A Grasping Configurations manifold: A framework based on dual-quaternions

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***Abstract*—This paper presents a technique to build a manifold from a set of grasping configurations which enables a straightforward interpolation between elements. We exploit the properties of dual-quaternion to describe every grasping configuration and then a structure is built linking all poses based on the Delaunay triangularisation. Generally, an algorithm generates a set of grasping candidates on the object which have the best chance to perform a successful and robust grasp. However, in many cases, slight movements from these cherry-picked candidates have comparable results. Therefore, we propose to develop a manifold of grasping configurations which allows retrieving intermediate poses within the originally selected ones that might be discarded using the grasping configuration algorithm synthesizer. A simulated example shows how our technique interpolates a bunch of grasping configurations.**

I. Introduction

In many industrial settings, moving and manipulating objects is an extremely critic task. In such kind of operations, a robot must choose the most suitable way of grasping an object to perform a trajectory, which accomplishes some precise action.

Generally, when we consider a task, like a "pick and place", we may split an entire action into a few essential steps. In the beginning, an algorithm proposes a set of poses for the gripper which are usually described as the position of the frame attached to the robot's palm or wrist, we refer to them as grasping configurations (GC) or grasping candidates. Then, the robot provided with that information must select a GC and plan a trajectory starting from it to perform the whole task. This collection represents a selection of the best candidates depending on a specific metric which may be either task or gripper dependant. However, in a broad variety of objects, like domestic items, the number of feasible GCs might be infinitely higher, and small changes from a candidate might result in fairly good solution as well.

In the past decades, the robotics community strived to propose better and better solutions to the grasping generation problem. In [9], a one-shot learning grasping algorithm generates possible contact points depending on the local geometry of the object and the structure of the gripper. In [5], the authors train a neural network for obtaining utterly robust GC for a parallel jaw gripper, taking a point cloud as input. Also, many works try to lean on the concept of affordance, namely the implied GCs suggested by the tool's design [2], e.g. the screwdriver handle.

No matter the used approach, representing a GC as the robot end-effector's wrist or palm pose is arguably the most common way to describe any grasping configuration point onto an object. A pose embeds both the object's position and the orientation, although the former has straightforward parametrisation in cartesian space, the latter demands a solid definition to avoid representation's singularities. A very well-known tool that avoid the beforehand told issue is the quaternion, which is quite known in the robotic community.

Generally, position and orientation are used separately one another with the big shortcoming of being hard to combine poses in a straightforward manner. A mathematical tool which allows taking into account both entities is the dual-quaternion. It is an extension of dual-numbers to quaternions and inherits very important properties of quaternions.

At the best of our knowledge, no works so far investigated the beneficial effects of using dual quaternion in the context of defining grasping configurations. Although many algorithms approach the problem of obtaining the structure implied by a set of points, they overlook the orientations component. The main reason behind this focus is understandable considering the major problem of reconstructing an object mesh from a point cloud. One of the most popular algorithms to link points is the Delaunay triangularisation which connect collection points. In this paper, we propose an extension of this approach for integrating dual quaternions rather than just points and we use the inherited SLERP property of dual-quaternions for smoothly interpolating dual-quaternions.

II. Problem Formulation

In this work, we propose to shape every GC as dual quaternion and build a structure based on [13], to make a mesh of all grasping candidates from the projection of the implicit manifold they yield. The dual-quaternion has been proposed by [14], but are seldom used by the robotic community.

A. Quaternions

Quaternions are a well-known methodology for describing orientations and are used in many domains from robotics to animation. Although they are more complex than Euler angles, quaternions are an efficient and robust solution for describing orientations in space.

Mathematically, they extend the complex-number theory to more dimensions and are composed of four parameters. A quaternion is shaped as:

$$\mathbf{q} = w + (x\mathbf{i} + y\mathbf{j} + z\mathbf{k})$$

where x, y and z are scalars and **i**, **j** and **k** are the immaginary vector components.

