ROBUST CONTROLLER TECHNIQUE OF AN AUTONOMOUS UNDERWATER VEHICLE FOR UNDERWATER POLE INSPECTION

by

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LIST OF ABBREVIATIONS

2D	Two-Dimensional
3D	Three-Dimensional
AUV	Autonomous Underwater Vehicle
CPP	Coverage Path Planning
COB	Centre of Buoyancy
COG	Centre of Gravity
DOF	Degree of Freedom
ESC	Electronic Speed Controller
IMU	Inertial Measurement Unit
INS	Inertial Navigation System
LQR	Linear Quadratic Regulator
MFHOSMC	Model Free High Order Sliding Mode Control
PID	Proportional-Integral-Derivative
PVC	Polyvinyl Chloride
PWM	Pulse Width Modulator
RMS	Root Mean Square
ROV	Remotely Operate Vehicle
SMC	Sliding Mode Control

SNAME	Society of Naval Architects and Marine Engineers
TDC	Time Delay Control
USB	Universal Serial Bus
UUV	Unmanned Underwater Vehicle

LIST OF SYMBOLS

a	Filtered acceleration data
A_x	Frontal area of AUV in surge direction
A_y	Frontal area of AUV in sway direction
A_z	Frontal area of AUV in heave direction
B	Buoyancy force acting on AUV
C	Coriolis-centripetal matrix
C_d	Ratio of drag for real object to drag for ideal object
d_f	Filtered IMU data
d_p	Diameter of target pole
d_r	Raw IMU data
D_L	Linear hydrodynamic damping matrix
D_{Lu}	Linear hydrodynamic damping in surge direction
D_{Lv}	Linear hydrodynamic damping in sway direction
D_{Lw}	Linear hydrodynamic damping in heave direction
D_{Lr}	Linear hydrodynamic damping in yaw direction
D_Q	Quadratic hydrodynamic damping matrix
D_{Qu}	Quadratic hydrodynamic damping in surge direction
D_{Qv}	Quadratic hydrodynamic damping in sway direction
D_{Qw}	Quadratic hydrodynamic damping in heave direction
D_{Qr}	Quadratic hydrodynamic damping in yaw direction
e	Vector of tracking error
f_s	Parameter of robust filter
f_l	Parameter of robust filter
F	Earth-fixed forces and moment matrix
F_{LP}	Low pass filter matrix
$F_{LP,x}$	Low pass filter in North direction

$F_{LP,y}$	Low pass filter in East direction
$F_{LP,z}$	Low pass filter in Heave direction
$F_{LP,\psi}$	Low pass filter in yaw direction
g	Vector of gravitational and buoyancy forces
h_c	Height of grid cell
h_p	Vertical height of target pole
h_{FOV}	Vertical field of view of camera
h_M	Metacentric height
i	Direction
I_d	Moment of inertia of the displaced water by AUV
I_z	Moment of inertia of AUV in yaw direction
J	Jacobian transformation matrix
K_D	Derivative gain matrix
K_{Dx}	Derivative gain in North direction
K_{Dy}	Derivative gain in East direction
K_{Dz}	Derivative gain in downward direction
$K_{D\psi}$	Derivative gain in yaw direction
K_P	Proportional gain matrix
K_{Px}	Proportional gain in North direction
K_{Py}	Proportional gain in East direction
K_{Pz}	Proportional gain in downward direction
$K_{P\psi}$	Proportional gain in yaw direction
l	Perpendicular distance between AUV and surface pole
l_h	Trajectory length of horizontal straight line motion across single grid cell
l_v	Trajectory length of vertical straight line motion across single grid cell
l_i	Trajectory length of inclined straight line motion across single grid cell
l_{sh}	Trajectory length of 90° sharp turning across single grid cell

l_{sm}	Trajectory length of circular smooth turning across single grid cell
l_x	Length of AUV in surge direction
l_y	Length of AUV in sway direction
l_z	Length of AUV in heave direction
m	Mass of AUV
M_A	Added mass system inertia matrix
M_{Au}	Added mass of AUV in surge direction
M_{Av}	Added mass of AUV in sway direction
M_{Aw}	Added mass of AUV in heave direction
M_{Ar}	Added moment of inertia of AUV in yaw direction
M_{RB}	Rigid-body system inertia matrix
n	n^{th} sample of data
n_c	Number of column of grid cells
n_r	Number of row of grid cells
N	Torque acting on AUV in yaw direction
q	Vector of equivalent disturbance
Q	Quality factor of robust filter
r	Radius of target environment
t_h	Inspection time of horizontal straight line motion across single grid cell
t_v	Inspection time of vertical straight line motion across single grid cell
t_i	Inspection time of inclined straight line motion across single grid cell
t_{sh}	Inspection time of 90° sharp turning across single grid cell
t_{sm}	Inspection time of circular smooth turning
T	Sampling time
u	Input signal given to thruster
u_N	Vector of nominal control signal
u_R	Vector of robust compensating signal
V	Total volume of AUV

