

Clement Petres

Trajectory Planning for Autonomous Underwater Vehicles

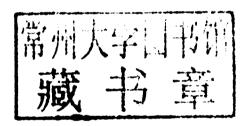
A Fast Marching based method for global trajectory planning



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LAP LAMBERT Academic Publishing

Impressum/Imprint (nur für Deutschland/ only for Germany)

Bibliografische Information der Deutschen Nationalbibliothek: Die Deutsche Nationalbibliothek verzeichnet diese Publikation in der Deutschen Nationalbibliografie; detaillierte bibliografische Daten sind im Internet über http://dnb.d-nb.de abrufbar.

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Coverbild: www.ingimage.com

Verlag: LAP LAMBERT Academic Publishing GmbH & Co. KG Dudweiler Landstr. 99, 66123 Saarbrücken, Deutschland Telefon +49 681 3720-310, Telefax +49 681 3720-3109

Email: info@lap-publishing.com

Herstellung in Deutschland: Schaltungsdienst Lange o.H.G., Berlin Books on Demand GmbH, Norderstedt Reha GmbH, Saarbrücken Amazon Distribution GmbH, Leipzig

ISBN: 978-3-8433-5704-3

Imprint (only for USA, GB)

Bibliographic information published by the Deutsche Nationalbibliothek: The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available in the Internet at http://dnb.d-nb.de.

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Email: info@lap-publishing.com

Printed in the U.S.A.

Printed in the U.K. by (see last page)

ISBN: 978-3-8433-5704-3

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Trajectory Planning for Autonomous Underwater Vehicles

Trajectory Planning for Autonomous Underwater Vehicles

Clément Pêtrès

Thesis submitted for the Degree of Doctor of Philosophy

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

October 5, 2007

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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.

Acknowledgement

First I would like to thank Dr. Katia Lebart because she is the one who introduced me in the Ocean Systems Lab. for the placement that led to this Ph.D. I don't forget the welcome from the G86 team at this period. Jonathan Evans, Kelvin Hamilton and many others were very patient with the French accent.

Of course I would like to thank my supervisor, Dr. Yvan Petillot, for his useful advice, and Dave Lane for his good mood all the time.

I give a particular "thank you" to Yan Pailhas. All the talks with him were extremely interesting. He let me know the existence of the Fast Marching algorithm and he has been a very important partner from the beginning of my stay in Scotland.

I would like to thank Pedro Patron, another close partner in my Ph.D. He translated many ideas into real (and working!) systems. I really appreciated his practical feedback about my trajectory planning theories.

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) arc-length parameter Ω C-space configuration field of force vector of a field of force cost function continuous metric ρ_d discrete metric h heuristic distance function 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 $\langle ... \rangle$ 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 2nd 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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