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Design and Control of Water Jet System for the Amphibious Autonomous Vehicles

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ABSTRACT: The research on water-jet propulsion technology is not deep enough at present. Especially the control system of water-jet propulsion is still in its primary stage. Therefore the overall scheme design of control system of water-jet propulsion was made with the single-machine single pump for the research object. A mathematical model of the system was established on these bases. The PID controller of the system speed and the steering controller of water-jet propulsion system were designed. The architecture of the AAV embedded motion control system is presented from the view point of the hardware and software.

KEYWORDS: water jet; amphibious vehicle; style; PID controller.

I. INTRODUCTION

DORIS as shown in figure 1 is a project research in the institute of real time system in Siegen University in Germany, the aim of this project is to drive the Vehicle on the ground and on the water, for driving on the water a water jet system should design and control properly. The water-jet propulsion is a special propulsion way rapidly developing and maturing for recent 20 years in propulsion ways applied in ship and Amphibious Vehicles. It has many advantages such as high propulsive efficiency good cavitation resistance excellent maneuverability and dynamic positioning performance and strong ability to adapt to variable conditions [1] .People understand and master the theory and technology of water jet propulsion far less deeply than the propeller propulsion technology. Therefore the theoretical study on the control system of the amphibious Vehicle water jet propulsion is of great importance for mastering the performances of spraying water propulsion system and guiding the design and testing of propulsion system of the amphibious Vehicle spraying water.
The main principle of a jet engine is to take advantage of Newton's third law of motion, to every action there is always an equal and opposite reaction. By creating a jet stream of the fluid, the jet stream will produce a forward motion in the opposite direction of the jet stream water jet design has all hydraulic driven Motor[2].The steering unit provides manoeuvre ability of the Amphibious Vehicle by redirecting the jet stream. This is achieved by adding a box outside the nozzle that the jet stream can pass through. The box rotates around its point of attachment and redirects the jet stream in the desired direction by using electrical motor provided with position sensor and linear actuator[3].

The mathematical models of hull main engine and water propulsion motor were established respectively. The designs on diesel speed controller and the speed controller of water jet propulsion system were completed. Thereby the simulation model of integrated control system of water jet propulsion is obtained. Then the control of the amphibious Vehicle steering is achieved by PID controller. The steering unit provides manoeuvre ability of the Amphibious Vehicle by redirecting the jet stream. This is achieved by adding a box outside the nozzle that the jet stream can pass through. The box rotates around its point of attachment and redirects the jet stream in the desired direction by using electrical motor provided with position sensor and linear actuator[4].

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Fig. 1 water jet mounted on AAV (DORIS)

II. HARDWARE ARCHATICTURE OF THE MOTION CONTROL SYSTEM

A. Hydraulic circuit

Fig.2 shows schematic diagram of the propulsion system fitted with hydrostatic transmission. The system is driven by a high-speed combustion engine type Suzuki. The engine, through a flexible coupling, directly drives unit of two oil pumps, the right Pump feeding a fixed displacement hydraulic motor through 6/2 Directional Valve as .The steering of the jet ski motor controlled through controlling the jet ski steering box which connected to DC motor and linear actuator.

