# An algorithm for determining permissible control inputs to unmanned Underwater Robotic Vehicle (URV) fitted with azimuth propellers

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ABSTRACT

*The paper deals with synthesis of automatic control system for an unmanned underwater robotic vehicle. The problem of determining permissible propulsive forces and moments necessary for optimum power distribution within a propulsion system composed of azimuth propellers (rotative ones). To allocate thrusts the unconstrained optimization method making it possible to obtain a minimum-norm solution, was applied. A method was presented for assessing propulsion system capability to generate propulsive forces (set control inputs). For the case of lack of such capability an algorithm was proposed making modification of their values and determination of feasible propulsive forces (i.e. permissible control inputs), possible. A numerical example which confirmed correctness and effectiveness of the proposed approach, was also attached.*

**Keywords** : underwater vehicle, propulsion system, azimuth propeller, control

## INTRODUCTION

Underwater Robotic Vehicles (URV) play an important role among various technical means used for searching seas and oceans. The unmanned floating units fitted with propulsors and capable of maneouvring are designed to realize tasks at the water depth from a dozen or so to several thousand meters.

Robot's motion of six degrees of freedom is described by means of the following vectors [1, 3] :

$$\boldsymbol{\eta} = [x,\ y,\ z,\ \phi,\ \theta,\ \psi]^T$$
$$\mathbf{v} = [u,\ \nu,\ w,\ p,\ q,\ r]^T \qquad (1)$$
$$\boldsymbol{\tau} = [X,\ Y,\ Z,\ K,\ M,\ N]^T$$

where :

$\boldsymbol{\eta}$ – vector of location and orientation in an inertial reference system
$\mathbf{v}$ – vector of linear and angular velocities in a hull-fixed reference system
$\boldsymbol{\tau}$ – vector of forces and moments acting on the robot in a hull-fixed reference system.

Contemporary underwater robots are often and often equipped with the automatic control systems which make it possible to execute complex maneuvers and operations without any intervention of operator. The main modules of such control system are shown in Fig.1. Its crucial element is the autopilot which – on the basis of comparison of a current location of controlled object with its set values – determines forces and moments to be generated by the propulsion system so as to make the object's behavior complying with that assumed. The thrust vector corresponding with them is computed in the thrust distribution module and sent to the propulsion system as a control quantity.

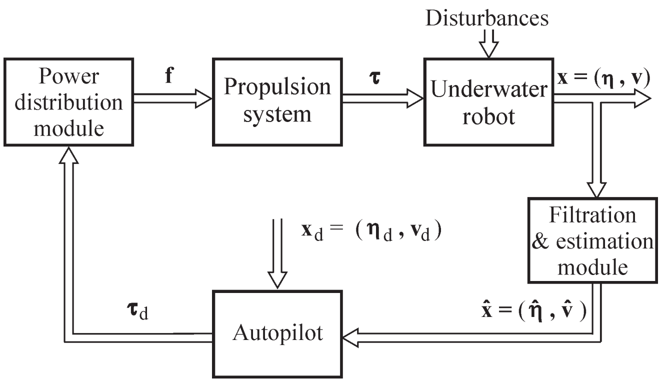


*Fig. 1. Schematic diagram of a control system for underwater robot*

The control laws implemented in the autopilot , which make it possible to determine propulsive forces and moments, have a general character; they do not take into account constraints put on maximum and minimum values of the thrusts which can be developed by particular propellers. It can cause that the obtained solution would be unfeasible for the propulsion system. Such situation may worsen control quality and cause that robot's behavior would greatly differ from that assumed.

Therefore a two-phase procedure of power distribution is proposed (Fig.2).

In the first phase propulsion system capability of generating the set control inputs $\boldsymbol{\tau}_d$ would be assessed and the permissible control inputs $\boldsymbol{\tau}'_d$ (i.e. such values of forces and moments which the propulsion system is able to generate) would be determined. Their values would be so calculated as – ensuring operation of propellers to a saturation limit at most – not to cause a drastic perturbation in the robot's motion control process.

