Contact Localization for Transparent Robots using Velocity Constraints

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SUMMARY

Robots operating in unstructured environments must localize contact to detect and recover from failure. For example, Fig. 1 shows a Minitaur robot that must localize where it has unexpectedly contacted the stair's edge so that it can properly step over it. We propose a kinematic method for proprioceptive contact localization using velocity measurements. The method is validated on two planar robots, the quadrupedal Minitaur and the DD Hand gripper, and compared to other state of the art proprioceptive methods. We further show that the method can be extended to spatial robots by fusing the candidate contact points over time with a particle filter.

I. BACKGROUND

In unstructured environments, robots must deal extensively with unexpected contact with unknown objects. It has been common to localize these contacts with exteroceptive sensors such as stereo cameras. However, these sensors are often too inaccurate to perform precise tasks, and perform poorly in cases with poor lighting, feature starvation, or occlusion. Tactile sensors can be used, but have undesired design constraints (bulk and cost) and their resolution scales with the number of sensors, requiring many individual sensors for good precision.

Proprioceptive sensing based contact localization methods can overcome these limitations. With proprioceptive methods, internal robot states, such as joint torques, are measured to detect contact on the robot's body. Position, velocity, and torque signals can all be used to localize contacts. Torque-based contact localization methods [1] are the most popular, but require accurate knowledge of robot dynamics. Uncertainty in parameters, such as friction, can make torque-based contact localization methods inaccurate. Position-based methods [2], rely only on kinematics, but require position measurements to be spaced out in time making them unfavorable for moving contacts, e.g. rolling contact. Velocity-based contact localization methods are less common, but recent work with contact detection on the HyQ robot [3] suggests they hold merit.

II. PROPOSED VELOCITY-BASED METHOD

We propose a generalized extension to the method used by Barasuol *et. al.* [3] for velocity-based contact localization. This extension finds the location of a candidate contact point where the linear velocity of the point is tangent to the robot's surface. The method searches for points that satisfy this velocity constraint and identifies them as candidate points at which contact could have occurred. In many cases, there will only be one unique candidate point.

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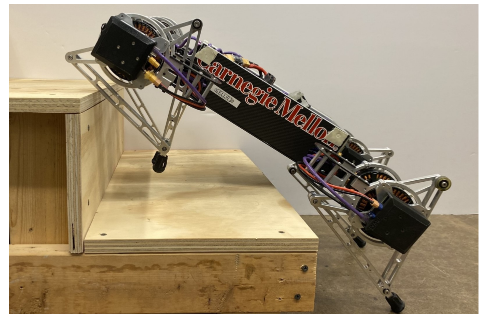

Fig. 1: The velocity of a contact point is constrained to be tangent to the robot's surface. By finding the point on the robot's body that satisfies this constraint, the robot can localize where contact has occurred and properly step over the stair.

This method has the following properties: 1) it provides an instantaneous estimate of contact point locations. 2) It requires no dynamical model of the robot. 3) It can be implemented on existing robots with only joint position and velocity sensors. 4) It uses a velocity constraint to produce a codimension 1 set of possible contact points. For general planar systems, including the legged robot of interest to us, this is sufficient to isolate the contact point to a 0-dimensional set (i.e. an individual point or, if there is ambiguity in shape, a set of possible points). For spatial systems, this produces a 1-dimension set of possible contact points (one or multiple lines). When there are more than one candidate contact point, a particle filter can be used to filter possible contact points over time, and reduce uncertainty of contact location.

III. RESULTS AND DISCUSSION

We evaluate the performance of the velocity-based method and compare it with position and torque-based methods in a simulation of a five-link planar robot. We also demonstrate the velocity based method in hardware experiments with a quadrupedal robot, Minitaur, and a two-finger gripper, DD Hand. We then show a spatial system where uncertainty of contact location is reduced with the help of a particle filter.

REFERENCES

[1] L. Manuelli and R. Tedrake, "Localizing external contact using proprioceptive sensors: The contact particle filter," in *IEEE/RSJ International Conference on Intelligent Robots and Systems*, 2016, pp. 5062–5069.

[2] M. Kaneko and K. Tanie, "Contact point detection for grasping an unknown object using self-posture changeability," *IEEE Transactions on Robotics and Automation*, vol. 10, no. 3, pp. 355–367, Jun. 1994.

[3] V. Barasuol, G. Fink, M. Focchi, D. G. Caldwell, and C. Semini, "On the detection and localization of shin collisions and reactive actions in quadraped robots," *CLAWAR*, 2019.