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Remotely Operated Submersible

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Abstract— This paper contains a brief description about the design of a Remotely Operated Submersible. ROS is a tethered submersible, controlled by a pilot located on land or from a boat or ship in the water. An umbilical tether containing a group of cables carry electrical power, video and data signals back and forth between the operator and ROS. Remotely Operated Submersible has manouvarability in Forward, Port, and Starboard directions by maintaining a constant heading. It can rotate in clock-wise and anticlockwise directions along its vertical axis. It can also dive underwater and hover at a particular depth.It is basically designed for underwater exploration.The paper addresses the basic system architecture and other design parameters in brief.

Index Terms — ROS, ROV, Submersible, Underwater Vehicle

1 Introduction

Remotely Operated Underwater vehicles are widely used in different marine applications particularly oceanography, naval applications, costal surveillance sub bottom profiling, reconnisance and is also effective in inspection of underwater structures like dams and off-shore rigs. This paper addresses various aspects in the design and development of a Remotely operated underwater vehicle, which can be controlled by a pilot located above water. The Pilot Control Station (PCS) will be connected to the Underwater Vehicle (UV) by an Umbilical Tether Cable (UTC) to carry power and navigation commands from control station to UV, and video pictures and data from UV back to the PCS.

2 Block Diagram

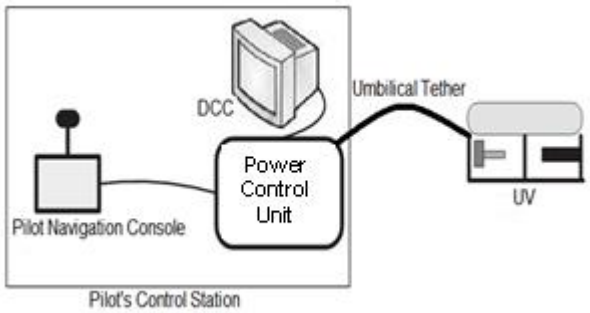

Fig 1 : Remotely Operated Submersible

2.1 Pilot Control Station

PCS is the module above water. It consists of Display and Control Computer (DCC), Power Control Unit and Pilot Navigation Console (PNC).

PNC is a small handheld module, but functionally it forms an integral part of the PCS. PNC is connected to the PCS through a cable to the RS232 port on the PCS. Pilot's Navigation Console houses all the main joystick controls to navigate the UV in water.

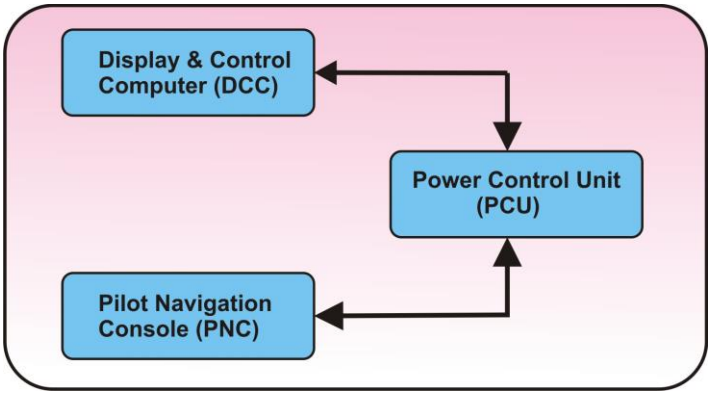

Fig 2 : Block diagram of Pilot Control Station

Pilot can carry the console to pool side or to the deck of the vessel, during the launching / retrieval operations, so that he can perform the Start/ Stop/ Navigation operations by visual contact. After submersing, when there is no visual contact with the UV, particularly at greater depths the only visual aid for the pilot is the video data received from the underwater camera mounted on an adjustable pan & tilt unit mounted on the UV and is presented on the LCD display. During this phase of the operation, PNC forms a part of the PCS. The Power Control Unit communicates with the underwater vehicle through the umblical tether cable, which is neutrally buoyant.