V_d	Volume of water displaced by AUV
w	Body-fixed environmental disturbances
w_c	Width of grid cell
w_{FOV}	Horizontal field of view of camera
W	Earth-fixed environmental disturbances
W_a	Weight of AUV
x	Position of AUV in North direction
x_d	Desired position of AUV in North direction
X	Force acting on AUV in surge direction
y	Position of AUV in East direction
y_d	Desired position of AUV in East direction
Y	Force acting on AUV in sway direction
z	Position of AUV in downward direction
z_d	Desired position of AUV in downward direction
Z	Force acting on AUV in heave direction
α	Rate of change of output force with respect to input signal
α_1	Root matrix of characteristic equation
α_2	Root matrix of characteristic equation
β	The value of input signal when the output force is 0 N
γ	Output of fuzzy logic controller
η	Earth-fixed positions and orientation matrix
η_d	Desired Earth-fixed positions and orientation matrix
η_{th}	Efficiency coefficient of thruster-hull interaction
θ	Angle of AUV in pitch direction
ρ	Density of fresh water
τ	Body-fixed forces and moment matrix
τ_B	Force generated by back thruster
τ_C	Force generated by centre thruster
τ_F	Force generated by front thruster

τ_L	Force generated by left thruster
τ_R	Force generated by right thruster
ν	Body-fixed linear and angular velocities matrix
ϕ	Angel of AUV in roll direction
ψ	Angle of AUV in yaw direction
ψ_d	Desired angle of AUV in yaw direction
ω_n	Undamped natural frequency

KAEDAH PENGAWAL TEGAP UNTUK KENDERAAN BAWAH AIR BERAUTONOMI BAGI PEMERIKSAAN TIANG BAWAH AIR

ABSTRAK

Pelantar luar pantai untuk minyak dan gas menghadapi masalah pertumbuhan organisma marin yang tidak diingini. Pemeriksaan berkala pada tiang pelantar yang terendam dalam air diperlukan. Kajian ini menyelidik kemungkinan untuk melibatkan Kenderaan Bawah Air Berautonomi (AUV) bagi aplikasi pemeriksaan tiang bawah air. Laluan pemeriksaan diperlukan untuk meningkatkan kecekapan AUV di dalam misi pemeriksaan. Sebaliknya, teknik pengawal tegap diperlukan untuk menyekat kesan ketidaktentuan dalam parameter hidrodinamik dan gangguan luaran pada sistem AUV. Sebagai jalan penyelesaian, kajian ini mencadangkan satu laluan pemeriksaan yang mempunyai masa pemeriksaan optimum untuk pemeriksaan tiang yang tegak dengan menggunakan Perancangan Laluan Liputan (CPP) berasaskan grid. Sebuah peta satah telah dimodelkan untuk mewakili ruang 3D dalam aplikasi pemeriksaan tiang. Lima corak laluan pemeriksaan telah direka dan dibandingkan untuk memilih laluan pemeriksaan yang terbaik. Selain itu, pengawal tegap yang menggabungkan teknik kawalan penapis dan teknik kawalan logik kabur telah dicadangkan. Teknik kawalan penapis digunakan untuk mengimbangi kesan jisim tertambah, kesan redaman hidrodinamik, ketaklelurusan model, kesan gandingan, dan gangguan luaran pada sistem AUV, manakala teknik kawalan logik kabur digunakan untuk memperbaiki daya kawalan. Selain itu, sebuah AUV berbentuk kotak yang sesuai dengan aplikasi pemeriksaan tiang telah dibangunkan untuk mengesahkan prestasi pengawal yang dicadangkan. Laluan pemeriksaan yang dicadangkan direka berdasarkan gerakan Boustrophedon dengan pusingan lancar dan