cutting path is important.

Comment 3:

The experiments provide no comparison and do not report any statistical information about the proposed method. Decompositions from these examples are not demonstrated.

Answer 3:

The optimality of the algorithm is guaranteed by the theory, which is not probabilistic. Moreover, we provide the demonstration of the concepts and the proposed three experiments in the video shown in footnote 1 at the end of Section I.

Comment 4:

All images are very small and the tiny text are not really legible. Many figures, such as Fig.3, Fig.6, Fig.7 are not well explained.

Answer 4:

Please refer to Answer 3.2.

Reviewer #2:

Comment 1:

I hope that the authors did some work to provide more insight and intuition before delving into mathematical rigor. It was not an easy read, and requires a few repeats.

Answer 1:

The idea of inductively solving algorithm originates from three observations:

(1) The areas embedded in a 2.5D surface can be classified by the number of “holes” within them.

(2) The original problem is defined on continuous surface, so the problem is finitely solvable only after we eliminate equivalent cellular decompositions and reserve finite unique cellular decompositions.

(3) For each category, we can find an optimal case, thus calling for an enumeration process to find all optimal solutions.

Comment 2:

One of the reasons why I had a difficulty was that even though provided illustrations are useful, but do not provide clear legends.

Answer 2:

Please refer to Answer 3.2.

Reviewer #3:

Comment 1:

Sec VI focuses on two methods: (1) treating the inner and outer parts as independent problems which can be solved for because each part is a simply-connected cell or (2) transforming the genus-one cell into a simply-connected cell (thus removing the hole) and then further dividing the cell.

Answer 1:

We do not present two methods, but show two situations: (1) transforming the cell into a simply-connected one or (2) regarding the inner and outer parts as two independent problems.

Comment 2:

(1) Fig.3 is a large complex figure and it is not immediately apparent in what direction to read it. While the text directs us to see that examples of the different topological divisions described by Eq (15) and (16) are visualized in Fig.3 the separation is not clear. The reader may need a more detailed caption or further annotations to fully appreciate Fig.3.

(2) While there are pairs of figures that share similar style, i.e., Fig.5b with Fig.7 and Fig.6 with Fig.8, the reader may need more details (in caption or in text) to interpret them properly. Many theoretical ideas were illustrated via the figures and I think more illustrative description could further solidify the understanding.

(3) Given the large number of symbols and terminology, it may be helpful to introduce a table of symbols to aid the reader in keep track of everything. Likewise, a flowchart of the algorithm may help summarize the algorithmic contribution and help guide the reader.

Answer 2:

(1) The problem of Fig.3 is possibly because the function “varphi” was introduced too late (at (14)-(16)). In Fig.3, we show the first equivalence--between “directly solving” (the left side of Fig.3) and “first solving the outer part without the inner part, then arbitrarily place the inner part” (the right side of Fig.3). More annotations in the figure are definitely helpful.

(2) We argue that the primary problem of Fig.5-8 is that all of them use concentric circles to represent the cell that to be discussed. After we use more generic shapes to create the figures, they won’t make the reader confused like “similar style”. And we agree that the font size in figures should be enlarged.

(3) Most of the symbols only appear one time in formulas, so it may not be a good choice to list them in a table. Introducing another figure showing the work flow with notations may solve the issue.

Comment 3:

One of the assumptions detailed in Sec. III is that all points on surface are within the robot's dexterous workspace, in that we do not need to consider singularities. This assumption was only made clear to me when watching the supplementary video. How limiting is this assumption?

Answer 3:

The singularities are the poses whose manipulability measure is zero. In such poses, the manipulator cannot deal with force/torque perturbations in at least one direction. Thus, these poses cannot be used in contact tasks. Similarly, it is reasonable to eliminate the poses with manipulability close to zero. As a result, our assumption (2) is reasonable.

Comment 4:

Sec V states that phi and psi, from Eq.13, will be defined later. However, in Sec VI.D, the text refers phi as defined in Eq.13. It is not clear where these quantities are defined.

Answer 4:

The reviewer may misunderstand the sentences at (13), where we said “for later consistency” but not “defined later”. While through re-checking, we find that the definition of Psi is redundant. As a result, simply removing Psi will solve the problem.

Comment 5:

Given that Eq.13 establishes a bound on phi, should the second equals sign in Eq.25 also be a bound?

Answer 5:

Yes, all equations (24-26, 30-36, 38-41, 43-46) are the upper bounds.

Comment 6:

Sec III, mentions a metric in joint space d(.,.) - is this the Euclidean distance?

Answer 6:

Yes. There may be some other manipulator measures, e.g., giving different weights to different joints. A metric satisfying the triangle inequality is proved to be valid for building NCPP problem.

Comment 7:

Is there a way to provide insight into how to interpret the various manipulability thresholds?

Answer 7:

Generally, as the manipulability threshold increases, the number of valid configurations decreases, which makes it more difficult to cover the full surface. So the choice of the manipulability threshold should be as little as possible. In contrast, more tricks may appear in how to find a good relative pose between the manipulator and the object.