Proceedings of the 8th IFAC International Conference on
Manoeuvring and Control of Marine Craft
September 16-18, 2009, Guarujá (SP), Brazil

Heuristic Parameter Tuning Procedures for a Virtual Potential Based AUV Trajectory Planner ⋆

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Abstract: This paper deals with the study and analysis of heuristics and tradeoffs incipient in the choice of method-independent parameters in an algebraic trajectory planner based on virtual potentials. The real-time trajectory planning framework for autonomous underwater vehicles (AUVs) is described in detail in Barisic et al. (2007), Barisic et al. (2008) and based on the referenced, as well as previous work of the authors. Of special interest among the parameters are those governing the strength of repulsion of obstacles (Barisic et al. (2007), and that of the strength of the rotary field (Barisic et al. (2008), Healey (2006)) that is introduced in order to eliminate obstacle-attached local minima present in classical virtual potential based methods (Healey (2006)).

Keywords: Unmanned systems, Intelligent control systems, Decentralised control

INTRODUCTION

Algebraic planners and algebra-based mathematical frameworks are prolific in contemporary path-planning and trajectory-planning solutions to AUV navigation problems (Healey et al. (2007), Sepulchre et al. (2005), Kalantar, S. and Zimmer, U. (2007)). This is due to the fact that modern embedded computing systems, used to run the suite of necessary control algorithms to steer AUVs are very efficient at performing algebraic operations. Also, algebraic operations are present at almost any level of abstraction when programming control systems – all the way down to processor assembler mnemonics.

In contrast to the methods used to evaluate inputs and arrive at commands, the input data of algebraical methods are generally at a high level of abstraction. This represents a natural counter-tendency to the control system engineer's choice of an algebraical method as the basis for trajectory planning. However, the strengths of algebraical methods must not be disregarded – high levels of abstraction that makes them easily "readable" by human code designers and system engineers, cross-layer design, great levels of leverage that existing coded capabilities represent for further modules exhibiting even more complex and desirable behavior etc. In order to make a certain algebraic system implementable in a physical AUV system, the demands on high levels of pre-processing or operator deliberation on the nature, range and values of input data need to be addressed.

⋆ This research was made possible by the infrastructure provided to the authors by the EU-funded FP7 Capacities REGPOT-2008-1 project "Developing the Croatian Underwater Robotics Research Potential".

In the broadest sense the inputs of algebraical real time trajectory planning systems can be divided into:

(1) Method-external data: Data dependent on the current real time situation of the AUV system: relative position and orientation of obstacles, AUV's own pose and location etc.
(2) Method-independent data: This data arises in the form of general numbers, like factors or additive terms, or alternatively as a choice of a constrained class of functions (upper and lower bounds vs. insensitivity range, vs. a three-level relay etc.).

There is a large volume of ongoing research dedicated to robust, non-intermittent, efficient, fast and memory-conservative ways to deal with the abstraction or extraction of perceptive and proprioceptive sensory data, i.e. the former. Control engineer's familiarity, leverage that a certain recipe's strengths bring to the overall system design of the whole AUV, and whose weaknesses are in turn leveraged against by other components and capabilities of the chosen systemic design. Some of the candidates for this "recipe" are: Kalman filtering techniques, sequential Monte Carlo methods, Markovian systems, various voting-based systems, Bayesian systems, neural networks, fuzzy logic inference systems, etc.

The latter type of inputs are generally much more difficult to ascertain with any level of consistency. Engineering constraints of the system, including sensor speed, bandwidth, accuracy, actuator dynamic range, energy balance, absolute limits of delivered strength, and stability lead to the formulation of necessary *ranges of values* for these data. However, the procedures to consistently link the values of these data to certain "hard" specifications on the

978-3-902661-51-7/09/$20.00 © 2009 IFAC

10.3182/20090916-3-BR-3001.0032

performance of the AUV, or to arrive at a form of inverse reasoning from desired performance indices to parameter values, are difficult. They turn to be entirely unavailable, prohibitively computationally expensive, intractable, or at the very least extremely reliant on the modeling of the AUV and therefore precariously non-robust.

This problem is exacerbated if generality is pursued, i.e. if the algebraic trajectory planner is being developed as a general platform regardless of the craft's kinematics (configuration of actuators, deliverable thrust, holonomic constraints etc.). This is the case with the virtual potentials based trajectory planner developed by Barisic et al. (2007), Barisic et al. (2008), which is being deployed in systems as varied as an AutoMarine module (Stipanov et al. (2007)) -equipped VideoRay (Miskovic et al. (2007)) as opposed to a Remus off-the-shelf tactical submersible (Healey et al. (2007)). It is critical that an initial heuristic analysis be undertaken. This will serve to narrow the range of values provided by the stability analysis further, so that the available range is non-prohibitive for a system engineer overseeing the deployment of one of the aforementioned craft. The motivation is to arrive at a small number of recipes of values can be deployed to foreseeable use scenarios of certain broad categories of AUV craft.

In Section 1, the proposed virtual potentials based real time trajectory planning method (Barisic et al. (2007), Barisic et al. (2008)) is briefly revisited, examining the method-independent parameters that regulate the influence of the stator and rotor classes of potentials on the trajectory. In Section 2, a heuristic criterion based on actual considerations in operating AUVs in constrained waterspaces and waterways is proposed. In Section 3 an analysis based on MATLAB simulation is undertaken for a set comprised of the most critical independent parameters. In Section 4 conclusions are reached and heuristic recommendations given based on the performed simulation. Work aimed at further optimization of the recommended values is suggested.