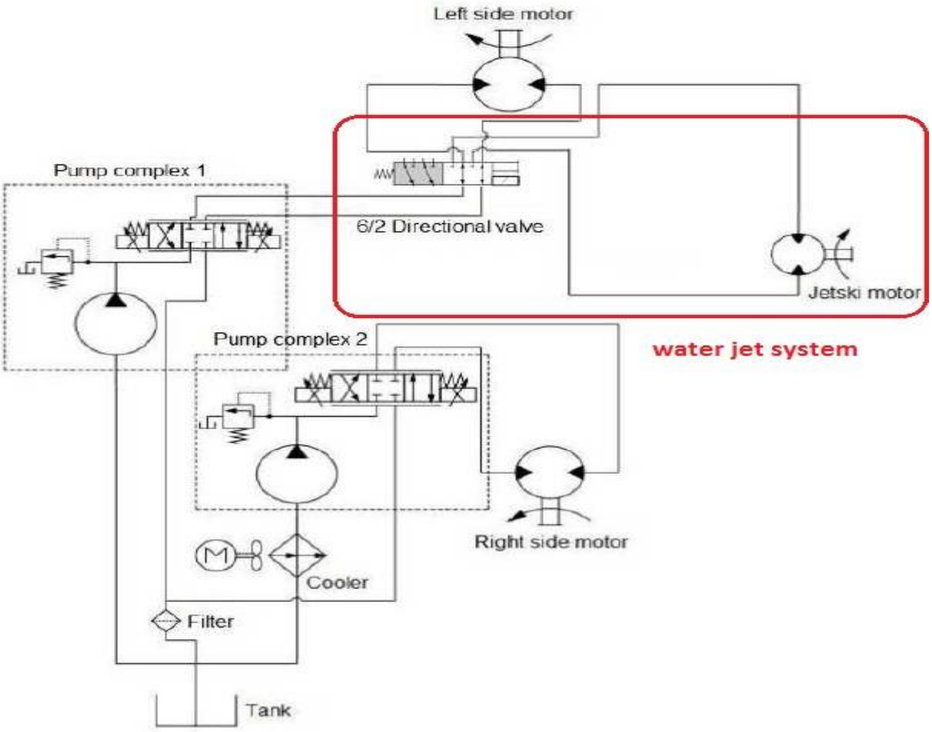

Figure 2 hydraulic system of DORIS AAV

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B. Pump controlled Motor system.

Pump controlled motors are the preferred power element in applications which require considerable horsepower for control purposes. This type of closed hydrostatic transmission gives much higher efficiency compared to a valve controlled actuator, since there are no flow orifices in the main circuit. However, the comparatively slow response of the pump displacement controller, limit their use in high performance systems. In Figure 3 a pump controlled motor used as an angular position Motor is .The variable displacement pump controlled through controlling the swash plate position, a DC Motor used to operate and control the swash plate angular position, where the speed of the hydraulic motor is controlled through controlling the hydraulic pump swash plate position which is discussed in details in the previous chapters.

