Radio Controlled Fish Robot *RR-9*

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Abstract − **A remote-controlled underwater robot fish is described. For motion control three actuator drives are used: one actuator is for tail frequency exchange, the second actuator is for the left or right turnings and the third actuator provides neutral swimming or up and down diving. From the robot's center of mass motion theorem (according to the given total mass of robot) the proportional distribution of masses of structural elements is found. Experimental indoor and outdoor investigation of robot fish is given.**

Keywords − **Fish robot, mass equation of existence, radio control system**.

I. Introduction

Researching biomimetic robot fish has a lot of practical applications. These robot fishes can simulate the principles of real fish swimming [1]. From various technical aspects it makes the motion of robot fish more efficient than the existing unmanned underwater vehicles with propeller propulsion mechanisms. According to the theory of classical mechanics theory robot fish has better abilities of swimming, drifting, accelerating, balancing and steering. Using the help of biomimetic robot fish, a lot of both civil and military tasks could be solved, for example: discovery of large concentrations of fish and pointing to fishing ships them , inspection of underwater part of the ships without individual divers, measurement of the speed of ocean currents at various depths, search for minerals on the seabed and the ocean, search for wrecks and mines [2].

Many companies in their publications show the quality and benefits of their product. But accordingly to them it is difficult to judge the theoretical problems of product design and production. In this context for under water robot design it is important to understand the theoretical task of distribution of masses of underwater robot fish elements that provide a neutral floating or diving and takeoff.

In this report authors (on the example of designing fish robot *RR-9*) formulate and offer five sub-criteria (or factors) for evaluation of efficiency of robot fish: factor specific power of electric motor; factor specific capacity of the accumulator; factor specific durability; factor perfection of a computer; factor of propulsion on the maximum speed.

According to these sub-criteria it is possible to compare different levels of development of robot fish.

This work was carried out within the framework of the International European project (FILOSE, Project reference: 231495; Funded under: FP7-ICT) «Robotic Fish Locomotion and sensing» together with Tallinn University of Technology , University of Verona, Italian Institute of Technology and University of Bath [3].

In this project the main task was to obtain a prototype: with total weight not more than 1.5 kg (micro robots), useful loading at least 40 % of the total weight, body length approximately 0.5 m, swimming speed no less than 1.5 km/h, turn radius of about two full lengths.

II. Underwater Robot Rest Position

For simple understanding of robot diving or neutral floating motion next vector equations of motion of center mass and moment of momentum exchange can be analyzed [4] (Fig. 1):

$$M_{\mathrm{r}} \cdot \bar{a}_C = \sum_1^n \bar{F}_k^{(e)}; \qquad (1)$$

$$\frac{\mathrm{d}\bar{L}_C}{\mathrm{d}t} = \sum_1^n \bar{M}_C(F_k^{(e)}), \qquad (2)$$

where M_{r} − total mass of the robot, $\bar{a}_C$ − acceleration of mass center C, $\sum_1^n \bar{F}_k^{(e)}$ − sum of external forces, acting on robot, $\bar{L}_C$ − moment of momentum against mass center, $\frac{\mathrm{d}\bar{L}_C}{\mathrm{d}t}$ − derivation of $\bar{L}_C$ by time t, $\sum_1^n \bar{M}_C(F_k^{(e)})$ − sum of external moments of forces against center C.

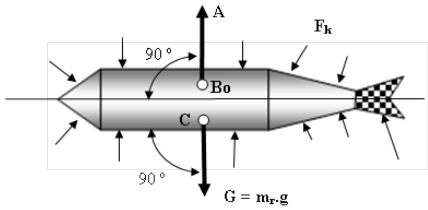


Fig. 1. Oversight scheme of robot at horizontal rest position. *C* – center of mass; *Bo* – center of buoyancy; *G* – gravity force; *A* – Archimedes force.

