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Modeling & Simulation of Autonomous Underwater Vehicles - AUV Dynamics

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Abstract: An autonomous underwater vehicle (AUV) is a robot that travels underwater without requiring input from an operator. AUVs constitute part of larger group of undersea systems known as unmanned underwater vehicles, a classification that includes non-autonomous remotely operated underwater vehicles (ROVs) - controlled and power from the surface by an operator/pilot via an umbilical or using remote control. In military applications, an AUV is more often referred to as an unmanned underwater vehicle (UUV). Underwater gliders are a subclass of AUVs.

Keywords: *Underwater Vehicle, Robot, Unmanned Vehicle, Intelligence.*

1. Introduction

Unmanned Undersea Vehicle UUV's Missions are

- Intelligence, surveillance, and reconnaissance
- Main countermeasures
- Anti-submarine warfare
- Inspection/identification
- Oceanography
- Communication/navigation network nodes
- Payload delivery
- Information operations
- Time-critical strikes

The plan divided all UUVs into four classes.

- Man – portable vehicles class: 25-100 lb displacement; 10-20 hours endurance; launched from small water craft manually (i.e., MK 18 MOD 1 Swordfish UUV).
- Lightweight vehicle class; **up to 500 lb** displacement, **20-40 hours** endurance; launched from **RHIB** using launch – retriever system or by cranes from surface ships (i.e., Mk 18 Mod 2 Kingfish UUV).
- Heavyweight vehicle class**; up to 3,000 lb** displacement, **40-80 hours** endurances; launched from **submarines**.
- Large vehicles class**; up to 10 long tons** displacement; launched from **surface ships and submarines**.

Vehicle designs

Hundreds of different AUVs have been designed over the past 50 or so years, but only a few companies sell vehicles in any significant AUVs on the international market, including Kongsberg maritime, HII (formerly Hydroid, and previously owned by Kongsberg maritime). Bluefin Robotics, Teledyne Gavia (previously owned by Hafmynd), International Submarine Engineering (ISE) Ltd, Atlas Elektronik, RTsys and oceanscan.

Vehicles range in size from man portable lightweight AUVs to large diameter vehicles of over 10 meters length. Large vehicles have advantages in terms of endurance and sensor payload capacity; smaller vehicles benefit significantly from lower logistics (for example: support vessel footprint; launch and recovery systems.

2. Literature Survey

Path Planning and obstacle avoidance for AUV

The objective of this paper was to give an overview about AUV and comparisons between different path planning algorithms. Introduction is briefly described with all the references mentioned. Comparison of different algorithms is made in view of advantages and disadvantages, improvements and the references used while doing this comparison. Path planning methods of AUV are mainly divided into two categories: global path planning with known static obstacles and local path planning with unknown and dynamic obstacles.

When there is a global map about everything including obstacles before planning a path, e.g., the location and contour of static obstacles can be measured or obtained beforehand, AUV can use this information to find a collision-free path between the starting point and the target point in advance with global path planning methods.

This paper explains and compares the algorithms which are A* Algorithm, Genetic Algorithm, Ant Colony Optimization, Particle swarm optimization, fuzzy logic algorithm, neural networks, reinforcement and deep reinforcement learning.

This paper introduced the kinematic and dynamic model of AUV and also described well about the ways at which each algorithm works. The fuzzy logic algorithm was shown to be robust in dealing with practical problems and has been widely used in AUV to avoid unknown and dynamic obstacles.

The fuzzy logic algorithm was shown to be robust in dealing with practical problems and has been widely used in AUV to avoid unknown and dynamic obstacles. It does not need an accurate mathematical model, and is suitable for solving highly complex and nonlinear problems.

Traditional neural networks need to collect samples before learning, which is a very time consuming process and might be difficult or even impossible in many situations for AUV path planning. AUV with reinforcement learning can plan an optimal path without any prior knowledge and work well in complex and fully uncertain environments.

Deep reinforcement learning further implements an end-to-end learning to map the original sonar image to the action of AUV

Research Progress of Path Planning Methods for Autonomous Underwater Vehicle

In this paper, they gave a brief detail about the development and application of various path planning algorithms in the present time mentioning its advantages and disadvantages of various algorithms.

This paper even analyzed how to deal with the complex underwater environment which adds some limits to AUV path planning algorithms.

