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ADAPTIVE SIMPLIFIED FUZZY LOGIC CONTROLLER FOR DEPTH CONTROL OF UNDERWATER REMOTELY OPERATED VEHICLE

MOHD SHAHRIEEL BIN MOHD ARAS

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Electrical Engineering)

Faculty of Electrical Engineering
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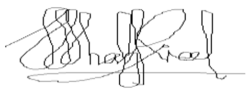
APRIL 2015

I declare that this thesis entitled "*Adaptive Simplified Fuzzy Logic Controller for Depth Control of Underwater Remotely Operated Vehicle*" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : 

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DEDICATION

This project is dedicated to my mom, Mariam binti Mahat, my lovely wife Norzaima binti Zainal Badri and my sons Ammar Zulqarnain, Adam Zahirulhaq and Annas Zulqairy and not forgets to my friends who have always sincerely pray for my success and glory.

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Thank you very much…

ABSTRACT

A Remotely Operated Vehicle (ROV) is one class of the unmanned underwater vehicles that is tethered, unoccupied, highly manoeuvrable, and operated by a person on a platform on water surface. For depth control of ROV, an occurrence of overshoot in the system response is highly dangerous. Clearly an overshoot in the ROV vertical trajectory may cause damages to both the ROV and the inspected structure. Maintaining the position of a small scale ROV within its working area is difficult even for experienced ROV pilots, especially in the presence of underwater currents and waves. This project, focuses on controlling the ROV vertical trajectory as the ROV tries to remain stationary on the desired depth and having its overshoot, rise time and settling time minimized. This project begins with a mathematical and empirical modelling to capture the dynamics of a newly fabricated ROV, followed by an intelligent controller design for depth control of ROV based on the Single Input Fuzzy Logic Controller (SIFLC). Factors affecting the SIFLC were investigated including changing the number of rules, using a linear equation instead of a lookup table and adding a reference model. The parameters of the SIFLC were tuned by an improved Particle Swarm Optimization (PSO) algorithm. A novel adaptive technique called the Adaptive Single Input Fuzzy Logic Controller (ASIFLC) was introduced that has the ability to adapt its parameters depending on the depth set point used. The algorithm was verified in MATLAB® Simulink platform. Then, verified algorithms were tested on an actual prototype ROV in a water tank. Results show it was found that the technique can effectively control the depth of ROV with no overshoot and having its settling time minimized. Since the algorithm can be represented using simple mathematical equations, it can easily be realized using low cost microcontrollers.

ABSTRAK

Kenderaan Operasi Kawalan Jauh (ROV), adalah salah satu daripada kenderaan dalam air tanpa manusia, mempunyai kabel dan mudah dikendalikan oleh jurumudi daripada platform di permukaan air. Bagi kawalan kedalaman ROV, sekiranya ia terlajak daripada had ketetapan kedalaman yang dikehendaki, maka risikonya adalah sangat berbahaya. Jelas sekali, sekiranya ia melebihi had kedalaman yang ditetapkan, kerosakan pada ROV atau pada struktur yang hendak diperiksa boleh berlaku. Penstabilan posisi ROV skala kecil di kawasan kerjanya adalah satu tugas yang sukar, terutamanya apabila ada arus dalam air dan ombak, walaupun dikendalikan oleh jurumudi ROV yang berpengalaman. Projek ini memberi fokus kepada reka bentuk pengawal ROV bagi memastikan ianya stabil dan mengikut kedalaman yang telah ditetapkan tanpa wujudnya lajakan, dengan memiliki masa naik dan masa pengenapan yang pantas. Projek ini bermula dengan permodelan matematik dan empirikal bagi mewakilkan keadaan dinamik sebuah ROV baru dengan diikuti oleh reka bentuk pengawal pintar bagi kawalan kedalaman ROV. Pengawal pintar yang digunakan adalah berdasarkan Pengawal Logik Kabur Satu Masukkan (SIFLC) dimana faktor-faktor yang mempengaruhinya seperti jumlah aturan, penggunaan persamaan linear dan penambahan model rujukan telah dikaji. Parameter yang optima bagi SIFLC telah ditentukan menggunakan algoritma Pengoptimuman Kumpulan Zarah (PSO). Satu kaedah pengawal mudah suai baru telah diperkenalkan iaitu Mudah Suai Pengawal Logik Kabur Satu Masukkan (ASIFLC) yang mempunyai kebolehan menyesuaikan parameternya bergantung kepada nilai kedalaman yang ditetapkan. Pelaksanaan pengawal baru ini telah disahkan menggunakan perisian MATLAB® Simulink. Algoritma ini kemudiannya diuji pada prototaip sebenar ROV di dalam tangki air. Keputusan membuktikan bahawa teknik ini berjaya mengawal ROV dengan berkesan dengan tiada lajakan dan dengan masa pengenapan yang singkat. Oleh kerana algoritma pengawal ini dapat diwakilkan menggunakan persamaan matematik yang mudah, ianya boleh direalisasikan dengan menggunakan pengawal mikro kos rendah.

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LIST OF SYMBOLS

B	–	Vehicle's buoyancy
C	–	Matrix of the Coriolis and centripetal forces
D	–	Vector of forces on vehicle due to drag
g	–	Vector of forces on vehicle due to gravitational effects
Ix, Iy, Iz	–	Moments of inertia around the vehicle's x-,y-, and z- axes respectively
J	–	Euler angle transformation matrix
K, M, N	–	Moment about the vehicle's x-,y-, and z- axis respectively
K_D	–	Derivative gain, a tuning parameter
K_I	–	Integral gain, a tuning parameter
K_P	–	Proportional gain, a tuning parameter
L_{NS}	–	Diagonal line of Negative Small membership function
L_{NL}	–	Diagonal line of Negative Large membership function
L_{PS}	–	Diagonal line of Positive Small membership function
L_{PL}	–	Diagonal line of Positive Large membership function
L_Z	–	Diagonal line of Zero membership function
L	–	Vehicle length
m	–	Vehicle's mass
N_1	–	The minimum costing horizon
N_2	–	The maximum costing horizon
Nu	–	The control horizon
p	–	Roll rate [rad/s]
q	–	Pitch rate [rad/s]
r	–	Yaw rate [rad/s]
$S(t)$	–	Set point trajectory

Tref	–	Speed response
Ts	–	Sampling interval
U	–	Surge speed [m/s]
V	–	Sway speed [m/s]
w	–	Heave speed [m/s]
X, Y, Z	–	Forces parallel to the vehicle's x-,y-, and z- axes respectively
x_B, y_B, z_B	–	Position of vehicle's centre of buoyancy
x, y	–	Horizontal position of vehicle with regard to earth-fixed coordinates
y(k)	–	Plant output
x_G, y_G, z_G	–	Position of vehicle's centre of mass
ym	–	Predicted output of the neural network
yr	–	Reference trajectory
z	–	Depth [m]
η	–	Vector of global vehicle coordinate
Φ	–	Vehicle global roll angle [rad]
Θ	–	Vehicle global pitch angle [rad]
Ψ	–	Vehicle global yaw angle [rad]
λ	–	Main diagonal line slope
µ	–	Degree of membership
ρ	–	The control input weighting factor