Guidance for time efficient path following of under-actuated differential thrust AUVs

Xue Jin

The University of Adelaide

South Australia 5005

Australia

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Summary

Autonomous Underwater Vehicles (AUVs) are relatively new underwater devices developed to execute missions in water without human operators. The advancements made in AUV technology have significant implications for a wide range of underwater applications. Guidance and control of AUVs plays an important role in many applications, and it is a challenging research topic, not only because of the significant nonlinearities and couplings in the AUV's dynamics, but the under-actuation found in typical AUVs.

This thesis presents new work contributing to time efficient path following of under-actuated AUVs. Different from the conventional fin-manoeuvred AUVs, the prototype vehicle considered in this thesis is a differential thrust manoeuvred AUV devoid of fins or rudders. Such a manoeuvring feature makes the vehicle very agile, but brings challenges in guidance and control.

A model of the prototype AUV is constructed based on the vehicle dynamics and manoeuvring features. In order to achieve time efficient path following, the AUV should operate at its motion limits. To derive the motion limits, a Monte Carlo analysis is conducted using the AUV model, which provides a numerical solution to derive the maximum admissible

motion of the vehicle with respect to the curvatures along given paths. Thus, a curvature-based guidance system is developed. The strategy alters the AUV path following speed according to the path curvature, hence increasing the overall time efficiency. The effectiveness of the proposed method is demonstrated through simulations of the AUV following a range of different paths.

Declarations

The work presented in this thesis contains no material which has been accepted for the award of any other degree of diploma in any university or other tertiary institution. To the best of the author's knowledge and belief, this work contains no material previously published or written by another person, except where due reference has been made in the text.

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Xue Jin

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Nomenclature

AUV	Autonomous Underwater Vehicle
DOF	Degree of Freedom
CoG	Centre of Gravity
CoB	Centre of Buoyancy
G-frame $\{G\}$	Global frame
B-frame $\{B\}$	Body frame
SF-frame $\{SF\}$	Serret-Frenet frame
$[x \quad y \quad z]$	AUV position w.r.t. X, Y and Z - axis in G-frame
α	Angle of attack
β	Sideslip angle
ψ	AUV heading angle
χ	Course angle
$[\emptyset \quad \theta \quad \psi]$	AUV orientation angle w.r.t. X, Y and Z-axis in G-frame
$[p \quad q \quad r]$	Angular velocity w.r.t. X, Y and Z – axis in B-frame (roll, pitch and yaw)
$[\dot{x} \quad \dot{y} \quad \dot{z}]$	Velocity w.r.t. X, Y and Z - axis in G-frame
$[u \quad v \quad w]$	Velocity w.r.t. X, Y and Z - axis in B-frame
V	Total velocity
R	Radius of curvature
R_e	Reynolds number
C_D	Drag coefficient

C_L	Lift coefficient
D	Drag force
L	Lift force
C_r	Yaw resistance coefficient
$[M_x \quad M_y \quad M_z]$	Moments using differential thrust
$[M_p \quad M_q \quad M_r]$	Rolling, pitching and yawing drag moment
m	Mass
ρ	Fluid density
$[I_{xx} \quad I_{yy} \quad I_{zz}]$	Moment of inertia vector
T	Total (collective) thrust
ΔT	Differential thrust
$\boldsymbol{e}_p$	Deviation vector
Δ	Lookahead distance
K_P	Proportional gain of a PI controller
K_I	Integral gain of a PI controller
k_e	Modulation factor of the steering rate for convergence
MCA	Monte Carlo Analysis
GNC	Guidance, Navigation and Control
LOS	Line of sight
LTA	Line to arc transition
ATL	Arc to line transition