This paper also discusses the development direction of AUV path planning algorithm. They have given detailed explanation about Swarm Intelligence Algorithms which include Particle swarm optimization and Ant Colony optimization with comparative charts and evolutionary algorithms and human inspired algorithms. Dijkstra algorithm is also described. A* and D* Lite algorithms have been explained.

All the algorithms explained have been proved with comparison charts and graphs. They mentioned that time-varying ocean currents, special obstacles, multi-objective constraints, and practicability will be the problems that AUV path planning algorithms need to solve. This paper mentions that the study is still under simulation stage due to the limitations of the experimental conditions.

Based on the introduction of typical environment modelling methods, the development of path planning technology is introduced in detail, and the advantages and disadvantages of various path planning algorithms are summarized.

The AUV path planning needs to consider the uncertainties and dynamic characteristics of the environment, real-time performance, effectiveness, and optimality of the planning algorithm. This paper states that AUV path planning cannot be solved simply by using a certain algorithm, and it must be handled flexibly according to the actual situation.

This paper gives very detailed and clean explanation about all the algorithms of path finding in AUV with its advantages and disadvantages.

Stochastic Optimization-Aided Energy-Efficient Information Collection in Internet of Underwater Things Networks

In this paper, they have proposed a heterogeneous AUV-aided information collection system with the aim of maximizing the energy efficiency of Internet of Underwater Things(IoUT) nodes taking into account AUV trajectory, resource allocation, and the Age of Information (AoI). Moreover, based on the particle swarm optimization (PSO), they have obtained the trajectory of AUVs with low time complexity.

And, a two-stage joint optimization algorithm based on the Lyapunov optimization is constructed to strike a tradeoff between energy efficiency and system queue backlog iteratively. Based on the PSO algorithm, we addressed the issue of avoiding the risk of vortexes and obtained an AUV trajectory with low time complexity. For the sake of maximizing the energy efficiency, a Lyapunov-based technique was applied to adjust the transmission power and AUV's computational capability under the constraints of queue stability.

In their simulation, they have considered a 400 m×300 m underwater rectangular region, where five IoUT nodes are deployed at regular intervals, which they have kept as 50m, and the positions of the vortexes are randomly generated.

In this paper they have simulated their concept and proved that the performance of MEN ($\omega 1 = 0.9$) scheme has better energy efficiency than the MEA ($\omega 1 = 0.1$), MTES ($\omega 1 = 0.5$) and Greedy based algorithms. They have clearly proved it with suitable graphs and charts. Both V value (which is weighted parameters) and the weight factors portrayed the tradeoff between energy efficiency and queue stability. They mentioned that it can be improved that the data arrival rate to reduce the average AoI (Age of Information) in the condition of relatively small V.

The basic important things for underwater vehicles have

- Sensors
- Navigation
- Propulsion
- Communications
- Power

Sensors

AUVs carry sensors to navigate autonomously and map features of the ocean. Typical sensors include compasses, depth sensors, side scan and other sonar's, magnetometers, thermistors and conductivity probes. Some AUVs are outfitted with biological sensors include fluorometers (also known as chlorophyll sensors), turbidity sensors, and sensors to measure Ph, and amounts of dissolved oxygen.

Navigation

Radio waves cannot penetrate water very far, so as soon as an AUV dives it loses its GPS signal. Therefore, a standard way for AUVs to navigate underwater is through dead reckoning. Navigation can however be improved by using an underwater acoustics positioning system. When operating within a net of sea floor deployed baseline transponders this is known as LBL navigation.

Propulsion

There are a couple of propulsion techniques for AUVs. Some of them use a brushed a brush-less electric motor, gearbox, lip seal, and a propeller which may be surrounded by a nozzle or not. All of these parts embedded in the AUV construction are involved in propulsion. Other vehicles use thruster unit to maintain the modularity. Depending on the need, the thruster may be equipped with a nozzle for propeller collision protection or to reduce noise submission or it may be equipped with a direct drive thruster to keep the efficiency at the highest level and the noises at the lowest level. Advanced AUV thruster has a redundant shaft sealing system to guarantee a proper seal of the robot even if one of the seals fails during the missions.

