DEVELOPING AN UNDERWATER ROBOT CONTROL SYSTEM

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Introduction

Underwater Robotics is one of the newest areas of science and technology. Development of automatic underwater vehicles can save people from the risk they may have during working under water. In addition, these robots can be used to explore the underwater world. Initially, underwater vehicles have been used by the military. However, today we can observe their use for a wide range of scientific and applied problems related to the exploration and monitoring of the World Ocean. In this connection, underwater robotic tools are designed for a wide range of applications [1].

The main part of any robot is control system. Through it works robots can perform various complex problems. This article discusses modeling of control systems and stabilization of depth immersion of the robot. Mathematical modeling was performed using Simulink MATLAB R2013a software package.

Structure of mathematical model

The main structure of the robot depth immersion control system model is shown in Figure 1.

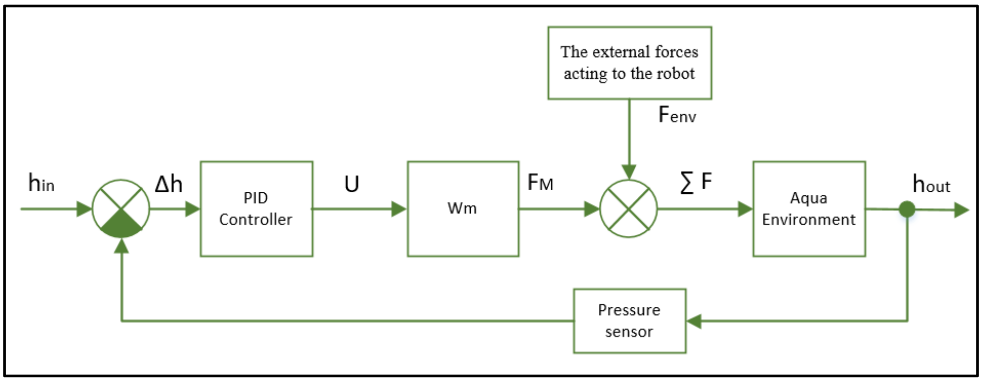

Figure 1. The main structure of the robot depth immersion control system model

The components of a mathematical model are $\mathbf{h_{IN}}$ – input signal, depth of robot immersion; $\mathbf{h_{OUT}}$ – output signal, the actual value of the depth at the current time. The vehicle is immersed by four vertical engines with blades. In Figure 1 this is the block $\mathbf{W_M}$. The feedback has a depth sensor, which regulates the value of robot immersion. Also, the impact of the water environment was taken into account.

Let us consider each unit of operator-structural scheme in more detail.

Controller

A proportional–integral–derivative controller (PID controller) generates a control signal to the engine, which act to the aquatic environment and produce robot immersion. PID controller is a control loop feedback regulator, which calculates an error value as the difference between a desired setpoint and a measured process variable. The controller attempts to minimize the error over time by adjustment of a control variable, such as the power supplied to engines, to a new value determined by a weighted sum of the proportional, integral, and derivative terms [2].

With regard to the designed model, in order to take the power of engines which must be provide, the difference between the desired depth of immersion and its value at the current time multiplied by a coefficient and feed the resulting signal to the engines. This is proportional term. It operates at the moment of error – the controller respond instantly to changes in the control signal, and the behavior of the object. Engines supply more force if the robot began float upward and vice versa. In the real conditions, this reaction manifested with delay. Moreover, the control object affected not only by the operator, but also by the environment: the attractive force of the earth, the Archimedes force, the force of water resistance. Therefore, proportional control value hesitates around point, which must be maintained. Fluctuations become greater with the increase of the impact of the environment [2].

In order to compensate for external influences to the robot, the circuit added the integral component. All errors (deflection) in control system provided to an integrator. In this case, if the robot is drowning – the integrator's value is decreasing, if the robot is popping up – the integrator's value is increasing. In this way, the accumulated integral increase or decrease the value of the engine's working power. As a result of this approach, the integrator generates contribution to a total capacity, which compensates for environmental influences: fluctuations disappear, the integral becomes stable and the value of power becomes constant. Since in this case the depth is supported, there is no deflections and the proportional component is not working at all [2].

To compensate for the delay between exposure and reaction of the system, a differential component is added to the regulator. Simply proportional controller provides the power all the time, until the robot reaches the required depth, but the proportional-differential (PD) controller begins to reduce the power supplied to the engines before than the robot plunge to a desired depth [2].