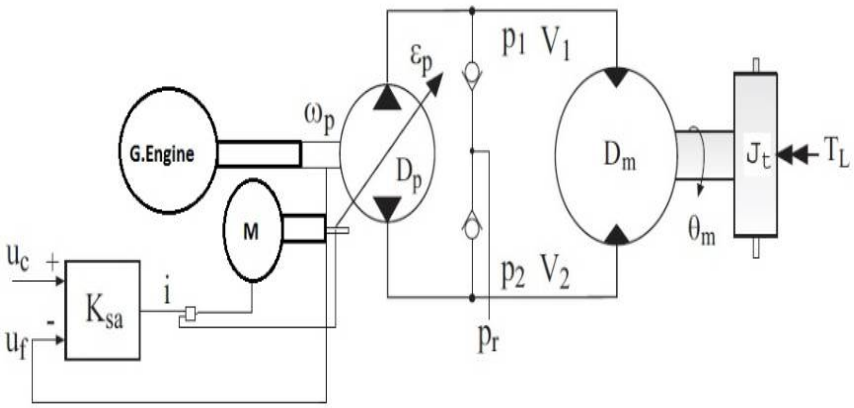

Fig. 3 pump controlled motor schematic

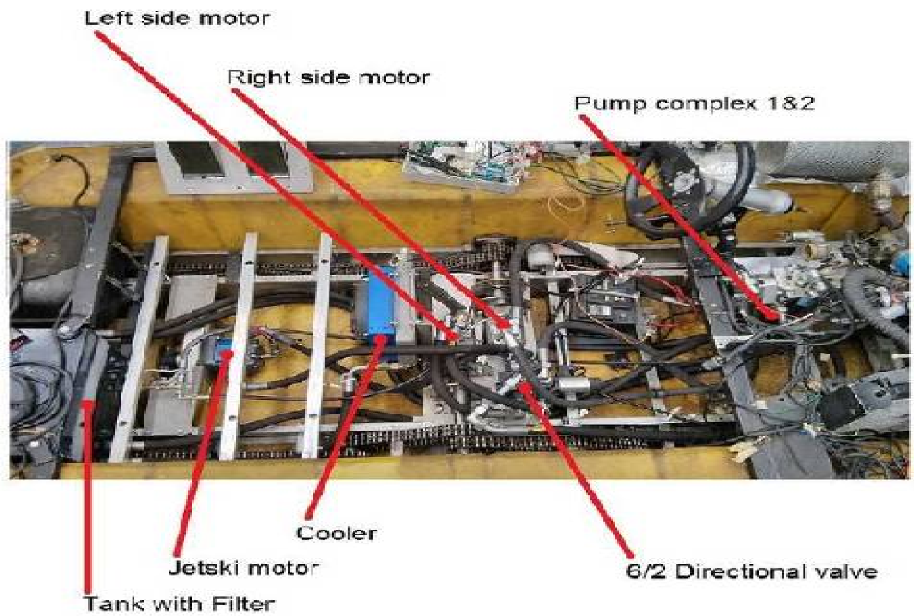

Fig. 4 hydraulic system mounted on AAV (DORIS)

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Fig. 5. steering box

III. MOTION CONTROL SYSTEM

A. Speed control system

The water jet pump speed controlled none directed through controlling the gasoline engine speed using servo motor and controlling the variable displacement pump swash plate position which is described in details in the previous works [4], the directional valve used to enable and disable the water jet system which is connected between the pump and hydraulic motor, the block diagram of the hull system illustrated in Fig 6.

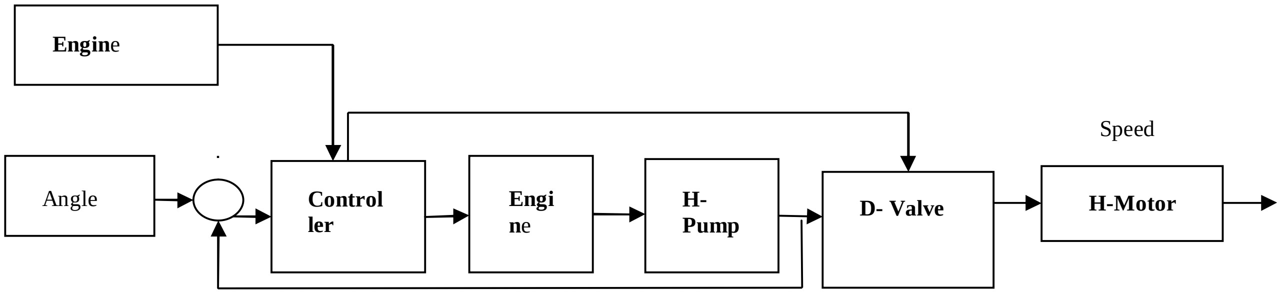

Fig. 6. block diagram of speed system

B. Steering control system

To steer the vehicle on the water steering device mounted on the water jet nozzle as shown in Fig 7a, the steering box attached to a metal cable connected to high power DC Motor as shown in figure .. which is used to position the steering box through controlling the DC Motor position, the block diagram of the steering system shows in figure 8 and for that PID controller used to control the DC Motor Position. Figure 7b shows the flow chart of the steering system

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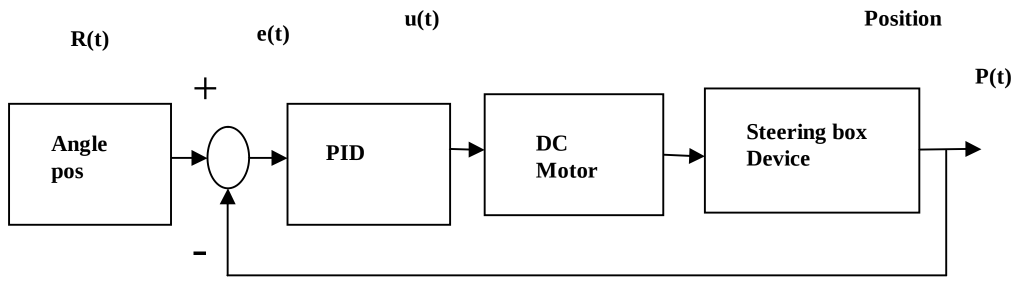