1. THE METHOD

Within the proposed virtual potential based trajectory planner, the influence of n obstacles on the AUV trajectory is represented by a summation $E_s(\boldsymbol{p}) = \sum_N^{i=1} f_s^{(i)}$, where each $f_{obs}^{(i)}(\cdot), i = 1 \dots N$ is given by:

$$f_s(\boldsymbol{p}) = \exp\left\{A_s^+ / r[\boldsymbol{p}_{obs}](\boldsymbol{p})\right\} \tag{1}$$

Where:
- $\boldsymbol{p}$ is the vector of point coordinates in the missions space whereat potential is being sampled,
- $r[\boldsymbol{p}_{obs}](\mathbb{R}^n)$ is a function returning the distance between the current AUV's location and the obstacle, parameterized by a representative point of the obstacle $\boldsymbol{p}_{obs}$ (geometric barycenter or some other typical point of the obstacle, e.g. a polygon vertex). These functions vary depending on the shape of the obstacle: a circle, an ellipse, a rectangle or a triangle.
- A_s^+ is a *method-independent static repulsion amplification.*

In Barisic et al. (2008), a modification including rotor potentials was proposed, along the following reasoning:

$$\begin{aligned}
&E_s(\boldsymbol{p}) \to E(\boldsymbol{p}) \\
&\therefore E(\boldsymbol{p}) \doteq E_s(\boldsymbol{p}) + E_r(\boldsymbol{p}) \\
&\qquad = \sum_N^{i=1} f_s^{(i)}(\boldsymbol{p}) + \sum_N^{i=1} f_r^{(i)}(\boldsymbol{p}, \boldsymbol{p}_{AUV}) \\
&\qquad = \sum_N^{i=1} \left[f_s^{(i)}(\boldsymbol{p}) + f_r^{(i)}(\boldsymbol{p}, \boldsymbol{p}_{AUV})\right] \\
&\therefore f_{obj} \doteq f_s + f_r
\end{aligned} \tag{2}$$

The redefinition of $f_{obj}(\cdot)$ from (2), based on Barisic et al. (2008) leads to:

$$f_{obj}(\boldsymbol{p}) = f_s(\boldsymbol{p}) + f_r\left[A_r^+, \boldsymbol{p}_{obs}\right](\boldsymbol{p}, \boldsymbol{p}_{AUV}) \tag{3}$$

Where:
- $f_r\left[A_r^+, \boldsymbol{p}_{obs}\right](\mathbb{R}^n, \mathbb{R}^n)$ is a rotor potential function parameterized by A_r^+ and $\boldsymbol{p}_{obs}$,
- A_r^+ is a *method-independent rotor amplification*,
- $\boldsymbol{p}_{AUV}$ is the coordinate vector of the AUV's current location.

Note that in accordance with Barisic et al. (2008):

$$\begin{gathered}
f_r(\boldsymbol{p}_{AUV}) \equiv 0 \\
\Rightarrow \\
f_{obj}(\boldsymbol{p}_{AUV}) \equiv f_s(\boldsymbol{p}_{AUV})
\end{gathered}$$

The potential field gradient $E(\boldsymbol{p}) = \sum_N^{i=1} f_{obs}^{(i)}$ is numerically approximated on the basis of a finite set of ordered pairs of the evaluations of $E(\boldsymbol{p})$ at p_{AUV} and at each of the points in $\mathcal{P}$, a set of radially spaced equidistant sample points around $\boldsymbol{p}_{AUV}$ at sample distance ϵ and angular increments $2\pi/n_\gamma$: $\mathcal{P} = \left\{\boldsymbol{p}_\epsilon^{(i)}\right\}$ (Barisic et al. (2007)). This leads to the an expression for the *controlling force*. The intention of the AUV's control system being fed by the trajectory planner is thereupon that the subsequent control allocation and the dynamic quality of actuator control reproduce this force as well as possible. The controlling force is bounded (in norm) by a *method-independent maximum force* F_{max}:

$$\boldsymbol{F} = \text{bound}\left\{\max_i\left[E(\boldsymbol{p}) - E\left(\boldsymbol{p}_\epsilon^{(i)}\right)\right] - \mu \cdot \boldsymbol{v}, F_{max}\right\} \tag{4}$$

Where:
- $\text{bound}\left\{\mathbb{R}^n, \mathbb{R}_0^+\right\}$ is a function of bounding a vector's norm, $\text{bound}\{\boldsymbol{a}, a_{max}\} = \boldsymbol{a}/|\boldsymbol{a}| \cdot a_{max}$.

Likewise, the helm speed command, v_c is bounded by a *method-independent maximum speed* v_{max}:

$$\begin{gathered}
v_c = |\boldsymbol{v}_c| \\
\phi_c = \text{atan2}(\boldsymbol{v}_c) \\
\boldsymbol{v}_c = \text{bound}\left\{T/2 \cdot (\boldsymbol{F}(k) - \boldsymbol{F}(k-1)) + \boldsymbol{v}_c(k-1), v_{max}\right\}
\end{gathered} \tag{5}$$

The technical maxima of F_{max} and v_{max} are of course although independent from the method used to plan the trajectory, dictated by the AUV's actuators and their configuration.

From the above analysis of the equations used in trajectory planning, it can be determined that the greatest influence