Engines

Since the transfer functions of engines are unknown, let us take them straight to simplify the calculations. However, because of the maximum traction of propellers is 50 H, the scheme contains a restriction (saturation component).

Outside influences

As a positive direction of the robot dives is selected Y-axis downward (Figure 2). In addition to the traction of engines on the robot affects the force of gravity, the Archimedes force and water resistance force, which occurs when the robot move and is directed opposite to the direction of its movement.

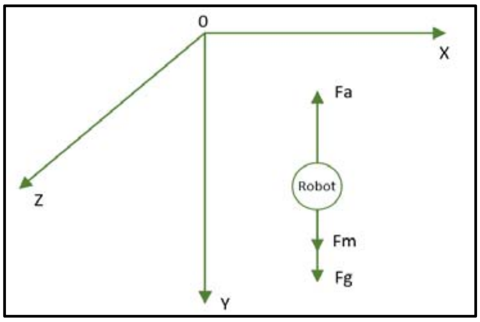

Figure 2. The forces acting to the robot under water

The viscous friction (resistance force (F_R on the Figure 3) of the water depends on the speed of movement of the robot. At low speeds, the resistance force is a linear function of the robot speed, because there is no turbulent flow of water.

Sum of force vectors is the resultant of all the forces at the current time. Taking advantage of 3rd Newton's law, the velocity of the robot will be:

$$F(t) = m\frac{dv(t)}{dt};$$

$$dv(t) = \frac{1}{m} \cdot F(t) \cdot dt;$$

$$v(t) = \frac{1}{m}\int_0^1 F(t) \cdot dt.$$

Consequently, the distance will be:

$$s(t)\int_0^t v(t) \cdot dt.$$

This way, we obtain the depth at which immerse / emerge the robot for a particular period.

Depth sensor

Pressure sensor is used as a depth sensor. Negative feedback enters to the adder, the output of which is a deviation from a predetermined depth.

Mathematical model of control system

All calculations are summarized in the mathematical model, built in Simulink. Consider in detail Figure 3.

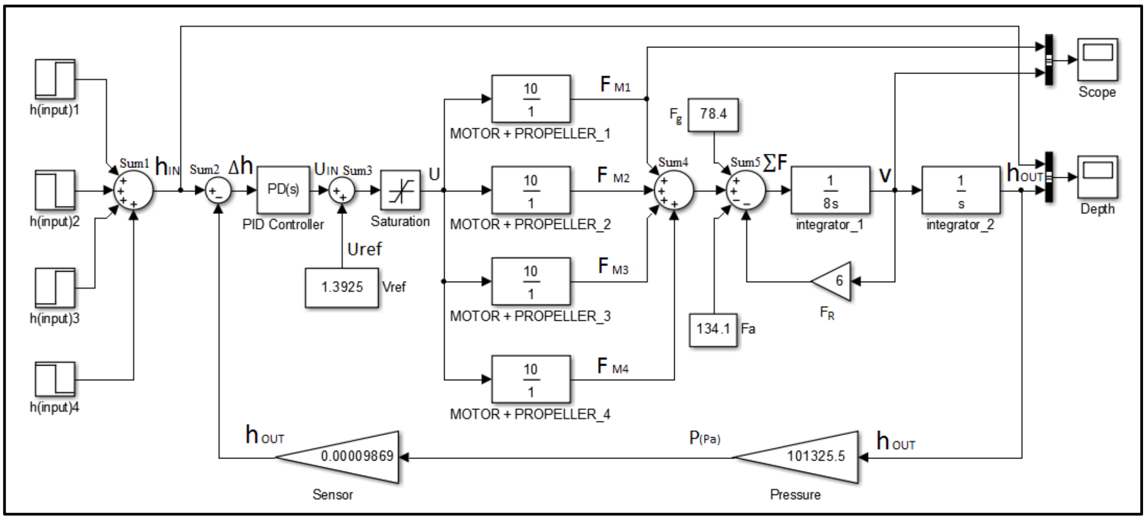

Figure 3. The mathematical model of control systems of depth immersion of the robot

The circuit has four blocks **h (input)**, which set the depth of robot immersion. At the time t_1**=1 s** depth is **6 m,** at t_2**=6 s** depth is **3 m**, at t_3**=17 s** depth is **10 m**, at t_4**=22 s** depth is 1 **m**. As a result, the output from the first adder has a signal specifying the depth of immersion of the robot at certain points in time.

The **PID Controller** block is a special regulator that implements control function of the main system's circuit. As applied to this system, the PID Controller should be set after modelling the immersion control system.