figure 7a. block diagram of steering system

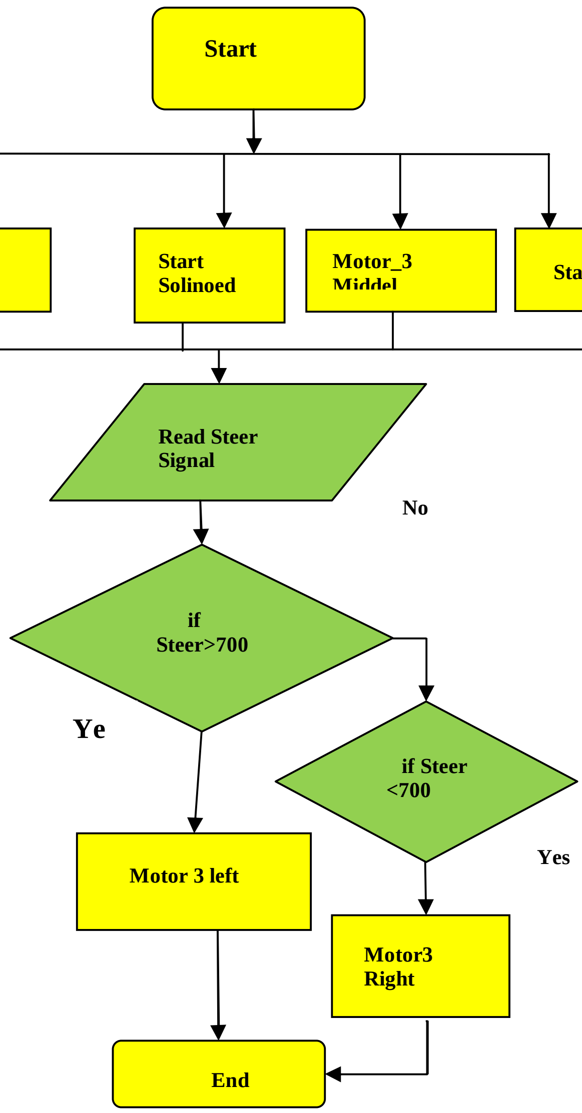

figure 7b. flow chart of steering system

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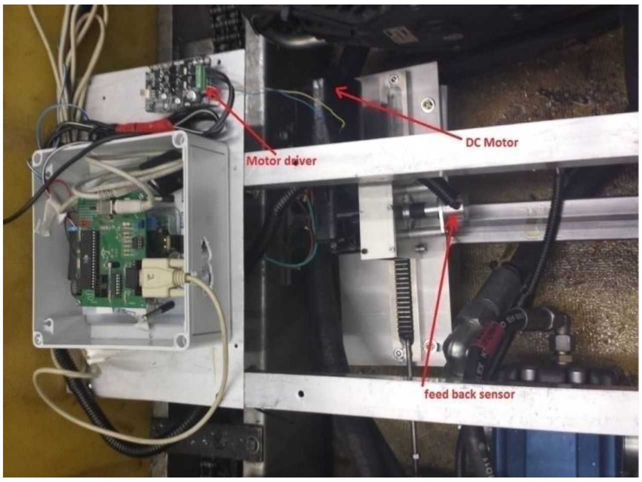

Fig. 8. steering system

IV. Modeling of Water Jet System

The application of water jets is rapidly growing and they are increasingly being chosen for propulsion in high-speed crafts. Water jet as a propulsion system of a vessel is also favourable when it comes to manoeuvring, appendage drag, draft and fuel consumption at high speeds. Furthermore, water jet system has recently gained more credibility for its acceptable efficiency because of the advent of more efficient and large pumps.

Water jet operated by gasoline engines that drive a jet water pump. Water is taken in through a water pick up on the bottom of the water jet, drawn into an internal propeller (an impeller) that creates a jet of high pressure water which exits through a nozzle on the back of the water jet .There is also a moveable "gate" that can be dropped over the nozzle to provide reverse thrust on some models. The selection of water-jet propulsion pump needs to determine the main parameters: pump flow pressure head spout area and pump type. The equilibrium equations considering main engine water jet propulsion system and hull are as follows Thrust equation is [1]:

$$T = R = \rho Q(V_j - V_i) \qquad \text{eq.(1)}$$

Power Equilibrium equation is

$$P_i = \gamma Q \frac{H}{\eta_p} \qquad \text{eq.(2)}$$

The equilibrium equation of head and loss is

$$H = (1 - \xi)\frac{V_j^2}{2g} - \frac{V_i^2}{2g} \qquad \text{eq .(3)}$$

The jet velocity corresponding to the best ratio of jet velocities is:

$$V_j = K_{opt} V_i \qquad \text{eq. (4)}$$

Head is:

$$H = \frac{V_i^2}{2g}(k^2 - \xi - 1) \qquad \text{eq. (5)}$$

The flow is:

$$Q = \frac{T}{\rho(V_j - V_i)} \qquad \text{eq. (6)}$$

The spout diameter is:

$$D = \sqrt{\frac{4Q}{\pi V_j}} \qquad \text{eq.(7)}$$

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V. MATHMATICAL MODEL OF PUMP MOTOR