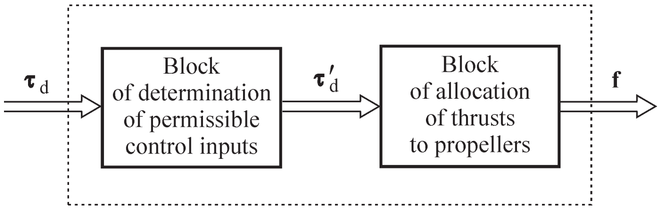


***Fig. 2.*** *Schematic diagram of power distribution module*

In the second phase on the basis of $\boldsymbol{\tau}'_d$ the thrust vector **f** would be calculated, i.e. the allocation of thrusts to particular propellers would be performed.

## THRUST ALLOCATION PROCEDURE FOR HORIZONTAL MOTION

The solution used in majority of conventional unmanned underwater robots is a structure having longitudinal and transverse metacentric stability which ensures motion with small trim and heel angles. Hence the basic motion of such objects is their translation in horizontal plane at changing depth of immersion, being a motion of four degrees of freedom.

It makes it possible to split the propulsion system into two independent subsystems, namely :

- vertical motion subsystem (in vertical plane)
- horizontal motion subsystem (in horizontal plane).

The first produces the propulsive force acting along vertical axis, and the second ensures translational motion along longitudinal and transverse axes and rotation around vertical axis.

In this paper an underwater robot is considered fitted with the propulsion system having the arrangement of propellers shown in Fig.3. Its vertical motion subsystem consists of two vertically arranged, ducted screw propellers. To assess capability of the subsystem to generate the set force $Z_d$ is not a difficult task as its absolute value cannot exceed the sum of maximum thrusts developed by the propellers [4].

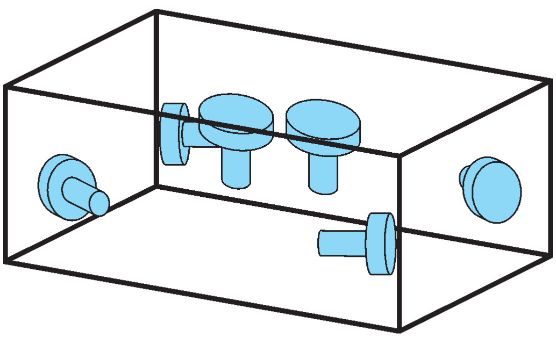

***Fig. 3.*** *Arrangement of the propulsion system fitted with six propellers*

The horizontal motion subsystem consists of four spatially arranged azimuth propellers producing forces along longitudinal and transverse axes as well as moment of force in vertical axis. To assess capability of the subsystem to generate the set forces $X_d$ and $Y_d$ as well as the moment $N_d$ is a complex task as each of the propellers contributes to generating both propulsive forces and propulsive moment. Therefore it is necessary to have a procedure making it possible to assess whether the set control inputs are feasible, and in the case if the subsystem is not capable to produce them to modify them in such a way as to ensure their feasible values. Hence further considerations are limited to plane horizontal motion of the robot.

Let $\boldsymbol{\tau}_d = [\tau_{d1}, \tau_{d2}, \tau_{d3}]^T = [X_d, Y_d, N_d]^T$ stand for the vector of set propulsive forces and propulsive moment, and $\mathbf{f} = [f_1, f_2, f_3, f_4]^T$ - for the vector of thrusts developed by the propellers.

Moreover let the components of the vectors be constrained by the following constraints :

$$\tau_{dj}^2 - \left(\tau_j^{max}\right)^2 \le 0 \quad \text{for} \quad j = \overline{1,3} \tag{2}$$

$$f_i^2 - \left(f_i^{max}\right)^2 \le 0 \quad \text{for} \quad i = \overline{1,4} \tag{3}$$

resulting from design parameters, arrangement and orientation of the propellers within the hull of the robot.

The vector of forces and moment, $\boldsymbol{\tau}$ , is associated with the thrust vector **f** by means of the following relationship [1,2] :

$$\boldsymbol{\tau}_d = \mathbf{T}(\boldsymbol{\alpha})\mathbf{f} \tag{4}$$

where :

$\mathbf{T}(\boldsymbol{\alpha})$ – arrangement matrix of propellers :

$$\mathbf{T}(\boldsymbol{\alpha}) = \tag{5}$$

$$= \begin{bmatrix} \cos(\alpha_1) & \cos(\alpha_2) & \dots & \cos(\alpha_4) \\ \sin(\alpha_1) & \sin(\alpha_2) & \dots & \sin(\alpha_4) \\ d_1 \sin(\alpha_1 - \varphi_1) & d_2 \sin(\alpha_2 - \varphi_2) & \dots & d_4 \sin(\alpha_4 - \varphi_4) \end{bmatrix}$$