In order to ensure a neutral buoyancy, block **Vref** sets the initial value of motor traction. Its value was obtained by summarizing the forces, which affect the robot from the environment, and represented as a constant value (volts) of the engine control signal. This way, the control signal to the motors is formed by the sum of **Vref** and **PID Controller** blocks. The **Saturation** block is situated after the third adder at the circuit and sets a value limit of the control signal. In other words, **Saturation** restricts the maximum speed of engines' work (maximum traction is **50 H**). Then, four **Motor + Propeller** blocks are connected in parallel. It represents the transfer function of every engine and propeller. Because the transfer engine function is unknown and its identification is not possible, it is presented as a linear function wherein the input signal is between **0 and 5 volts**, and the output traction is **from 0 to 50 H**. Thus, the transfer function of the engine and propeller is represented as a coefficient with a value of 10. Further, the total value of traction from all thrusters $\sum F_M$ is summarized with the external forces acting on the robot: F_G – the force of gravity, F_A – Archimedes force, the F_R – frictional force/water resistance. At the output is the vector of the resultant force $\sum F$. After integrating, the value of this vector becomes speed, the value of which passes through the feedback to the fifth adder as frictional force. By integrating again, we obtain the movement h_{OUT} – the output signal (the actual depth value at which the robot is at the current time). The output signal is read and converted into pressure. Then the pressure comes to the depth sensor (**Sensor** block) and through feedback comes to the second adder. At its output, error is generated – deviation between the real value of the depth and the its set value. The scheme shows two **Gain** blocks, because the sensor detects pressure and then the software converts it into depth (10 m = 101325.5 Pa). The coefficients of the PID were obtained through the built-in Simulink automatic tuning function.

Modelling

The result of the simulation of the system is shown in Figure 4, where the blue color shows the input signal and the violet – the output (testing of the control system with an input signal).

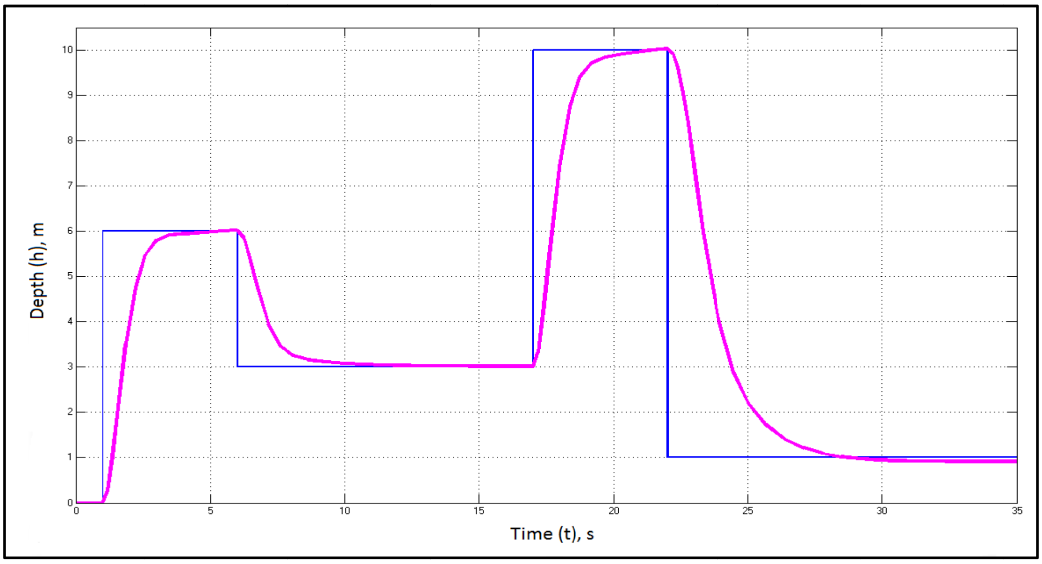

Figure 4. The result of simulation of depth immersion control system

At the result, the model fulfills well the depth of immersion of the robot, all the transient processes have aperiodic character and overshoot values are minimal. This model will be used to construct underwater robot «BoxNep». This model takes into account the weight and size dimensions of the robot and the forces acting on it. To implement the process of stabilization of the robot, the PID controller must being created as a code on the single board computer Raspberry Pi 2 (or any other computer / controller).

Conclusion

The resulting control system has high-quality parameters of depth stabilization. Future, this control system will be used in telemetry controlled underwater robot «BoxNep», which will be designed in the laboratory of «Telecommunications, Instrumentation and marine geology», Institute of cybernetic, National research Tomsk polytechnic university.

References

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