The mathematical model of the pump motor derived by [7] the block diagram of the closed loop for the hull system shown in figure 9 .The transfer function consist of the transfer function of the DC Motor ,hydraulic pump ,directional valve , hydraulic motor and disturbance transfer function.

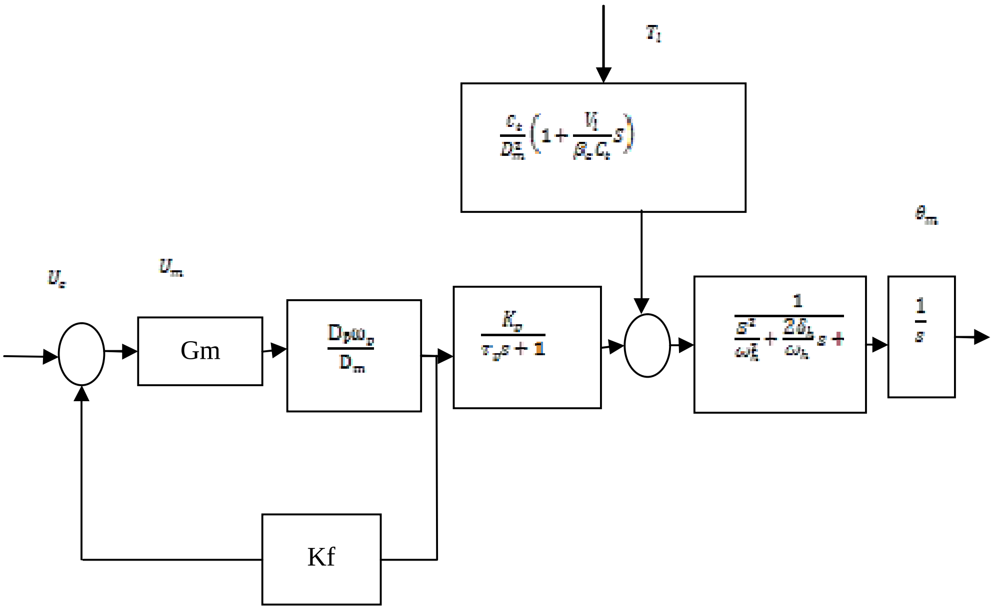

Fig. 9 block diagram of the pump controlled motor transfer functions

$$A_u(s) = \frac{K_a D_P \omega_P \frac{K_f}{D_m}}{Gm(s).S.\left(\frac{s^2}{\omega_h^2}+\frac{2\delta_h}{\omega_h}S+1\right)} = \frac{K_v}{Gv(s)Gm(s).S.\left(\frac{s^2}{\omega_h^2}+\frac{2\delta_h}{\omega_h}S+1\right)} \qquad \text{eq. (8)}$$

$$Gm(s) = \frac{1}{0.05+3.8s+0.78} * \frac{1}{s} \qquad \text{eq. (9)}$$

$$\omega_h = \sqrt{\frac{\beta_e D_m^2}{J_t}\left(\frac{1}{V_1}+\frac{1}{V_2}\right)}$$

$$\omega_h = \sqrt{\frac{4\beta_e D_m^2}{J_t V_t}}$$

$$\delta_h = \frac{C_t}{D_m}\sqrt{\frac{\beta_e J_t}{V_t}} + \frac{B_m}{4D_m}\sqrt{\frac{V_t}{\beta_e J_t}}$$

The valve behaves as if it were linear and that the dynamic performance could be approximated by the linear transfer function [6]

$$G_p(s) = \frac{\Delta P}{V} = \frac{K_p}{\tau_p s+1} \qquad \text{eq.(10)}$$

The table below shows the most important parameters for the system transfer function.