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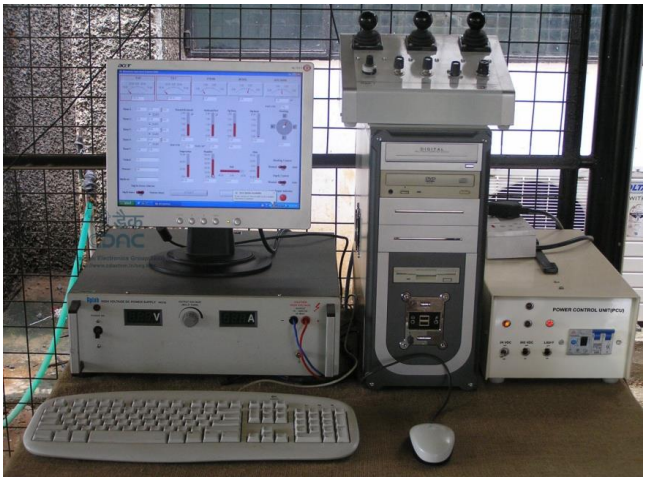

Fig 3 : Pilot Control Station

Hardware part of this module consists of :

1. Joysticks for UV Navigation
2. Trim Pots for navigation
3. Joysticks for camera control (Pan & Tilt Unit)
4. Thruster Trim , Range setting pots and incremental encoder.
5. ROS Controller Card
6. Thruster Controller Card
7. Display and Control Computer.

Fig 4 : Pilot Navigation Control

Joysticks are used for navigation control. A joystick with two axes control is used for horizontal navigation (Forward/Backward, port/starboard). A joystick with one axis control is used to control vertical movement (up/down). ROS is a vehicle with four degrees of freedom. Rotation (Turn) command of UV is applied by a digital optical encoder on the PNC. Two more pots are used for trimming the vertical position, and to set the range for horizontal thrusters. A joystick with 2 axis control is used for PAN and TILT movement of the camera.

2.2 Underwater Vehicle

This is the vehicle part of the system which goes under water. It is an underwater vehicle which responds to the control signals from the PNC. Navigation means the guidance of this vehicle from place to place. It is a vehicle with four degrees of freedom. Horizontal motion is affected by four thrusters mounted in a horizontal plane. Similarly vertical movement is done by the fifth thruster. The prime logical design issue of the UV is distribution of forces to different thrusters with respect to an input control signal. The control word with respect to input command signal is generated by the Control PC. This command frame is send to the ROS Controller Card of the UV through the UTC (Umbilical Tether Cable).

The Controller Card is same as in PNC but here the functions are different. So, only the additional module and functionally different modules are explained here.

The Thruster Controller Card generates analog voltage signals which control the speed of each thruster separately. The voltages from this card are controlled by control word from PCS through ROS Controller Card in UV.

Here an additional DSP is used for interfacing various sensor information. The sensor information shows the current position and state of the UV. These information are collected by the DSP and send to the Display and Control Computer to monitor different parameters and then to control the system.

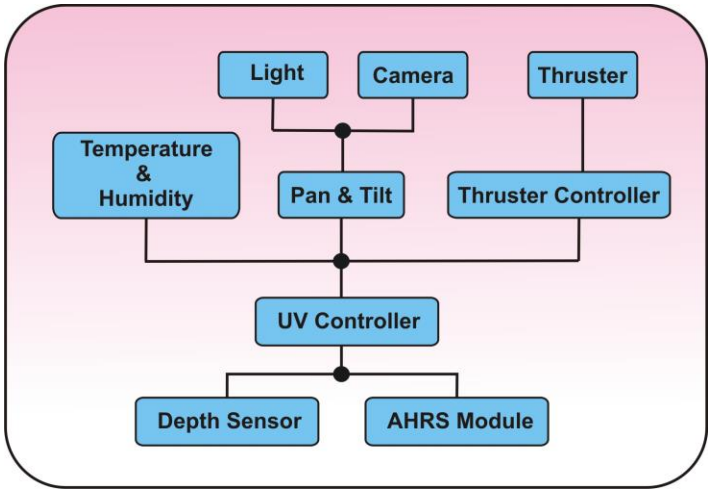

Fig 5 : UV block diagram

The ROS propulsion system consists of five thrusters .Four thruster are mounted symmetrically in a horizontal plane, which enables the linear motion in forward,reverse, port and star-board direction. One thruster is mounted vertically, that enable hovering to a said depth .Thrusters are so positioned in the vehicle , that the moment arm of their thrust force, relative to the central mass of the vehicle, allows a proper amount of manoeu-

vrability and controllability.