Among the variety of quaternions' properties, we are interested in their spherical linear interpolation (SLERP), which allows interpolating smoothly and continuously two or more quaternions.

$$s(\hat{t};\mathbf{P},\mathbf{Q}) = \frac{sin\left(\frac{\theta}{2}(1-\hat{t})\right)\mathbf{P} + sin\left(\frac{\theta}{2}\hat{t}\right)\mathbf{Q}}{sin\left(\frac{\theta}{2}\hat{t}\right)}, \hat{t} \in [0,1] \quad (1)$$

where $\mathbf{P}$ and $\mathbf{Q}$ are quaternions, θ is the angle between $\mathbf{P}$ and $\mathbf{Q}$ and $\hat{t}$ is a parameter which normalises the transition.

To improve the efficiency in real-time applications, a second technique, called Quaternion Linear Blending (QLB) linearly interpolates two quaternions. This method is particularly useful when we approach high real-time applications especially involving GPU computations.

B. Dual Quaternion

Dual quaternions are an application of dual numbers[12] to quaternions. For a given pose described by the position vector $p = [p_0, p_1, p_2]$ and the quaternion $q = [w_p, x_p, y_p, z_p]$, we set the dual part as the quaternion $q_d = q$ and the real part as a new quaternion q_r whose w component is set to zero, and the vector p fills the remaining room, $q_r = [0, p_0, p_1, p_2]$.

$$\hat{q} = q_r + q_d\epsilon$$

A remarkable property of dual-quaternion is that they inherit the SLERP feature of quaternions (ScLERP). For a more thoroughly description of dual quaternions and its properties look at [8].

As for the quaternions, [7] proposes an extension of the QLB for dual-quaternions, called Dual quaternion Linear Blending (DLB). It is a direct generalisation of QLB and it might be easily extended to multi dual-quaternion interpolation as:

$$DLB(\mathbf{w};\mathbf{\hat{q}_1},..,\mathbf{\hat{q}_n}) = \frac{w_1\mathbf{\hat{q}_1} + ... + w_n\mathbf{\hat{q}_n}}{||w_1\mathbf{\hat{q}_1} + ... + w_n\mathbf{\hat{q}_n}||} \quad (2)$$

where w are coefficients to scale all the dual-quaternion, and $\sum w = 1$.

C. Delaunay Triangularisation

Given a set of discrete points P in a plane, the triangularisation $\mathcal{M}(P)$ of P is the set of triangles which interconnects all points in P such that no point in P is within the circumcircle of any triangles. This is a very well-known technique that has been introduced by [1]. Although many methodologies exist to compute the Delaunay triangularisation, we adopt a particular technique called the Bowyer-Watson algorithm [13]. It is an incremental algorithm which starts creating a super triangle enclosing all point in P. Then, it iteratively evaluates all points $p \in P$ and builds a new triangle which has as a base one of the already created triangles' side, and as a third vertex the new point p. As the last stage, it removes all triangles whose vertexes are in common with the super-triangle.

III. Proposed Framework

We present a framework to build a GC manifold from a given set of grasping configurations $gc \in \mathcal{G}$, where each gc is described using a dual quaternion. The algorithm has two phases, in the beginning, it creates a mesh which links all dual quaternion using the Delaunay method in section II-C, then the eq. 2 is applied to interpolate poses within a particular triangle. As a result of the Delaunay algorithm, we obtain a mesh $\mathcal{M}$ of triangles, $t \in \mathcal{M}$, which is composed of three dual quaternion $t = [\hat{q_1}\,\hat{q_2}\,\hat{q_3}]^T$. Although several works, [4, 6], extend the Delaunay result to 3 dimensions, in this initial stage we reduce the complexity of the problem projecting the position component of the dual quaternion on the XY plane and dismissing the orientation, so that we can apply the Bowyer-Watson to compute the tree of the obtained 2D points. To generate a new point within a particular triangle, we use the three coefficient described in the DLB equation, whose sum must be 1.0.

