High-performance Proximity Query: An Enabling Technique for Improving Safety of Human-robot Interactive Tasks

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***Abstract*— This short paper presents software library capable of carrying out proximity query (PQ) implemented on graphics processing units (GPUs), which runs on ROS, for detection of collision, as well as calculation of the minimal Euclidean distance between two non-convex objects, namely the robot and the environment. The flexible operation and computation workflow of this GPU-based PQ is introduced, showing its practical values for improving safety of human-robot interactive tasks.**

Index Terms – Graphics processing units (GPUs), haptic feedback, proximity queries (PQs), industrial robot safety.

I. Introduction

Factory automation has been advanced by the increasing use of industrial robots, posing significant impact in manufacturing. Safety of industrial robot manipulation will inevitably be a major concern that has to be well addressed, particularly when the tasks involve human-robot cooperation with the aim to combine the strength of the participants and robots. Motion planning for collision-free robotic trajectory is the prerequisite of tactically keeping robot separated from the participants. Avoidance of collision causing any injury could then be ensured. This safe manipulation involves real-time stereo vision-based sensing of dynamic environment, also due to the human interactive motion. Advances in robot vision and sensing enable to acquire 3D mesh representing the geometric details of environment; however, such mesh data could be highly unstructured and usually large in size.

Proximity Query (PQ) is a general process to compute relative configuration or placement among 3D objects [1], facilitating robots interacting with environment without causing avertible collision. This is also a historical problem in robotics. Numerous methods proposed and classified in two stages of such computation: broad-phase PQ which require objects bounded in a confined volumes such as box [2] and sphere [3] with the aim to offer rough estimation whether few objects are likely being overlapped. It will then be followed by narrow-phase PQ [4] which finds out the shortest distance in between the geometry details, e.g. triangular meshes. Most of the conventional PQ approaches could not be effectively adopted when complicated geometric (non-convex) structures are involved. Besides, computing relative geometric configuration, namely shortest distance, among unstructured meshes to generate robust safety guidance in real-time is a very intensive process, which has not be well-resolve by existing strategies or techniques.

Our proposed PQ approach flexibly implemented on graphics processing units (GPUs) is capable to deal with complicate data hierarchy of collision model, but the representation of unstructured geometry in form of triangular meshes can still be preserved. The new software library of this GPU-based PQ will be soon available on an open-source platform, Robot Operating System (ROS), thus being further tested in different applications.

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II. Work Principle

Only a simple pre-processing procedure is required for defining a continuum structure [5] which is discretized or tessellated as a series of segments tightly enclosing along the robot manipulator. It will represent the robot entity and its configuration will also be flexibly changed in real time based on its updated kinematic chain (**Fig. 1**). Such a procedure could be conducted under ROS. In contrast, the environment structure will then be frequently detected either using passive or active sensing devices/techniques. Note that the resultant structure could be simply represented by the most commonly-used primitive, namely the triangular meshes. The parallel computation of PQ between segments and meshes will then be applied effectively on GPUs.

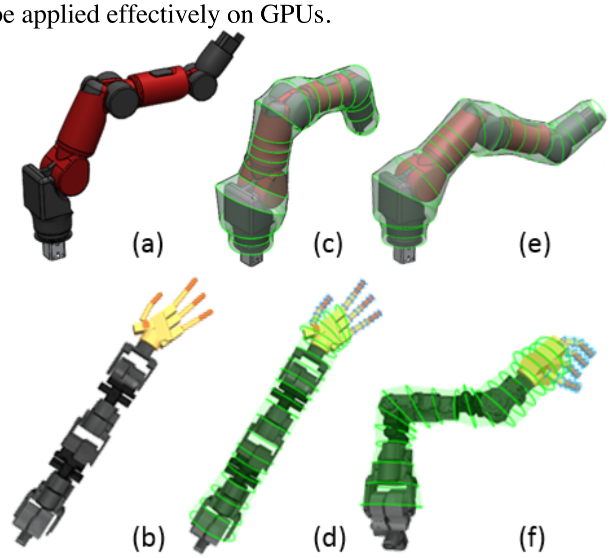

Fig.1. CAD models of the Baxter (a) and ATLAS (b) robot arm with the Sandia Robotic Hand; (c,d) Volumetric pathways comprising twenty segments (in green) tightly enclosing along the corresponding arms; (e,f) The circular contours attached flexibly along with their kinematic configurations updated.

In the segment-to-mesh PQ process, each edge of the triangle mesh acts as an independent entity. The shortest distance between the edge and segment will be first estimated. This finds its way into a rather efficient computational problem by solving such a shortest distance as a convex optimization problem, outperforming conventional approaches that process triangles independently [6]. Plus the use of a customized parallel computation with multiple threads on GPU, which shows >200 times faster than an optimized single core CPU, offering substantial acceleration over the process of PQ can ever be achieved [7]. The previous performance analysis of our PQ algorithm has led to many future explorations of its proper application.

