Clement Petres

Trajectory Planning for Autonomous Underwater Vehicles

A Fast Marching based method for global trajectory planning

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Thesis submitted
for the
Degree of Doctor of Philosophy

Ocean Systems Laboratory, Heriot-Watt University
Department of Computing and Electrical Engineering

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Abstract

Efficient trajectory planning algorithms are a crucial issue for modern autonomous underwater vehicles. Classical trajectory planning algorithms in artificial intelligence are not designed to deal with wide continuous environments prone to currents. Furthermore torpedo-like underwater vehicles are strongly nonholonomic. A novel Fast Marching based approach is proposed to address the following theoretical issues. First, an algorithm called FM* is developed to efficiently extract a 2D continuous and derivable curve from a discrete representation of the environment. Second, underwater currents are taken into account thanks to an anisotropic extension of the original Fast Marching algorithm. Third, the vehicle turning radius is introduced as a constraint on the curvature of the optimal trajectory for both isotropic and anisotropic media. Further developments are proposed to optimize the Fast Marching based method to real-time constraints. On one hand, a fast multiresolution method is introduced to extract suboptimal trajectories. On the other hand, a dynamic version of the Fast Marching algorithm called DFM is developed to efficiently replan trajectories in dynamic unpredictable environments. Besides, it is shown that DFM algorithm is an excellent tool for visibility-based trajectory planning in a-priori unknown domains. The overall Fast Marching based trajectory planning method has been tested on simulated underwater environments and validated on a real experimental platform in open water.

Keywords: artificial intelligence, trajectory planning, Fast Marching algorithm, autonomous underwater vehicle, isotropic and anisotropic ordered upwind methods, functional minimization, curvature radius, unknown environment, multiresolution method, dynamic replanning, visibility-based navigation.

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Many other people contributed to my day-to-day pleasure to come at work, they will recognize themselves!

Table of symbols

C	path (or curve)
s	arc-length parameter
Ω	C-space
x	configuration
$\mathcal{F}$	field of force
$\vec{F}$	vector of a field of force
τ	cost function
ρ	continuous metric
ρ_d	discrete metric
h	heuristic
u	distance function
v	estimate of u
F	speed of the front
f	speed of the vehicle in chapter 5, state transition function in chapter 6
$\|.\|$	absolute value
$\|.\|$	L_2 norm
$\|.\|_\infty$	L_∞ norm
$< .,. >$	dot product in $\mathbb{R}^2$
∇	nabla operator
$\partial/\partial x$, $\partial/\partial y$	partial differential operators
$\vec{T}$	tangential unit vector to a curve
$\vec{N}$	normal unit vector to a curve

Publications and rewards

Most of the material detailed in this thesis has been published in the journal IEEE Transactions on Robotics and in the proceedings of two international conferences:

- Clement Petres, Yan Pailhas, Pedro Patron, Jonathan Evans, Yvan Petillot and Dave Lane, Path Planning for Autonomous Underwater Vehicles, IEEE Transactions on Robotics, vol. 23, issue 2, pp. 331-341, 2007.

- Clement Petres and Pedro Patron, Path Planning for Unmanned Underwater Vehicles, BCS International Joint Conference in Artificial Intelligence, Workshop Planning, Learning in A Priori Unknown or Dynamic Domains, pp. 47-54, Edinburgh, Scotland, August 2005.

- Clement Petres, Yan Pailhas, Jonathan Evans, Yvan Petillot and Dave Lane, Underwater Path Planning Using Fast Marching Algorithms, IEEE Oceans - Europe Conferences, vol. 2, pp. 814-819, Brest, France, June 2005

During his Ph.D. studies the author also carried out some research activities in image processing for retinal images and some consultancy in machine learning for the NATO Undersea Research Center in La Spezia (Italy). Both works have been published in the following international conferences:

- I.Alabboud, G.Muyo, C.Petres, and A.R.Harvey, New spectral imaging techniques for blood oximetry in the retina, SPIE Conference, San Diego, California, USA, August 2007.

- Clement Petres and Patrick Grignan, Applicability of Neural Network Techniques to Underwater Naval Tactics, IEEE Oceans - Europe Conferences, Aberdeen, Scotland, June 2007.

The author also received the 2^{nd} Year Postgraduate Research Prize 2006 from the School of Engineering and Physical Sciences of Heriot-Watt University in recognition of "his research performance during the second year of postgraduate study".

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