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Sym	Description	Unit
K_v	Proportional gain	-----
ω_p	Pump angular speed	Rad/sec
J_t	Inertia of motor and load	Kg.m2
V_t	Total fluid volume in pipes	m3
B_m	motor Viscous damping coefficient	N.m.sec./rad
D_m	Motor displacement	m3 /rad
ρ	Density of the Hydraulic oil	Kg/m3
C_t	total leakage coefficient for pump and motor	m3/sec. Pa
D_P	Pump displacement	m3/ rad
β_e	Effective bulk modulus	N/m2
ω_m	Motor rotational speed	rpm

VI. PID CONTROLLER

PID controllers are commonly used to regulate the time-domain behaviour of many different types of dynamic plants. These controllers are extremely popular because they can usually provide good closed-loop response characteristics. Consider the feedback system architecture that is shown in figure 8.13 where it can be assumed that the plant is a DC motor with the steering box whose position must be accurately regulated. The PID controller is placed in the forward path, so that its output becomes the voltage applied to the motor's armature the feedback signal is a position, measured by angular position sensor .the output position signal P (t) is summed with a reference or command signal R (t) to form the error signal e (t). Finally, the error signal is the input to the PID controller as shown in figure 10.

$$u = KPe + Ki\int edt + Kd\frac{de}{dt}$$

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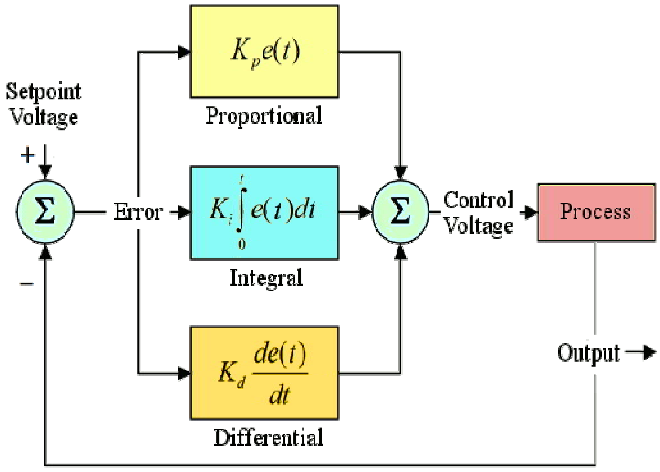

Fig 10. PID controller

VII. EXPIREMNTS AND RESULTS

From Figure 11 we can see that the response of the DC motor which drive the jet ski hydraulic motor follows the input signal which fulfill the system requirement. For the task of stable control, a PID controller is used. For controlling the jet ski steering box PID controller used with the parameters of Kp =5.0, Kd = 0.00, Ki = 0.00 as shown in figure 12. And the step response of PID controlled DC motor is shown in Figure 13. We can see that by using PID controller, the stable time of step response is 1s which is enough for the task of our Amphibious Autonomous vehicle . Figure 14 shows the jet ski motor current during the jet ski box steering the maximum current is 450 mA , table 1 below shows the hull PID controller parameters which fulfill the system requirements with steady state error 0.2% ,step responce 0.5 sec. and 7.1% overshoot.

parameters	value
P	5.0
I	0.00
D	0.00
Step response	0.5 second
Overshoot	7.1%
Steady state error	0.002

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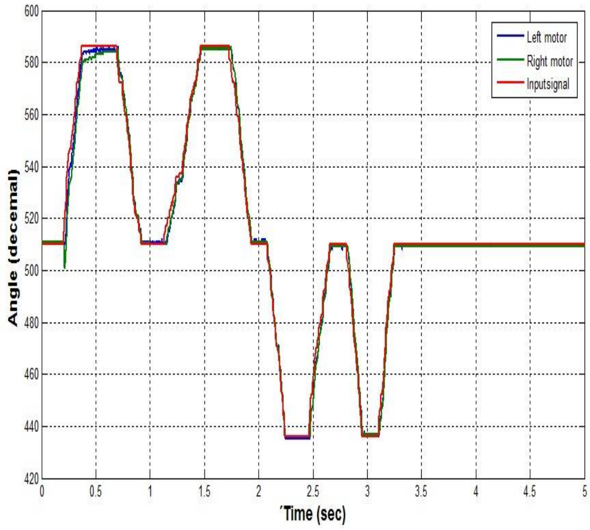
Table 1. PID controller parameters