$\boldsymbol{\alpha} = [\alpha_1, \alpha_2, ..., \alpha_4]^T$ – vector of thrust angles

$\alpha_i$ – thrust angle of i-th propeller, i.e. the angle between vehicle's longitudinal axis and direction of its thrust force

$\varphi_i$ – orientation angle of i-th propeller, i.e. the angle between vehicle's longitudinal axis and the line connecting the vehicle's mass centre and the propeller axis

$d_i$ – distance of i-th propeller from the vehicle's mass centre.

The quantities $\alpha_i$ , $\varphi_i$ and $d_i$ are shown in Fig.4.

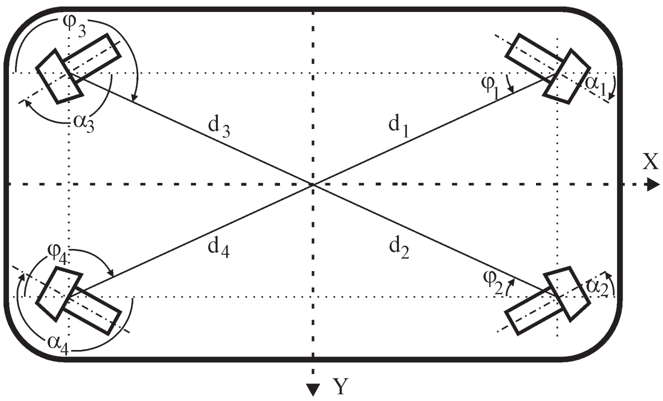


***Fig. 4.*** *Arrangement of 4 propellers in horizontal motion subsystem*

The propellers are aimed at developing such thrusts which can ensure generating the vector of set control inputs $\boldsymbol{\tau}_d = [\tau_{d1}, \tau_{d2}, \tau_{d3}]^T$. Allocation of thrust values to particular propellers is realized in the power distribution module. The problem of determination of values the thrust vector **f** on the basis of the vector of set control inputs $\boldsymbol{\tau}_d$ is usually considered as an unconstrained optimization problem in which a minimum-norm solution is searched for. The solution has the following form [1,5] :

$$\mathbf{f} = \mathbf{T}^*(\boldsymbol{\alpha})\boldsymbol{\tau}_d \qquad (6)$$

where :

Moore-Penrose's pseudo-inverse matrix :

$$\mathbf{T}^*(\boldsymbol{\alpha}) = \mathbf{T}^T(\boldsymbol{\alpha})[\mathbf{T}(\boldsymbol{\alpha}) \cdot \mathbf{T}^T(\boldsymbol{\alpha})]^{-1}$$

Its practical application is possible then and only then, when no demand of developing a thrust value exceeding the limit value (3) by anyone of the thrust propellers is declared. If it is the case then the set control inputs cannot be generated and a modification of their values is necessary, i.e. determination of the vector of permissible control inputs $\boldsymbol{\tau}'_d = [\tau'_{d1}, \tau'_{d2}, \tau'_{d3}]^T$. Together with the vector of control inputs the vector of azimuth angles is computed. A way of determining their values is presented below.

## ALGORITHM FOR DETERMINING THE VECTOR OF PERMISSIBLE CONTROL INPUTS

Let the robot's propulsion subsystem ensuring its planar horizontal motion be consisted of four azimuth propellers of the following features :

- of the same type, hence the thrust $f_i^{max} = f_k^{max} = f^{max}$ for $i, k = \overline{1,4}$
- located at the same distance from the mass centre, symmetrically against the robot's plane of symmetry, namely :

  $d_i = d_k = d$ and $\varphi_i \bmod \frac{\pi}{2} = \varphi_k \bmod \frac{\pi}{2} = \varphi$ for $i, k = \overline{1,4}$
- whose thrust angles satisfy the relationships :
  - at every instant $t$ for $i, k = \overline{1,4}$ and $i \neq k$ :

$$\alpha_i(t) \bmod \frac{\pi}{2} = \alpha_k(t) \bmod \frac{\pi}{2} = \alpha(t)$$

$$0 < \alpha_{min} \le \alpha(t) \le \alpha_{max} = \frac{\pi}{2} - \alpha_{min}$$

$$|\sin[\alpha_i(t)]| = |\sin[\alpha_k(t)]| = \sin[\alpha(t)] \qquad (7)$$

$$|\cos[\alpha_i(t)]| = |\cos[\alpha_k(t)]| = \cos[\alpha(t)]$$

$$|\sin[\alpha_i(t) - \varphi_i]| = |\sin[\alpha_k(t) - \varphi_k]| = \sin[\alpha(t) + \varphi]$$

  - thrust angle change by the value $\pm\Delta\alpha$ occurs in all the propellers simultaneously.