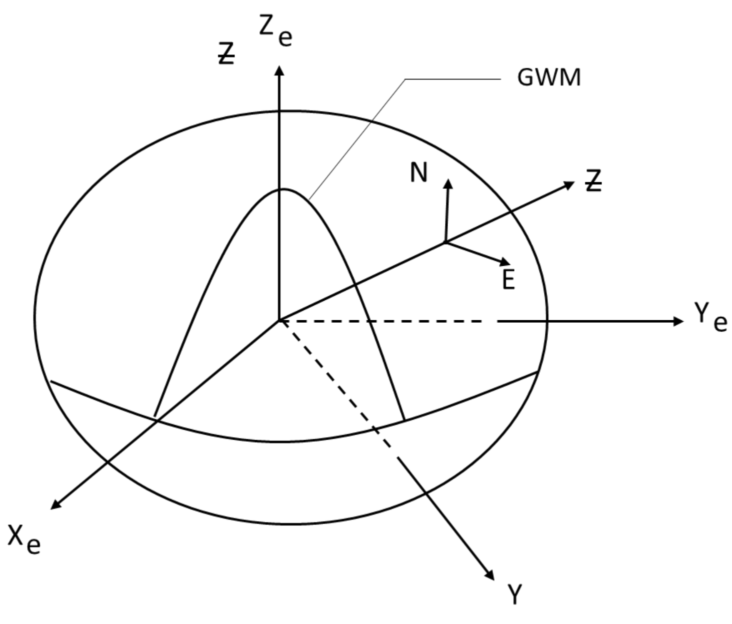
Communications

Since radio waves do not propagate well under water, many AUV's incorporate Acoustic Moderns to enable remote command and control. These moderns typically utilize proprietary communications techniques and modulation schemes. In 2017, NATO ratified the ANEP-87 JANUS standard for subsea communications. This standard allows for 80 BPS communications links with flexible and extensible message formatting.

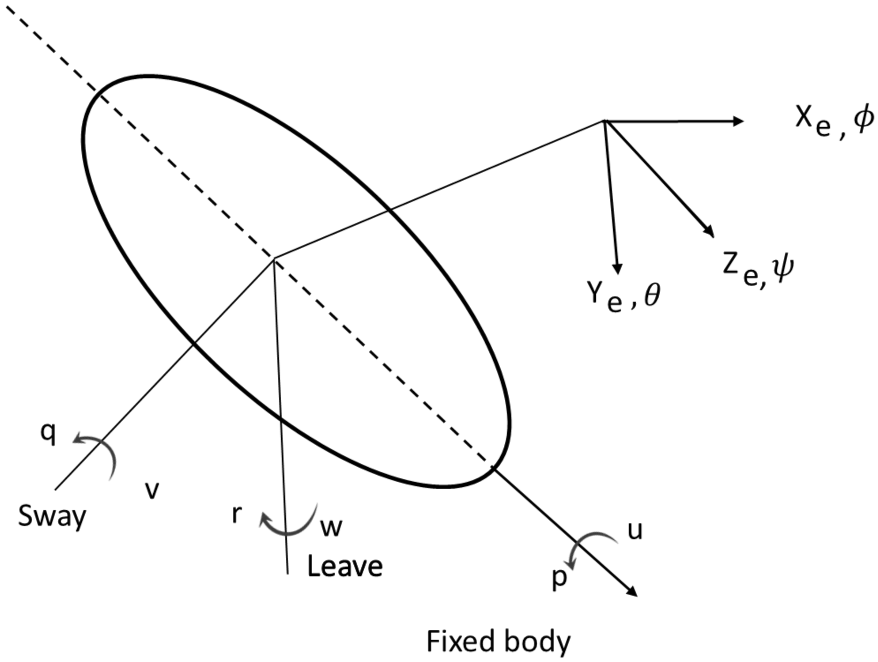
Power

Most AUVs in used today are powered by rechargeable batteries (lithium ion, lithium polymer, nickel metal hydride etc.), and are implemented with some form of Battery Management System. Some vehicles use primary batteries, which provide perhaps twice the endurance-at a substantial extra cost per mission. Previously some systems used aluminum based semi-fuel cells, but these require and produce waste product that must be handled safely. An emerging trend is to combine different battery and power systems with super capacitors.

3. General Model Structure of AUV



Navigational Frame



X_e, Y_e, $Z_e$each fixed with X_e, $Y_e$plane in the water surface $Z_e$down in the ocean. Each fixed time it's measured to CB of the AUV. If , ψ, θ are equal to zero then X, Y, Z will be parallel to X_e, Y_e, Z_e.

X_f, Y_f, Z_f fixed with respect to Fluid, which can be with constant Velocity [u_f, v_f, w_f] relative to each fixed frame always.

ϕ , ψ, θ => Euler angles.