Fig 6 : Thruster (Tecnadyne Model 560)

3 Thrust Allocation

The main problem arising is distribution of forces to different thrusters, those are engaged in horizontal motion control. So the algorithm is concentrated on the horizontal motion of UV. The thrust arrangement is as shown in fig 7.

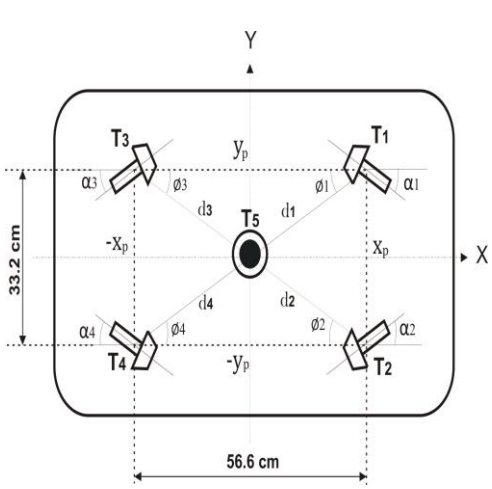

Fig 7 : Thruster arrangement in horizontal plane

The general motion of marine vessels in 6 degrees of freedom (DOF) can be described by the following vectors

$\eta = [\, x, y, z, \Phi, \theta, \Psi \,]^T$,
$\upsilon = [\, u, v, w, p, q, r \,]^T$,
$\tau = [\, X, Y, Z, K, M, N \,]^T$, ... (1)

where
η – the vector of the position and orientation in the world fixed frame,
x, y, z – position coordinates,
Φ, θ, Ψ – orientation coordinates (Euler angles),
υ – the vector of linear and angular velocities in the body-fixed frame,
u, v, w – linear velocities along longitudinal, transversal and vertical axes,
p, q, r – angular velocities about longitudinal, transversal and vertical axes,
τ – the vector of forces and moments acting on the vehicle in the body-fixed frame,
X, Y, Z – the forces along longitudinal, transversal and vertical axes,
K, M, N – the moments about longitudinal, transversal and vertical axes.

The relationship between the forces and moments and the propeller thrust is a complicated function that depends on the vehicle's velocity, the density of water, the tunnel length and cross-sectional area, the propeller's diameter and revolutions. In practical applications the vector of propulsion forces and the moment τ acting on the vehicle in the horizontal plane can be described as a function of the thrust vector f by the following expression.

$\tau = T(\alpha)Pf$ ..... (2)
$\tau = [\tau 1 \;\; \tau 2 \;\; \tau 3]^T$
$\tau 1$ – force in the longitudinal axis,
$\tau 2$ – force in the transversal axis,
$\tau 3$ – moment about the vertical axis,
T – thruster configuration matrix,

$$T = \begin{bmatrix} \tau_1 \\ \tau_2 \\ \tau_3 \end{bmatrix}$$

$$= \begin{bmatrix} \cos\alpha 1 & \cos\alpha 2 & \cos\alpha 3 & \cos\alpha 4 \\ \sin\alpha 1 & \sin\alpha 2 & \sin\alpha 3 & \sin\alpha 4 \\ d1\sin\gamma 1 & d2\sin\gamma 2 & d3\sin\gamma 3 & d4\sin\gamma 4 \end{bmatrix} \quad .... (3)$$

where $\gamma_1 = \alpha_1 - \varphi_1$, $\gamma_2 = \alpha_2 - \varphi_2$, $\gamma_3 = \alpha_3 - \varphi_3$,
$\gamma_4 = \alpha_4 - \varphi_4$

here α_i denotes the Vector of thrust angles, angle between the longitudinal axis and the direction of propeller thrust f_i
d_i – distance of the i-th thruster from the centre of gravity,
φ_i – Angle between the longitudinal axis and the line connecting the centre of gravity with the symmetry centre of the i-th thruster,