In Fig.1, an example of the proposed framework has been implemented using three GC onto a flat surface. Fig.1b shows the sample of interpolation between the three initial poses and on the right most two pictures, the changes of position and orientation due to the interpolation are shown.

A. Known Problems

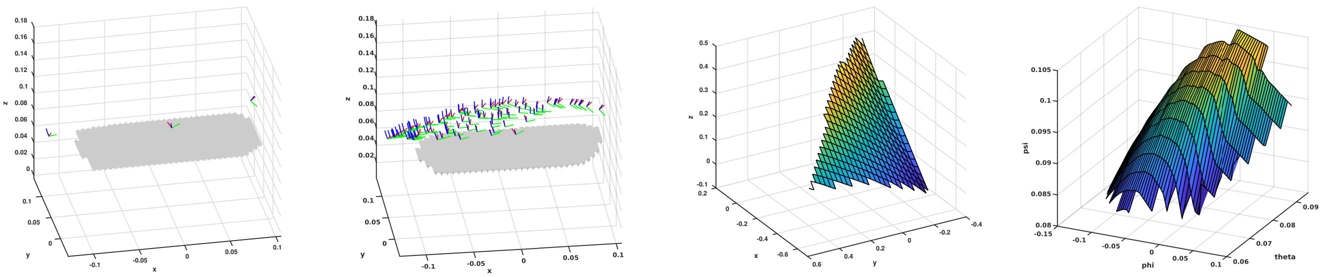
The proposed approach suffer of a few known issues due to the oversimplification we impose to the problem. In particular,

- poses with the same position and different orientation are projected on the same 2D point
- given a set $\mathcal{G}' \subset \mathcal{G}$, composed of all elements with the same x and y, but different z in $\mathcal{G}$. All $gc \in \mathcal{G}'$ are projected on the same 2D point
- Given a triangle t_i of the mesh, the interpolated poses are not linear neither in translation or orientation.

The first two issues are related to the type of algorithm used to make the mesh linking the poses, and a more complex structure may solve them quite easily. As for the latter, it is due to the inherent structure of dual quaternion and the necessity to link continuously both position and orientation. Although this might be a problem when two very far poses are interpolated, the issue is very mitigated considering a local set of grasping configurations which allow little variation in orientation and position. For example, consider the task of picking up a bottle along the side; a grasping synthesiser would propose a finite set of GCs describing the continuous surface whose position changes over the edge, but the orientation has little variation.

IV. Conclusion

In this paper, we propose to create a manifold of grasping configuration from a set of GC generated by a grasping algorithm. To make this structure, we use the Delaunay triangularisation methodology under some assumptions which reduce the complexity of the problem to 2D. The resulting mesh is composed of triangles, and every triangle has dual quaternion as a vertex. Thanks to a linearisation of the ScLERP, we compute all poses which interpolate a given triangle. In the



(a) (b) (c) (d)

Fig. 1: Fig.1a shows three grasping configurations upon a plane surface, each GC is shown using a reference frame. In Fig.1b, the interpolation between the initial tree dual quaternion is visualised. Fig.1c and 1d represent the change of position and orientation during the interpolation respectively. In Fig. 1d, the resulting ZYZ (ψ, ϕ, , θ) paremetrisation is shown for sake of a simple visualisation.

last years, many works address the problem of selecting the best grasping configuration, from a set of given candidates, to optimise a specific objective into the post-grasp trajectory, [3, 10, 11]. In these works, the authors propose to evaluate every GC based on a series of objectives which consider manipulability, force or collision-free along the post-grasp trajectory for the robot. However, the evaluation is within the set of already generated GCs. We, therefore, present this work which goes toward the direction of a continuous manifold to improve the exploration, and it is built on top of a discrete set of GCs.

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