Adopted Euler angles were to reference frame to referred body frame, following Z-Y-X [3-2-1] notation sequence, So

$T_e \xrightarrow[\psi]{u_3} T_1$ [First Rotation]

$T_1 \xrightarrow[\theta]{u_2} T_2$ [Second Rotation] $\quad {}^{b}_{e}T\uparrow$ Equation 1

$T_2 \xrightarrow[\emptyset]{u_1} T_b$ [Third Rotation]

$$T(\emptyset,\psi,\theta) = \begin{bmatrix} cos\psi cos\theta & sin\psi cos\theta & -sin\theta \\ cos\psi sin\theta sin\emptyset - sin\psi cos\emptyset & sin\emptyset sin\psi sin\theta + cos\emptyset cos\psi & sin\emptyset cos\theta \\ cos\emptyset cos\psi sin\theta + sin\emptyset sin\psi & cos\emptyset sin\psi sin\theta - sin\emptyset cos\psi & cos\emptyset cos\theta \end{bmatrix} \quad \text{Equation 2}$$

$$\begin{bmatrix} u \\ v \\ w \end{bmatrix} = T(\emptyset,\psi,\theta) \begin{bmatrix} X^o \\ Y^o \\ Z^o \end{bmatrix} \Rightarrow Transform\ global\ relocator\ vector\ to\ local\ relocator\ vector \quad \text{Equation 3}$$

Parallelly,

$$\begin{bmatrix} \overset{0}{\phi} \\ \overset{0}{\psi} \\ \overset{0}{\theta} \end{bmatrix} = \begin{bmatrix} 1 & \sin\phi \tan\theta & \cos\phi \tan\theta \\ 0 & \cos\phi & -\sin\phi \\ 0 & \sin\phi / \cos\theta & \cos\phi / \cos\theta \end{bmatrix} \begin{bmatrix} p \\ q \\ r \end{bmatrix}$$

Eqn 4

Model

- Environment disturbance model in which sea water generated due to wind and sea current.
- These will be addictive and multiplicative to the Eqn 3

Transformation from body frame (T_b) to sea current frame (T_w) using orientation angle of α and β is

$$T_b \xrightarrow[u_2]{-\alpha} T_1$$

$$T_1 \xrightarrow[u_3]{\beta} T_w$$

Eqn 5

$$T \overset{w}{\underset{b}{\uparrow}} = R_2(-\alpha) \times R_2(\beta)$$

$$= \begin{bmatrix} \cos\alpha \cos\beta & -\cos\alpha \sin\beta & -\sin\alpha \\ \sin\beta & \cos\beta & 0 \\ \sin\alpha \cos\beta & -\sin\alpha \sin\beta & \cos\alpha \end{bmatrix}$$

Eqn 6

The current velocity components assumed to be fixed delegate to axis fixed on earth. This enables fluid fixed axes as Inertial frame of reference

△ uv velocity with respect to Sea i>

$$\vec{V}_{w \uparrow b} = \vec{V}_{e \uparrow b} - \vec{V}_{e \uparrow w} \longrightarrow$$

Eqn 7

The dynamic pressure were

$$Q_d = \frac{1}{2} S V^2_{b/w} \longrightarrow$$

Eqn 8

4. On First Simplification

Sea current ignore

Wind generated wave phenomenon Ignore

⇨ **Only focus on motion**

Apply Newton's law

Conservation of linear and angular momentum

Forces [F] and Momentum [M] referred to body CG.

$$\bar{F} = d/dr\,[m\bar{v}]$$

$$\bar{M} = d/dr\,[\vec{H}] \longrightarrow$$

Eqn 9

$\bar{F}$ = Sum of all externally applied forces

$\bar{M}$ =Sum of all externally applied Torques

M ➔△ uv Mass assumed to be constant for Initial Simulator

$$\bar{F} = \bar{F}_0 + \triangle F = m\,d/dt\,[\bar{V}]$$

$$\bar{M} = \bar{M}_0 + \triangle M = d/dt\,[\bar{H}] \longrightarrow$$

Eqn 10

F_0, M_0 equilibrium values. This means unaccelerated motion along a straight path. During this phase Linear Velocity vector relative to fixed space is Invariant and angular velocity which will be zero.
So F_0 and M_0 can be zero.