According to equations (1) and (2) for stable equilibrium (neutral floating − before motion starts) the center of gravity *C* can be below center of buoyancy *Bo* on one line (Fig. 1, Fig. 2) [4], [5]. Additionally, water and robot surface interaction forces or Archimedess' force *A* can be equal to gravity force *G*:

$$\rho \cdot V_{\mathrm{r}} = M_{\mathrm{r}} \cdot g, \qquad (3)$$

were $\rho = 1000\ \mathrm{kg \cdot m^{-3}}$ − the density of water (approximately for temperature 4° C); $g = 9.81\ \mathrm{m \cdot s^{-2}}$ − acceleration of free fall; V_{r} − volume of the robot. Therefore from simple condition (3) it follows that if volume V_{r} of robot is given, then total mass

M_r can be efficiency distributed between seven elements of the robot (4).

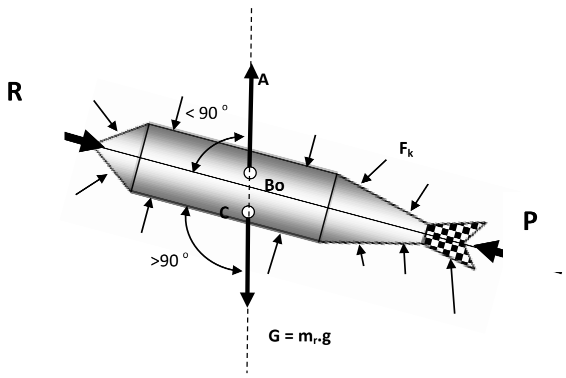


Fig. 2. Oversight scheme of robot on oblique position. *C* – center of mass, *Bo* – center of buoyancy, *G* – force of gravity , *A* – Archimedes' force, *R* – force of water resistance , *P* – propulsion force.

III. Mass Equation of Existence

Components of the general mass of fish robot M_r are presented in the formula:

$$M_r = M_{tc} + M_{ac} + M_{em} + M_{cs} + M_{cd} + M_{km} + M_{ul} , \quad (4)$$

where M_{tc} – mass of the housing (tight case), M_{ac} – mass of the accumulator, M_{em} – mass of the electric motor, M_{cs} – mass of control system (a radio receiver, servo-drivers, a regulator of turns), M_{cd} – mass of control devices (depth wheels, a tail), M_{km} – mass of the kinematic mechanism transfers of capacity from the electric motor to a tail, M_{ul} – mass of useful loading. Having divided all members of the equation (4) on M_r we will receive the same equation in relative parameters:

$$1 = \zeta_{tc} + \zeta_{ac} + \zeta_{em} + \underline{\zeta_{sc}} + \zeta_{cd} + \zeta_{km} + \zeta_{ul} , \quad (5)$$

where:

$\zeta_{tc} = M_{tc}/M_r$, $\zeta_{ac} = M_{ac}/M_r$, $\zeta_{em} = M_{em}/M_r$, $\zeta_{cs} = M_{cs}/M_r$, $\zeta_{cd} = M_{cd}/M_r$, $\zeta_{km} = M_{km}/M_r$, $\zeta_{ul} = M_{ul}/M_r$.

Relative factors of mass ζ are indicators of technical efficiency of the fish robot.

From the equation (5) it is seen, that each numerical value of relative factor of mass ζ always is less than one, and their sum cannot exceed one. From this follows, that at the given level of development of technique it is impossible to design the fish robot that simultaneously has all good technical characteristics. For example, if we wish to design robot with large swimming distance by increasing the mass of accumulators, then factors ζ_{ac} will increase too and will decrease other factors, for example the factor ζ_{em} . This will lead to the necessity of reduction of mass of the electric motor and so to the reduction of propulsion force and as consequence − to reduction of the maximum speed of robot fish.