By virtue of the above given assumptions and the relationship (4) the forces and moment at the instant $t$ are described by the following equations :

$$\tau_1[\alpha(t)] = \sum_{i=1}^{4} \cos[\alpha_i(t)] f_i = \qquad (8)$$
$$= \cos[\alpha(t)] \sum_{i=1}^{4} \text{sign}\{\cos[\alpha_i(t)]\} f_i$$

$$\tau_2[\alpha(t)] = \sum_{i=1}^{4} \sin[\alpha_i(t)] f_i = \qquad (9)$$
$$= \sin[\alpha(t)] \sum_{i=1}^{4} \text{sign}\{\sin[\alpha_i(t)]\} f_i$$

$$\tau_3[\alpha(t)] = \sum_{i=1}^{4} d_i \sin[\alpha_i(t) - \varphi_i] f_i = \qquad (10)$$
$$= d \sin[\alpha(t) + \varphi] \sum_{i=1}^{4} \text{sign}\{\sin[\alpha_i(t) - \varphi_i]\} f_i$$

where :

$\tau_1[\alpha(t)]$ , $\tau_2[\alpha(t)]$- propulsive forces along longitudinal and transverse axis, respectively

$\tau_3[\alpha(t)]$- force moment around vertical axis.

(To make the mathematical description more clear, the time symbol $t$ in the notation of the thrust angle $\alpha(t)$ is further omitted).

The maximum values of the quantities, possible to be generated by the propulsion system are as follows :

$$\tau_{1max} = \max_{\alpha_{min} \le \alpha \le \alpha_{max}} \tau_1(\alpha) = 4\cos(\alpha_{min}) f_{max}$$

$$\tau_{2max} = \max_{\alpha_{min} \le \alpha \le \alpha_{max}} \tau_2(\alpha) = 4\sin(\alpha_{max}) f_{max} \qquad (11)$$

$$\tau_{3max} = \max_{\alpha_{min} \le \alpha \le \alpha_{max}} \tau_3(\alpha) = 4 d f_{max}$$

for :

$$\alpha = \frac{\pi}{2} - \varphi$$

An analysis of Eq. (10) shows that the propulsive moment $\tau_3(\alpha)$ depends on the thrust angle $\alpha$ through the term $\sin(\alpha + \varphi)$, where the angle $\varphi$ is a time - independent design parameter.

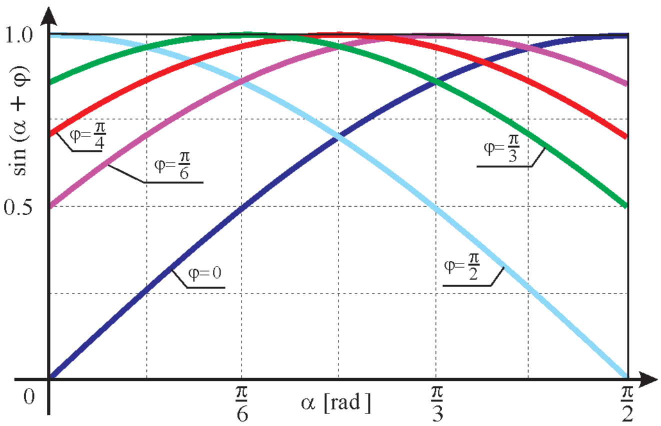


***Fig. 5.*** *Influence of selected values of the angle φ on sin(a + φ) value*

In Fig.5 runs of the relationship $\sin(\alpha + \varphi)$ in function of the angle $\alpha \in (0, \frac{\pi}{2})$ are illustrated for some values of the angle $\varphi$ contained in the interval $(0, \frac{\pi}{2})$. They demonstrate that for a fixed value of the angle $\varphi$ it is possible to determine such value of the propulsive moment which can be always generated independently of a current value of the thrust angle $\alpha$. The value is further marked $\tau_{3max}$ and calculated as follows :