Since Earth fixed axis system is called as directed force of reference

$$\Delta F = m\frac{d}{dr}[\overrightarrow{v_T}]_E \longrightarrow$$

Eqn 11

$$\Delta M = \frac{d}{dr}[H]_E$$

$$\vec{F} = mv\left(\overline{\frac{dv}{df}}\right)_b + \omega \underset{a}{\overset{e}{\uparrow}} + m\bar{v} \longrightarrow$$

Eqn 12

Wex $w \underset{b}{\overset{e}{\uparrow}}$ is angular velocity of AUV with respect to earth fixed.

From Eqn 12 an explanation is obtained

$$\vec{F} \Rightarrow F_x = x = m[\mathring{u} + q\omega + r\vartheta]$$
$$\vec{F} \Rightarrow F_y = y = m[\mathring{\vartheta} + ru - p\omega]$$
$$\vec{F} \Rightarrow F_z = z = m[\mathring{\omega} - qu + p\vartheta]$$

Eqn 13

From Eqn 13 $\longrightarrow$

$$\mathring{u} = \frac{F_x}{m} - q\omega + r\vartheta$$

$$\mathring{\vartheta} = \frac{F_y}{m} - ru + p\omega$$

$$\mathring{\omega} = \frac{F_z}{m} - p\vartheta + qu \longrightarrow$$

Eqn 14

Parallelly,
Momentum equation to be transformed from body fixed frame to Earth fixed frame.

$$\bar{M} = d/dr\,[\bar{I}\ \ \bar{w}\,\overset{e}{\underset{b}{\uparrow}}]_e \longrightarrow$$

Eqn 15

$$= d/dt\,[\bar{I}\ \ w\,\overset{e}{\underset{b}{\uparrow}}]_{Bary} + \bar{w}\,\overset{e}{\underset{b}{\uparrow}}\ X\ [\bar{I}\ \ \bar{w}\,\overset{e}{\underset{b}{\uparrow}}] \longrightarrow$$

Eqn 16

On expanding,

$$\vec{M} = \begin{cases} M_x = k = I_{x\mathring{p}} - I_{yz}(q^2 - r^2) - I_{zx}(\mathring{r} + pq) - I_{xy}(\mathring{q} - rp) - (I_y - I_z)\,qr \\ M_y = m = I_{y\mathring{q}} - I_{zx}(r^2 - p^2) - I_{xy}(\mathring{p} + qr) - I_{yz}(\mathring{r} - pq) - (I_z - I_x)\,rp \\ M_z = n = I_{z\mathring{r}} - I_{xy}(p^2 - q^2) - I_{yz}(\mathring{q} + rp) - I_{zx}(\mathring{p} - qr) - (I_x - I_y)\,pq \end{cases} \longrightarrow$$

Eqn 17

Where, k= Rolling moment

M= Pircing moment

N= yawing moment

The inertial Matrix

$$I = \begin{bmatrix} I_{xx} & -I_{xy} & -I_{xz} \\ -I_{xy} & I_{yy} & -I_{yz} \\ -I_{xz} & -I_{yz} & I_{zz} \end{bmatrix} \longrightarrow$$

Eqn 18

Parallelly Symmetry is assigned along XY, XZ planes,

$$I_{xy} = I_{yz} = I_{xz} = 0 \qquad I_y = I_z$$

with this assumption,

$$M_x = I_x \mathring{p}$$
$$M_y = I_y \mathring{q} - (I_z - I_x) rp$$
$$M_z = I_z \mathring{r} - (I_x - I_y) pq$$

Eqn 19

From given,

$$\mathring{p} = \frac{M_x}{I_x}$$
$$\mathring{q} = \frac{[\, M_y + (I_z - I_x)\, rp \,]}{I_y}$$
$$\mathring{r} = \frac{[\, M_z + (I_x - I_y)\, pq \,]}{I_z}$$

Eqn 20

The derivative of Eular Angle is determined as

$$\mathring{\psi} = \frac{q \sin \phi + r \cos \phi}{\cos \theta}$$
$$\mathring{\theta} = \frac{q \cos \phi - r \sin \phi}{1}$$
$$\mathring{\phi} = p + (\, q \sin \phi + r \cos \phi) \tan \theta$$