The GPU-based PQ library, which runs on ROS, receives the 3D point clouds and the joint configuration from robot. As depicted in **Fig. 2**, having refreshed the environment mesh and the configuration of the segments enclosing the robot manipulator, the algorithm will instantly affect the corresponding motion planning as result of the computed minimum distances.

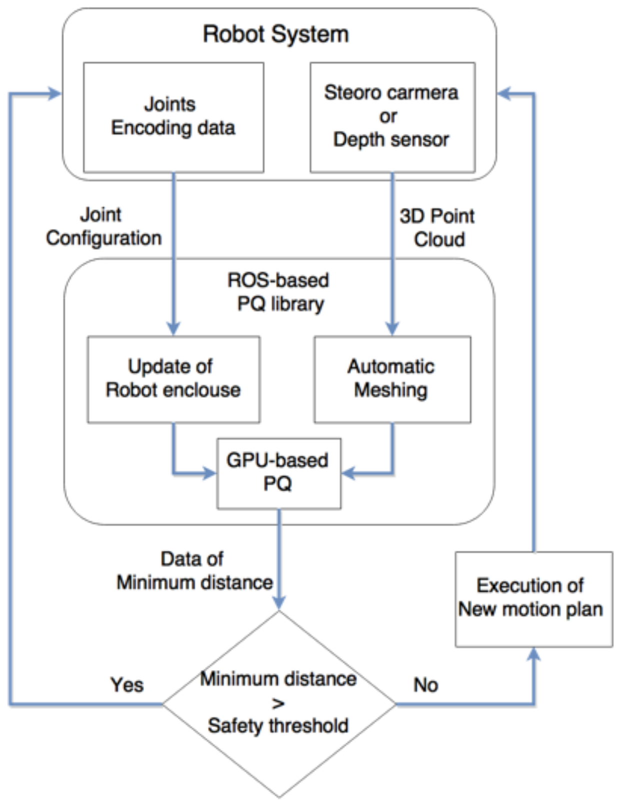

Fig. 2. Schematic diagram showing an example control workflow of using our proposed PQ for a human-robot collaborative task.

III. APPLICATION

A typical scenario of human-robot collaborative task was simulated, as shown in **Fig. 3**. Robots are programmed to avoid collisions with the surrounding objects, operators or environments during its operation. The developed PQ software library is used in applications demanding for safety, not limited to human-robot interactive tasks, but also for surgical robotics [9]. As can be seen in **Fig.3a**, an industrial robot, Baxter (Rethink Robotics), is used to demonstrate a potential application of the GPU-based PQ library proposed. A depth active sensing unit (Xtion Pro Live) is installed at the robot chest for scanning the 3D object in front of the robot workspace. Data of both the robot configuration and the 3D mesh will be sent to the GPU-based PQ library. Given the number of mesh below 10K, the PQ can be mainland at rate above 1kHz. The PQ running on ROS (**Fig.3b**) keeps checking the distances between the robot body and the two operators. The robot motion will be interacted in response to the conditions of such distances below the safety threshold pre-defined. With the advances of object recognition techniques [8], it is envisage that the proposed PQ will allow for smooth and safe collaborative tasks carried out both by human and robot simultaneously.

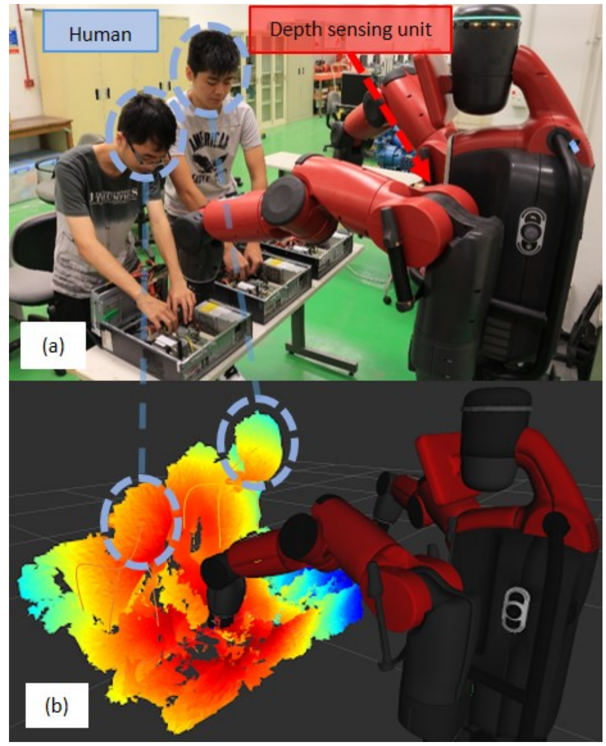

Fig.3. (a) Two operators working on a simulated assembly task which is being assisted by the Baxter robot; (b) A graphic result of GPU-based PQ implemented on ROS. The warmer the colour on the mesh surface, the closer the separation from the robot.

IV. REFERENCE

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