BIOMIMETIC SENSING FOR ROBOTIC MANIPULATION

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Abstract

by

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In manipulation tasks, humans have the advantage over machines due to an unparalleled ability to process information from various inputs, including touch. A set of four robot end-effectors was equipped with force sensors to provide haptic feedback to aid in performing the manipulation tasks of rotating a sphere and a cube. The motion planning algorithm used to compute the robots' joint angles is called steering-using-piecewise-constant-inputs and is applicable to nonlinear, nonholonomic, driftless systems. Nonholonomic constraints arise during contact, requiring the fingers to only roll relative to the object. However, the algorithm gives rise to new vector fields called Lie brackets that allow the fingers to be reconfigured without releasing the object, effectively increasing the workspace of the manipulation system.

Experiments were conducted with fixed-point manipulation to produce a baseline for comparing reconfigurable manipulation experiments. Both open loop and closed loop, reconfigurable manipulation experiments were conducted on a spherical object. For the open loop cases, the entire trajectory was computed offline and executed on the robots as position commands to each of the joints. For the closed loop cases, the force sensors provided information to a fuzzy controller which periodically checked

the grasp's quality. The force sensors also updated the algorithm with the finger's contact locations.

In both forms, the reconfigurable manipulation experiments increased the system's workspace over that for fixed-point manipulation. Furthermore, the closed loop system proved to be more robust than the open loop system. This was shown by its improved repeatability and its improved performance when rotating about an arbitrary axis.

An approach to switching between faces on a nonsmooth polygonal object while Lie bracketing was verified. To do this requires discernment of the edge, and the sensors used were found to be adequate for this task. In addition, it was shown that end-effectors with a compliant surface could be used to grasp the cube on its edges as an aid in manipulation.

While the experiments were successful, the complexity of performing Lie bracket motions coupled with the small movements they give rise to was not conducive to manipulations requiring large object displacements. However, the method would be applicable for fine-scale, dextrous manipulations.

To my children: That you may continue what we have left right and right what we have left wrong.

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PREFACE

Video clips associated with the discussion herein can be found, for the time being, on the World Wide Web at http://controls.ame.nd.edu/∼npetroff.

ACKNOWLEDGMENTS

We've all heard stories of individuals who, in the face of tremendous adversity, managed to persevere to make themselves rich. I am not one of those individuals. In fact, it's taken help from myriad people to finish this work. The fact that I had access to such knowledgeable and supportive people, however, makes me rich in my own right.

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As you can see, a lot of people deserve credit for helping to make this text a reality. Through it and during the remainder of my career and life, if I've had the good fortune to see further than others it was because I could stand on the shoulders of giants.

FREQUENTLY USED NOMENCLATURE AND VARIABLES

POE	Product of Exponentials
$SUPCI$	Steering Using Piecewise Constant Inputs
$DOFs$	Degrees of Freedom
$\mathbb{R}^n$	n-dimensional Euclidean space
M	a manifold $\in \mathbb{R}^n$
TM	the tangent space of manifold M
p	a point $\in M$
X_p	a tangent vector
C^n	the set of n-times differentiable functions
$SO(3)$	the set of all 3×3 special orthogonal matrices
u_i	control input i
T	tool frame, attached to the manipulator's wrist
S	station frame, attached to the manipulator's base
P	palm frame, global frame-of-reference
F	finger frame, attached to the finger at its center
f	finger frame, attached to the finger at its tip
O	object frame, attached to the object at its center
l_f	local frame on the finger at the point of contact
l_o	local frame on the object at the point of contact
g_i	vector field i
ω	a unit vector $\in \mathbb{R}^3$ in the direction of a rigid-body motion

$\hat{c}$	the skew-symmetric matrix c
ξ	twist, an infinitesimal screw motion
$\hat{\xi}$	matrix version of a twist ξ