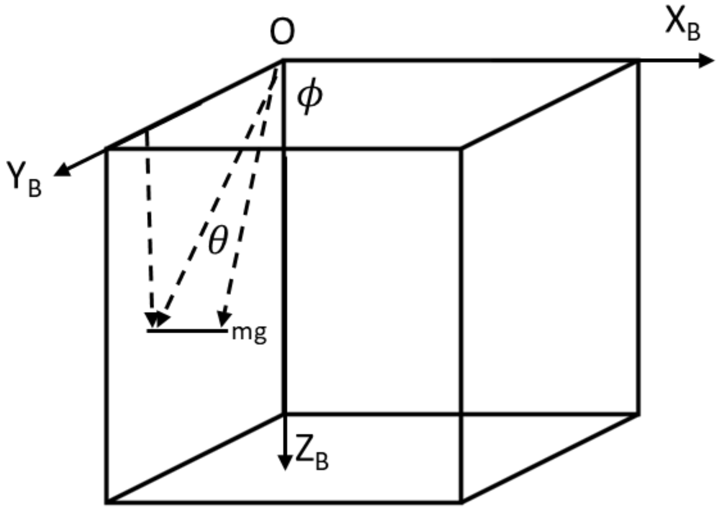
Eqn 21

Gravity forces:

➢ 3 components (I_x ,I_y ,I_z) on body frame.

- I_x ,I_y ,I_z depends as attitude on AUV relative to Initial frame
- Gravitational force acting on AUV will be expressed in terms of Earth axes. With respect to this axis, gravity vector is directed along Z_e axis.

Sign Conventions:



Orientation of gravity vector w.r.t body axis system

θ xy axis pitch angle between gravity vector and Y_b Z_b plane.
θ positive when NUV of AUV goes up
ϕ roll angle between Z_b axis and projection of gravity on Y_b Z_b plane.
Gravity vector solved into components using force

$$I_x = mg \sin(+\theta) = -\ mg \sin\theta$$
$$I_y = mg \cos(-\theta) \sin\phi = mg \cos\theta \sin\phi$$
$$I_z = mg \cos(-\theta) \cos\phi = mg \cos\theta \cos\phi$$

$\longrightarrow$

Eqn 22

Adding above to external force acting on AUV

$$X = F_x + g_x$$
$$Y = F_y + g_y$$

$\longrightarrow$

Eqn 23

Adding equation 22 and 23 the force equation becomes

$$F_x = m\,[\,u + qw - rv + g\sin\theta\,]$$

$$F_y = m\,[\,v + ru - pv - g\cos\theta\,\sin\phi\,]$$

$$F_z = m\,[\,w - qu + pv - g\cos\theta\,\cos\phi\,]$$

Eqn 24

When AUV is submerged in a fluid under the effect of gravity two forces act as the vehicle, i.e., gravitational force and buoyant axis called hydro static effect.

The buoyant force acting on centre of Buoyancy will be represented in body fixed frame. It can be recognized that the difference between gravity and buoyancy (W-B) affects the linear force acting on the vehicle.

Apply hydro static efficient to force equation 24 can be evaluated as

$$F_x = m\,a_{xg} = m[\,\mathring{u} + qw - rv] + (W\text{-}B)\sin\theta$$

$$F_y = m\,a_{yg} = m\,[\,\mathring{v} + ru - pw] - (W\text{-}B)\cos\theta\,\sin\phi$$

$$F_z = m\,a_{zg} = m\,[\,\mathring{w} - qu + pv] - (W\text{-}B)\cos\theta\,\cos\phi$$

Eqn 25

Parallely apply hydrostatic moment coefficients to eqn 19 we get,

$$M_x = I_x\,\mathring{p} + (Z_gW - Z_bB)\cos\theta\,\sin\phi$$

$$M_y = I_y\,\mathring{q} - (I_z - I_x)\,rp\,(Z_gW - Z_bB)\sin\theta$$

$$M_z = I_z\,\mathring{r} - (I_x - I_y)\,pq$$

Eqn 26

Represented hydrostatic term in equation 25 and 26

Hydrodynamic forces and moments: (To get)

Force coefficients CF_x, CF_y, CF_z

Static moment coefficients $CMSF_x$, $CMSF_y$, $CMSF_z$ for predefined AUV geometry.

The coefficients are calculated due to parameters of δ_e, δ_r, α, β and $V_{b/w.}$

Added Mass and Inertia:

Density of water is comparable with density of vehicle like AUV. AUV when moving in water, Additional inertia of water surrounding the body gets accelerated, which requires a force. This force is added mass contributions. This added mass is a function of AUV geometry.

For complexity submerged vehicle added mass can be assumed to be constant.

Parallelly for first simulation added mass and Inertia effects not included for simulation.