$$\tau_{3max} < \min_{\alpha \in (\alpha_{min}, \alpha_{max})} \tau_3(\alpha) = \qquad (12)$$
$$= \begin{cases} 4d\sin(\alpha_{min} + \varphi) f_{max} & \text{for} \quad \varphi \in \left(0, \frac{\pi}{4}\right\rangle \\ 4d\sin(\alpha_{max} + \varphi) f_{max} & \text{for} \quad \varphi \in \left(\frac{\pi}{4}, \frac{\pi}{2}\right) \end{cases}$$

Therefore, by applying the following constraint onto the propulsive moment $\tau_{d3}$ :

$$\tau_{d3}^2 - \tau_{3max}^2 \le 0 \qquad (13)$$

its feasibility is ensured within the entire range of variability of the thrust angle $\alpha$.

Values of the propulsive forces which should be developed by the propellers to generate the moment $\tau_{3max}$ independently of a value of the thrust angle $\alpha$ , are determined by the relationship:

$$f_{\tau_{3max}} = \begin{cases} \dfrac{\tau_{3max}}{4d\sin(\alpha_{min} + \varphi)} & \text{for} \quad \varphi \in \left(0, \dfrac{\pi}{4}\right\rangle \\ \dfrac{\tau_{3max}}{4d\sin(\alpha_{max} + \varphi)} & \text{for} \quad \varphi \in \left(\dfrac{\pi}{4}, \dfrac{\pi}{2}\right) \end{cases} \qquad (14)$$

The reserving of a part of propeller's output to generate the force moment $\tau_{3max}$ makes that the maximum values of the forces $\tau_{1max}$ and $\tau_{2max}$ which can be generated by the propulsion system, will be smaller. Their new values marked $\tau_{1max}$ and $\tau_{2max}$, respectively, are now :

$$\tau_{1max} = 4\cos(\alpha_{min})(f_{max} - f_{\tau_{3max}})$$
$$\tau_{2max} = 4\sin(\alpha_{max})(f_{max} - f_{\tau_{3max}}) \qquad (15)$$

In further considerations it was assumed that :

$$\tau_d = [\tau_{d1} , \tau_{d2} , \tau_{d3}]^T$$

is the vector of set control inputs whose components satisfy the constraints :

$$\tau_{d1}^2 - \tau_{1max}^2 \le 0 \;,\; \tau_{d2}^2 - \tau_{2max}^2 \le 0 \;,\; \tau_{d3}^2 - \tau_{3max}^2 \le 0$$

and P is a point of planar coordinates ($\tau_{d2}$, $\tau_{d1}$).

By analyzing the relationships (8) and (9) it was stated that the demanded propulsive forces $\tau_{d1}$ and $\tau_{d2}$ can be simultaneously generated by the propulsion system then and only then if the point P is located inside or at the edge of a geometrical figure shown in Fig.6. The figure is an asteroid described as follows :

$$\tau_1^{\frac{2}{3}} + \tau_2^{\frac{2}{3}} - \tau_{1max}^{\frac{2}{3}} = 0 \qquad (16)$$

whose vertices are the points of the coordinates :

($\tau_{2max}$ , 0) ; (0 , $\tau_{1max}$) ; (- $\tau_{2max}$ , 0)

and (0 , - $\tau_{1max}$) respectively.

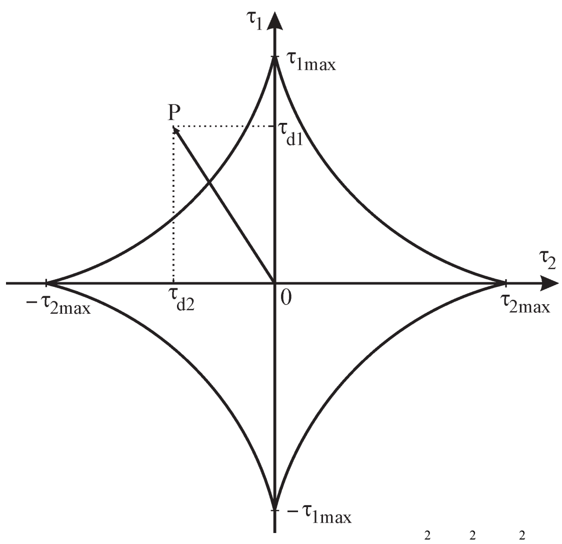


***Fig. 6.*** *The asteroid described by the equation* $\tau_{d1}^{\frac{2}{3}} + \tau_{d2}^{\frac{2}{3}} = \tau_{1max}^{\frac{2}{3}}$, *and the position vector* OP