$f = [f_1, f_2, f_3, f_4]^T$ – thrust vector,

P – Diagonal matrix of the readiness of the thrusters

$$P_{ii} = \begin{cases} 0 & if \;\; i_{th} \;\; thruster \;\; is \;\; off \\ 1 & if \;\; i_{th} \;\; thruster \;\; is \;\; on \end{cases}$$

From the above relationship, the value of the thrust vector f could be resolved using SVD (Singular Value Decomposition) or using Walsh Matrix Method.

The human pilot forms an active element in the control loop of ROS1. To navigate UV from the current location to a new location, or to change the current orientation in the current position itself, or to achieve both, the navigation commands are given by the pilot.

The UV has got two PCBs mounted in it, namely

1. ROS Controller Card
2. Thruster Controller Card

The data required for the thruster control board will be given from the ROS Controller Card . The ROS controller card will be getting these data from the Pilot Control Station through an RS 485 interface.

4 Performance Characteristics

Manoeuvrability	: 4 DOF (X, Y, Z & Rotation about Z)
Longitudinal Speed	: 1 knot
Transverse Speed	: 0.5 knot
Vertical Speed	: 1 knot
Operating Depth	: 30 m
Total Payload	: 17.85kg
Additional Lifting Capacity	:4.5 kg

5 Physical Characteristics

Vehicle Dimensions :-

Length	: 924 mm
Width	: 660 mm
Height	: 710 mm
Weight in air	: 91.24 kg

6 Features in Brief

- Motion in four Degrees Of Freedom
- Auto Heading and Depth
- Five powerful, reliable, magnetically coupled DC brushless thrusters for propulsion
- Colour camera with pan/tilt feature
- Depth, heading, pitch, roll, temperature and humidity sensors on board
- Multiple I/O's (RS-232, RS-485)
- Operates from 230V, 50Hz

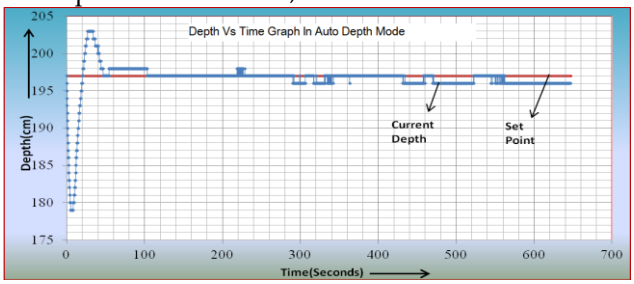

Fig 8 : Depth Vs Time Analysis of UV in Auto Depth Mode

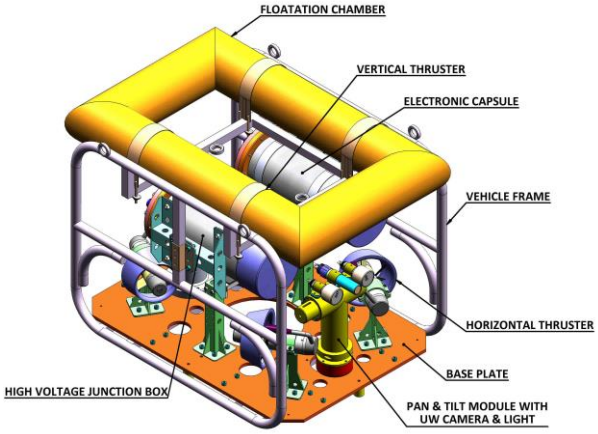

Fig 9 : ROS nomenclature

Fig 10 : Underwater Vehicle

Conclusion

This version of ROS is successfully assembled and tested in still water and flowing water. A three thruster model of ROS (ROS-3T) is also released, which is having less size and weight compared to ROS. Three thruster model of ROS is aimed for an environment which is not accessible by ROS. Next version is aiming for an autonomous underwater vehicle (AUV) with enhanced features equipped with more sensors along with the features of ROS.

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