Thrust model

A propeller with a rudder can produce thrust vector within a range of directions and magnitude in horizontal plane to low-speedmanoeuvring and dynamic positioning.

Here we use simple model due to AUV velocity.

Final equations: (Combining all the equations)

Surge: (Translational along x axis)

$$X = X_u\mathring{u} + m[\,-\mathring{u} - z_g\mathring{q} + y_g\mathring{r}] + xu|u| + (x_{wq} - m)\,wq + (X_{qq} + mxg)\,q^2 + (X_{vr} + m)vr + (X_{rr} + mxg)\,q^2 - m^2 pr - (W\text{-}B)\sin\theta + Xpr_{op} \longrightarrow$$

Eqn 27

Sway: (Translational along y axis)

$$Y = Y_v\mathring{v} + m[\,-\mathring{v} - z_g\mathring{p} + x_g\mathring{r}] + Y_{uv}uv + (Y_{wp} + m)\,wp + (Y_{ur} + m)\,ur - (-\,m_{zg})qr + (Y_{pq} - mxg)\,pq + Y_{vv}v|v| + Y_{rr}r|r| + (W\text{-}B)\cos\theta\,\sin\phi + Y_{uu}\delta_r\; u^2\delta_r \longrightarrow$$

Eqn 28

Heap: (Translational along z axis)

$$Z = Z_w\mathring{w} + Z_q\mathring{q} + m[-\mathring{w} - x_g\mathring{q} + z_g\mathring{p}] + (z_{uq} + m)uq + (Y_{up} - m)\,up + (m_{zy})\,p^2 + z_{uw}uw + (m_{zg})q^2 + (z_{rp} - mxg)\,rp + z_{ww}\,w|w| + z_{qq}\,q|q| + (W-B)\cos\theta\cos\phi + Z_{ww}\delta_e\,u^2\delta_e \longrightarrow$$

Eqn 29

Roll:

$$K = mz_g\mathring{u} - my_g\mathring{r} - (I_{xx} - K_{\mathring{p}})\,\mathring{p} + (my_g)\,\mathring{w} - (I_{zz} - I_{yy})\,qr - (m\,z_g)\,wp + (mz_g)ur - (z_g\,w - z_b\,B)\cos\theta\cos\psi + k_{pp}\,p\,|p| + k_{prop} \longrightarrow$$

Eqn 30

Pierce:

$$L = -mz_g\mathring{u} + (mx_g + m_{\mathring{w}})\mathring{w} - (I_{yy} - M_{\mathring{q}})\,\mathring{q} + (m_{rp} + I_{zz} - I_{xx})\,rp - (mz_g)\,vr - (-mz_g)wq + (M_{uq} - m_{xg})uq + M_{uw}\,uw + (M_{rp} + m_{xg})\,vp + M_{qq}\,q|q| + M_{ww}\,w|w| - (z_g w - z_b B)\sin\theta - (x_g w - x_b\,B)\cos\theta\cos\psi + M_{uu}\,\delta_e\,u^2\delta_e \longrightarrow$$

Eqn 31

Yaw:

$$N = -m_{yg}\mathring{u} + (N_v - m_{xg})\mathring{v} + (N_r - I_{zz})\,\mathring{r} + (N_{pq} + I_{xx} - I_{yy})pq + (N_{wp} - mx_g)\,wp + (N_{ur} - mx_g)\,ur + N_{uv}uv + N_{rr}\,v|v| + N_{vv}\,v|v| + (x_g w - x_b B)\cos\theta\sin\psi + (y_g w - y_b\,B)\sin\theta + N_{uu}\,\delta_r\,u^2\delta_r \longrightarrow$$

Eqn 32

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All the forces (X,Y,Z) and moments (K,M,N) are with respect to body fixed co-ordinates.

Solve above by Numerical Integrations to obtain speed, Position and attitude.

AUV Scale Vector

$$X = [u \quad v \quad w \quad p \quad q \quad r \quad x \quad y \quad z \quad \phi \quad \theta \quad \psi]^T$$

Data required

AUV Physical Parameters:

ρ – Fluid density g/m^3

g – gravitational acceleration 9.81 m/s^2

d – Hall cylinder radius (m)

l –length

δ_w– submerged Area (m^2) – T dl

A_p– Body base Area (m^2) - dl

A_f– Body cross Area (m^2) – T d^2/4

Cds – Surface drag coefficient

CdF – Drag coefficient

Cda – Total drag coefficient (for Sw)

l_{cp}– Distance to centre of pressure (m)