However if the point P lies outside the asteroid then the propulsion system is uncapable to develop set forces. Then the vector of permissible forces and moment $\boldsymbol{\tau}'_d = [\tau'_{d1} , \tau'_{d2} , \tau_{d3}]^T$ and the corresponding thrust angle $\alpha'$ should be determined.

The schematic diagram of the algorithm for determining the permissible control inputs $\boldsymbol{\tau}'_d$ and the angle $\alpha'$ is shown in Fig.7. Input data for the algorithm are :

- the set vector of control inputs $\boldsymbol{\tau}_d$
- the maximum value of the propulsive force $\tau_{1max}$
- a current value of the thrust angle $\alpha$

and, the task of determining the permissible values of propulsive forces $\tau'_{d1}$ and $\tau'_{d2}$ as well as of the thrust angle $\alpha'$ is realized for the following conditions :

- the propulsive moment is kept unchanged : $\tau'_{d3} = \tau_{d3}$
- the mutual ratio of the forces : $\dfrac{\tau'_{d1}}{\tau'_{d2}} = \dfrac{\tau_{d1}}{\tau_{d2}}$ is maintained.

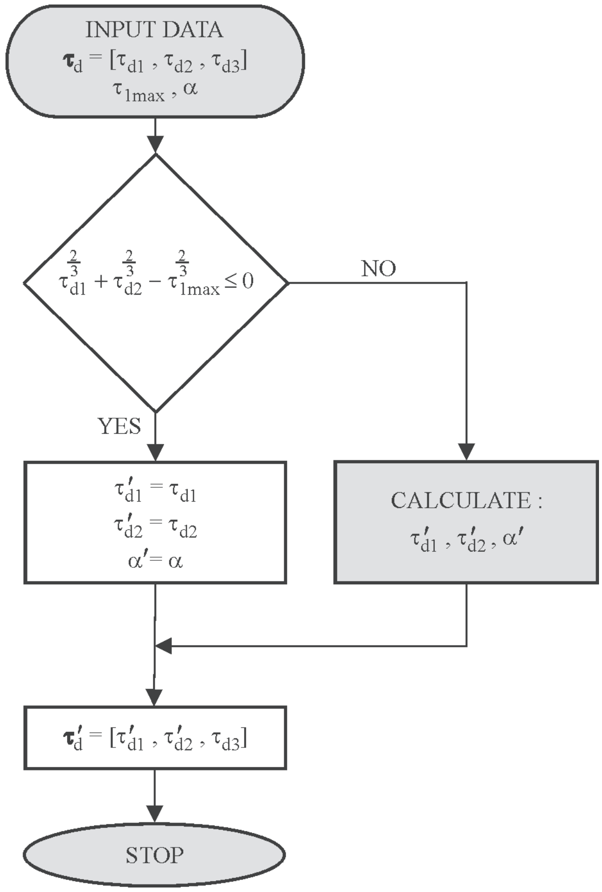


***Fig. 7.*** *Schematic diagram of the algorithm for determining permissible control inputs and thrust angle*

The algorithm in question consists of the following steps :

**1**. ***Calculate the expression*** :

$$\tau_{d1}^{\frac{2}{3}} + \tau_{d2}^{\frac{2}{3}} - \tau_{1max}^{\frac{2}{3}} \le 0 \qquad (17)$$

to check whether the point P = ($\tau_{d2}$ , $\tau_{d1}$) lies inside or at the edge of the asteroid.

**2**. ***If the inequality* (17) *is true then apply substitutions*** :

$$\tau'_{d1} = \tau_{d1}$$
$$\tau'_{d2} = \tau_{d2}$$
$$\alpha' = \alpha$$

and go to Step 4.