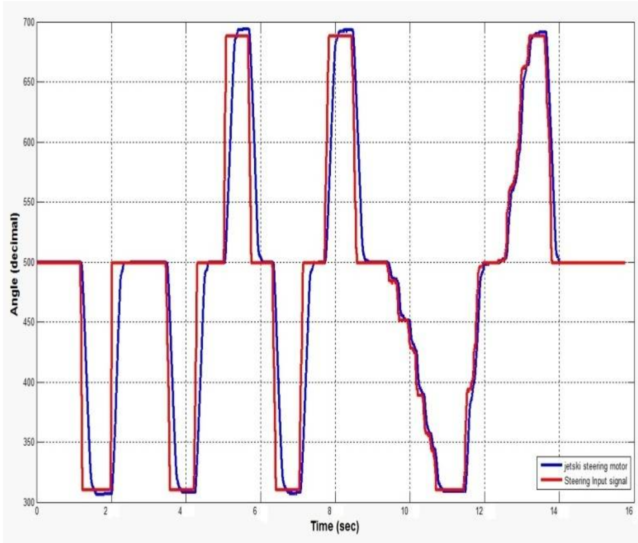
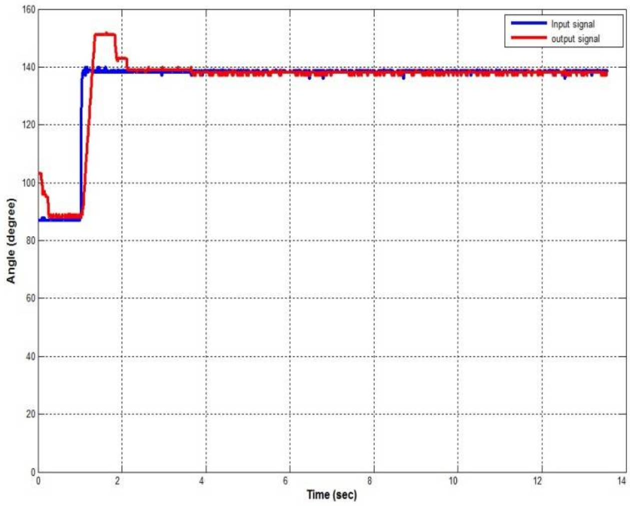


Fig. 11 PID controller for pumps motors Fig. 12 PID controller for jet ski steering system



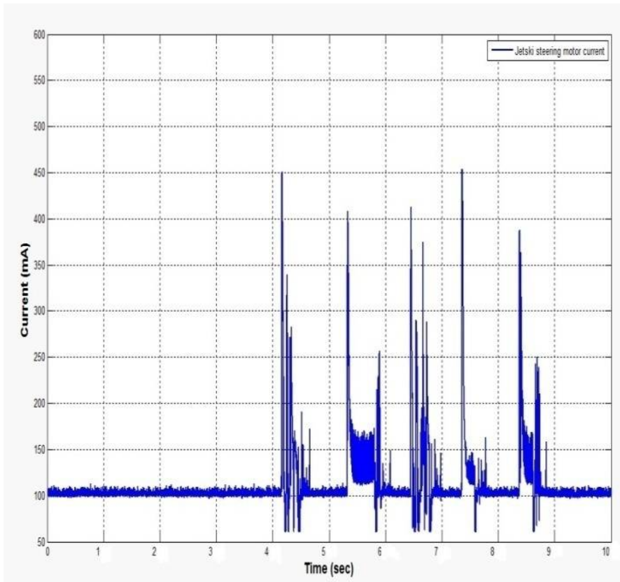


Fig.13 jet ski steering box PID controller step response Fig. 14 jet ski Motor current

VIII .CONCLUSION

In this paper we have designed and implemented water jet control system with PID controller for controlling the amphibious autonomous vehicle steering system on the water. The water jet circuit and the mathematical model for water jet system designed. The results of these experiments are shown above and confirm that the PID Control System can enhance a good and smooth steering left and right.

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BIOGRAPHY

sailan khaled was born in Sanaa, Yemen, in 1978.He received the B.S. from Sanaa University in 2001 and M.S. degree in Mechatronics from Siegen University of in Germany in 2010 . Since 20012, he is a PhD student in Siegen university institute of Real Time Systems His research interests are control systems, embedded systems, Robotics and Autonomous Systems.

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