A_r, A_s– Vertical/Horizontal rudder surface area

C_{df}– Rudder drags coefficient

W – Buoyant Force (W)

x_b, y_b, z_b – Buoyancy centre about x,y,z, axis (m)

x_g, y_g, z_g – G above x,y,z axis (m)

I_{xx}, I_{yy}, I_{zz} – MI above x,y,z axis (kg-m^2)

R design of propeller (m)

u_0 design velocity (m/sec)

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Hydro dynamic force coefficients

$X_{u|u|}$ Axial drag (kg/m)

$X_{\dot{u}}$ Added mass (kg)

$Y_{u|u|}$ Cross flow drag (kg/m)

$Y_{r|r|}$ Cross flow drag (kg.m / rad)

Y_{uv} Body and rudder buoyancy (kg/m)

Y_{v} Added mass (kg)

Y_{r} Added mass (kg m/rad)

Y_{ur} Added mass + Rudder buoyancy (kg/rad)

$Y_{uu}\,\delta_r$ Buoyant force of rudder (kg/m/rad)

$Z_{w|w|}$ Cross flow drag (kg/m)

$Z_{q|q|}$ Cross flow drag (kg m/rad^2)

Z_{ww} Body and rudder buoyancy (kg/m)

Z_{w} Added mass (kg)

Z_{q} Added mass (kg m/rad)

Z_{uq} Added mass + Rudder buoyancy (kg/rad)

$Z_{uu}\,\delta_r$ Buoyant force of rudder (kg/m/rad)

Hydro dynamic moment coefficients

$K_{p|p|}$ Roll drag (kgm^2/ rad^2)

K_{p} Added Mass moment (kg m^2/ rad^2)

$M_{w|w|}$ cross flowdrags (kg)

$M_{q|q|}$ cross flow drags (kg m^2/ rad^2)

M_{uw} Added mass + Rudder buoyancy (kg)

M_{w} Added mass vector (kg-m^2)

M_{q} Added mass vector (kg-m^2/rad)

M_{uq} Added mass vector +Rudder buoyancy (kg-m/rad)

$M_{uu}\,\delta e$ Rudder buoyancy moment (kg/rad)

$N_{v|v|}$ Cross flow drag (kg)

$N_{r|r|}$ cross flow drags (kg m^2/ rad^2)

N_{uv} Added mass + Rudder buoyancy (kg)

N_{v} Added mass Inertia(kg-m^2)

N_{r} Added mass Inertia (kg-m^2/rad)

M_{uq} Added mass vector +Rudder buoyancy (kg-m/rad)

$N_{uu}\delta r$ Rudder buoyancy moment (kg/rad)

Critical challenges facing current design of AUVs

1. Energy efficiency and power management
2. Communications
3. Navigations
4. Control

During design and development phase- creating simulation tool to predictive response of vehicle which can be extended to modification process of vehicle. simulation can shorten development time adequately. Simulation refine a designed AUV, it is essential to predict the changes in response of vehicle resulting from changes made to vehicle.

5. Conclusion

In conclusion, the field of modeling and simulation of autonomous underwater vehicles (AUVs) plays a crucial role in understanding and improving the dynamics of these robots. By studying and analyzing the dynamics of AUVs, researchers can develop more efficient control systems, algorithms, and strategies to enhance their performance, autonomy, and safety.

Furthermore, the future scope of AUV dynamics lies in several key areas. Firstly, there is a need for advancements in hydrodynamic modeling to accurately capture the complex interactions between the AUV and the underwater environment. This includes better understanding and modeling of hydrodynamic forces, drag, buoyancy, and maneuverability.

Secondly, improved control systems and algorithms are essential to optimize AUV performance in various mission scenarios. This involves the development of robust and adaptive control techniques, efficient trajectory planning, obstacle detection and avoidance, as well as coordinated behavior for multi-vehicle systems.

Additionally, as AUV technology advances, there is a growing interest in incorporating machine learning and artificial intelligence techniques. These approaches can enhance the ability of AUVs to adapt, learn, and make decisions in real-time, leading to increased autonomy and improved performance.

Moreover, AUV dynamics research can also benefit from advancements in underwater communication and sensing technologies. Enhanced communication capabilities enable better coordination between AUVs and the surface control station, as well as efficient data transfer and localization. Improved sensing techniques, such as advanced imaging systems and environmental sensors, can provide more accurate data for navigation, mapping, and environmental monitoring.

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