**3**. ***If the inequality* (17) *is false then calculate*** :

$$\tau'_{d1} = \mathrm{sign}(\tau_{d1})\left|\frac{\tau_{d1}}{\tau_{d2}}\right|\left(\left(\frac{\tau_{d1}}{\tau_{d2}}\right)^{\frac{2}{3}}+1\right)^{-\frac{3}{2}}\tau_{1max}$$

$$\tau'_{d2} = \mathrm{sign}(\tau_{d2})\left(\left(\frac{\tau_{d1}}{\tau_{d2}}\right)^{\frac{2}{3}}+1\right)^{-\frac{3}{2}}\tau_{1max} \qquad (18)$$

$$\alpha' = \frac{\pi}{2} - \arctan\left(\left|\frac{\tau_{d1}}{\tau_{d2}}\right|^{\frac{1}{3}}\right)$$

**4**. ***Apply substitutions*** :

$$\boldsymbol{\tau}'_d = [\tau'_{d1}, \tau'_{d2}, \tau_{d3}]^T$$

**5**. ***The end of the algorithm***.

The proof of Eq. (18) can be found in [6].

## Numerical example

Numerical calculations were carried out for the following data :

$\tau_d$ = [700 N ; - 120 N ; 50 Nm]$^T$

$\tau_{3min}$ = 50 Nm , $f_{max}$ = 250 N

$\varphi$ = 30° , d = 0.4 m

The value of $\tau_{1max}$ was calculated for the worst case, i.e. for the angle $\alpha_{min}$ = 0° :

$$\tau_{1max} = 4(f_{max} - f_{\tau_3}) =$$

$$= 4\left(250 - \frac{50}{4 \cdot 0.4 \cdot \sin(30°)}\right) = 750\,\mathrm{N}$$

### Step 1

Check if the point ($\tau_{d2}$ , $\tau_{d1}$) lies inside or at the edge of the asteroid, i.e. check the condition (17) :

$$\tau_{d1}^{\frac{2}{3}} + \tau_{d2}^{\frac{2}{3}} - \tau_{1max}^{\frac{2}{3}} \le 0$$

$$700^{2/3} + (-120)^{2/3} - 750^{2/3} = 20.6 > 0$$

### Step 2

As the inequality has appeared false the point ($\tau_{d2}$ , $\tau_{d1}$) lies outside the asteroid. Calculate – by using (18) – permissible values of forces and thrust angle :

**A**. *Calculation of the value of the force* $\tau'_{d2}$:

$$\tau'_{d2} = \mathrm{sign}(\tau_{d2})\left(\left(\frac{\tau_{d1}}{\tau_{d2}}\right)^{\frac{2}{3}}+1\right)^{-\frac{3}{2}}\tau_{1max} =$$

$$= \mathrm{sign}(-120)\left(\left(\frac{700}{-120}\right)^{\frac{2}{3}}+1\right)^{-\frac{3}{2}}750 = -85.9$$

**B**. *Calculation of the value of the force* $\tau'_{d1}$ :

$$\tau'_{d1} = \mathrm{sign}(\tau_{d1})\left|\frac{\tau_{d1}}{\tau_{d2}}\right|\left(\left(\frac{\tau_{d1}}{\tau_{d2}}\right)^{\frac{2}{3}}+1\right)^{-\frac{3}{2}}\tau_{1max} =$$

$$= \mathrm{sign}(700)\left|\frac{700}{-120}\right|\left(\left(\frac{700}{-120}\right)^{\frac{2}{3}}+1\right)^{-\frac{3}{2}}750 = 501$$

**C**. *Calculation of the value of the angle* $\alpha'$ :

$$\alpha' = \frac{\pi}{2} - \arctan\left(\left|\frac{\tau_{d1}}{\tau_{d2}}\right|^{\frac{1}{3}}\right) =$$

$$= \frac{\pi}{2} - \arctan\left(\left|\frac{700}{-120}\right|^{\frac{1}{3}}\right) = 0.51\,\mathrm{rad} = 29.1°$$

### Step 3

Calculation of the vector of permissible control inputs :

$$\boldsymbol{\tau}'_d = [501 \;;\; -85.9 \;;\; 50]$$

To assess correctness of the calculations it was checked if the ratio of longitudinal and transverse forces was kept unchanged:

$$\frac{\tau_{d1}}{\tau_{d2}} = \frac{700}{-120} = -5.83 \quad ; \quad \frac{\tau'_{d1}}{\tau'_{d2}} = \frac{501}{-85.9} = -5.83$$

The obtained result showed that after correction the ratio of the forces was of the same value.

