Lazy motion planning for robotic manipulators

Citation for published version (APA):

Document status and date:
Published: 27/03/2017

Document Version:
Author's version before peer-review

Please check the document version of this publication:

• A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher’s website.
• The final author version and the galley proof are versions of the publication after peer review.
• The final published version features the final layout of the paper including the volume, issue and page numbers.

Link to publication

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

• Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
• You may not further distribute the material or use it for any profit-making activity or commercial gain
• You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the “Taverne” license above, please follow below link for the End User Agreement:
www.tue.nl/taverne

Take down policy
If you believe that this document breaches copyright please contact us at:
openaccess@tue.nl
providing details and we will investigate your claim.
Lazy Motion Planning for Robotic Manipulators

Alex Andriën, René van de Molengraft, Herman Bruyninckx
Department of Mechanical Engineering, Eindhoven University of Technology
P.O. Box 513, 5600MB Eindhoven, The Netherlands
A.R.P.Andrien@tue.nl M.J.G.v.d.Molengraft@tue.nl H.P.J.Bruyninckx@tue.nl

1 Introduction
Robotic manipulators are making a shift towards mobile bases in both industry and domestic environments, which puts high demands on efficient use of the robot’s limited energy resources. In this work, the problem of reducing energy usage of a robot manipulator during a task is investigated.

Energy reduction is often formulated as an optimization problem, which due to the high dimensionality and nonlinearity of robot manipulators is often computationally expensive. This is avoided by separating the task into two parts and subsequently using feedback linearization and optimization on each part.

2 Approach
Our approach begins with the insight that the original, switched, nonlinear problem consists of two distinct phases, as shown for a planar manipulator with two revolute joints in Figure 1. In phase 1 the manipulator has an unconstrained motion as shown in Figure 1a, until it reaches the surface as in Figure 1b, which we call the switch configuration. In phase 2 manipulator moves from the switch configuration until the final configuration, constrained by the surface.

Using the following feedback linearization (FBL) law with \( u \in \mathbb{R}^n \) a virtual input and

\[
\tau_m = M_p(q)\dot{q} + C(q, \dot{q}) + g_p(q) + u \quad (2)
\]

\[
M_p(q) = M(q) - \hat{M} \in \mathbb{R}^{n \times n} \quad (3)
\]

\[
g_p(q) = g(q) - \hat{g} \in \mathbb{R}^n \quad (4)
\]

chosen so that by combining (1)-(4) we arrive at a linear synthesis of phase 1:

\[
\hat{M}\ddot{q} + \hat{g} = u \quad (5)
\]

and \( q_L \) being the configuration in which the dynamics are feedback linearized.

2.2 Optimization
An optimization problem that reduces energy use is formulated as

\[
\text{minimize} \quad \int_0^{t_f} u^T R u dt \quad (7a)
\]

subject to \( \dot{\hat{M}}\ddot{q} + \hat{g} = u \quad (7b) \)

\[
q(0) = q_0 \quad q(t_s) = q_s \quad (7c)
\]

\[
\dot{q}(0) = \dot{q}_0 \quad \dot{q}(t_s) = \dot{q}_s \quad (7d)
\]

where it is assumed that the begin configuration, \( q_0 \), and velocity, \( \dot{q}_0 \in \mathbb{R}^n \) are known and the switch configuration \( q_s \), and velocity, \( \dot{q}_s \in \mathbb{R}^n \) are to be determined. Since the dynamics are linear and the objective function is convex, the problem can be solved using Pontryagin’s Minimum Principle [2], resulting in the optimal input \( u^* \) as a function of the initial and switch conditions.

By following a similar approach for the second phase, we have optimal inputs for both phases as a function of the initial, switch and final conditions, where the initial and final conditions are assumed to be known, leaving only the switching conditions to be determined. This is done by solving a nonlinear optimization with \( 2(n - 1) + 1 \) variables using a nonlinear solver.

References

![Figure 1: Configurations of a planar manipulator](image)