## RECAPITULATION

- The presented paper concerns synthesis of an automatic control system for unmanned underwater robot, particularly its phase connected with power distribution in multi-propeller propulsion system. Planar horizontal motion of the robot executed by means of four azimuth propellers was considered.
- For thrust allocation to the propellers an unconstrained optimization method was applied. To use the method practically in a propulsion system of a limited power output a procedure which makes it possible to assess its capability of generating demanded forces and moment was elaborated.
- For the case when the task appears unfeasible an algorithm was proposed allowing to modify propulsive forces by proportional decreasing their values and determining permissible ones, i.e. the forces which the propulsion system is capable to develop.
- The performed numerical tests confirmed correctness of the applied approach.

**NOMENCLATURE**

$d_i$ – distance from i-th propeller to robot's mass centre
$f_i$ – i-th propeller's thrust
**f** – vector of thrusts
K – propulsive moment around longitudinal axis of hull-fixed reference system

M – propulsive moment around transverse axis of hull-fixed reference system
N – propulsive moment around vertical axis of hull-fixed reference system
p – angular velocity around longitudinal axis of hull-fixed reference system
q – angular velocity around transverse axis of hull-fixed reference system
r – angular velocity around vertical axis of hull-fixed reference system
t – time
$\mathbf{T}(\mathbf{a})$ – arrangement matrix of propellers
u – linear velocity along longitudinal axis of hull-fixed reference system
$\mathbf{v}$ – vector of linear and angular velocities in hull-fixed reference system
w – linear velocity along vertical axis of hull-fixed reference system
x – x – coordinate of vehicle's position in inertial reference system
X – propulsive force along longitudinal axis in hull-fixed reference system
y – y – coordinate of vehicle's position in inertial reference system
Y – propulsive force along transverse axis in hull-fixed reference system
z – z – coordinate of vehicle's position in inertial reference system
Z – propulsive force along vertical axis in hull-fixed reference system

$\alpha_i$ – i-th propeller thrust angle
$\boldsymbol{\eta}$ – vector of location and orientation of vehicle in inertial reference system
$\theta$ – heel angle
$\nu$ – linear velocity along transverse axis of hull-fixed reference system
$\boldsymbol{\tau}$ – vector of propulsive moments and forces
$\boldsymbol{\tau}_d$ – vector of demanded propulsive moments and forces
$\varphi_i$ – i-th propeller orientation angle
$\phi$ – trim angle
$\psi$ – course angle

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## Conference

# MECHANIKA 2005

On 4 February 2005,
Mechanical Faculty,
Gdańsk University of Technology,
organized the Scientific Conference :

***Mechanika***

**on the occasion of 60th anniversary of its activity**.

Such conferences were earlier arranged in the years 1995, 1997 and 1999. Their idea was to promote achievements of scientific workers from mechanical faculties of the technical universities located in North Poland, i.e. in Gdańsk, Gdynia, Szczecin, Koszalin, Bydgoszcz, Olsztyn, Białystok and Elbląg., as well as of the Institute of Fluid Flow Machinery, Polish Academy of Sciences, Gdańsk. It was mainly expected to draw interest of industrial enterprises of that region to those achievements. However effects of the attempts appeared unsatisfactory as technological parks, industrial fairs and branch conferences have become more effective occasions for contacts between scientific and industrial circles.

As a result of the situation, this-year Conference was devoted to mutual presentation of selected research results and discussion on prospects of development of mechanical sciences within the frame of developing international cooperation.

In compliance with the Conference's program 35 papers were presented during three topical sessions :

- ***Techniques and engineering processes of manufacturing*** (12 papers)
- ***Drives and energy systems*** (12 papers)
- ***Computer methods in mechanics*** (11 papers).

Representatives of the Conference's organizer - - with 17 papers - contributed the most to the elaboration of the presented papers.

The remaining ones were prepared by authors from :

the Faculty of Ocean Engineering and Ship Technology – – Gdańsk University of Technology, Olsztyn Technical Agricultural Academy, Białystok University of Technology, Technical University of Szczecin, Warmia-Mazury University, Institute of Fluid-Flow Machinery of PAS – – Gdańsk, Koszalin University of Technology, Polish Naval University, the State Higher School of Engineering in Elbląg, and ALSTOM company.