Therefore, for real robot fish design tasks it is necessary to solve the problem of a multi criteria optimization of a system [6]. In this task of synthesis of efficiency robot fish can be analyzed as minimum of the following five sub-criteria (factors) of robot development:

- factor specific power of the electric motor $\varphi_{em} = N_{em}/M_{em}$,
- factor specific capacity of the accumulator $\varphi_{ac} = C_{max}/M_{ac}$,
- factor specific durability $\varphi_\sigma = \sigma_{max}/\gamma$,
- factor perfection of a computer $\beta = B_c/M_c$,
- factor of propulsion on the maximum speed $\varphi_t = T/M_r$,

where: N_{em} − power of the electric motor, C_{max} − the maximum electro capacity of the accumulator, σ_{max} − the maximum working pressure for the housing material, γ − relative density of the material of the housing, B_c − memory size of the computer, M_c − mass of the computer, T − draught of the fin actuator, M_r − total mass of the fish robot.

IV. General Characteristic of Fish Robot *RR-9*

For designing the robot a trout was chosen as basis fish (Fig. 3). The following parameters were accepted:

- mass − 1.5 kg,
- total volume – 1500 cm^3,
- total length – 0.56 m,
- length of thw tail equal to 1/3 of length of the fish,
- the tail executed for technological reasons is made in the form of an elastic flat plate of variable rigidity on length (Fig. 4),
- the centre of buoyancy is located ahead of the centre of gravity and is in the bottom part of fish robot, that provides a cross-section stability,
- electric motor with direct current power 30 W and voltage 7.2 V was used.

The head part is made in the form of a cone, the central middle part is made in the form of a cylinder, but the tail is in the form of an elastic flat plate with the area 82 cm^2 (Fig. 4 – Fig. 6). Contours of the tail of fish robot repeat the contours of a tail of a trout (Fig. 3).

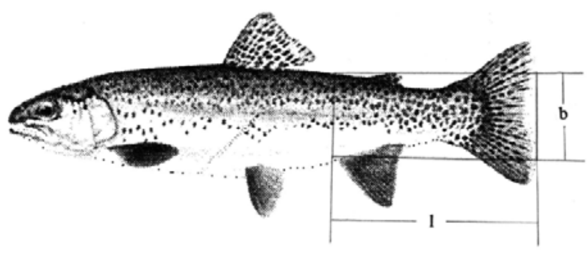


Fig. 3. A trout.

Inside the robot body there are is: the accumulator, the radio receiver, the servomotor (step driver) for depth control, the regulator of side turns by the course servomotor, the tail frequency control driver.

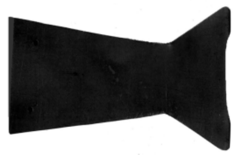
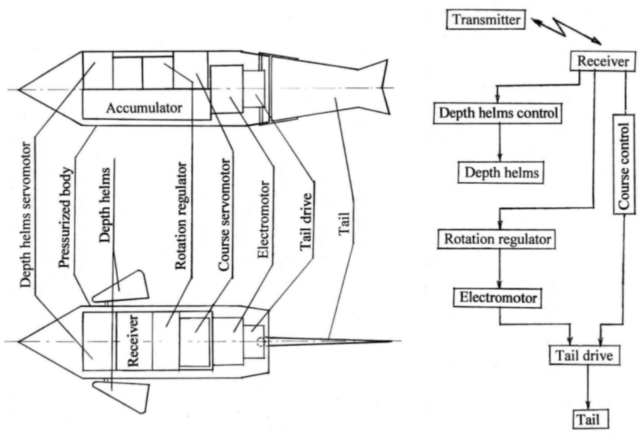


Fig. 4. A flexible laminated tail of the fish robot.

The model works as follows (Fig. 5 a, b). The signals sent from a radio transmitter arrive on the corresponding channel of a radio receiver. Then the control signals of management of two step drivers (for course and speed control) act on the tail, providing chosen motion velocity and course regime in horizontal plane. The signal for depth control by third step driver provides diving or stowage motion in the vertical plane.



a b

Fig. 5. Fish robot *RR-9*: a − a design; b − the management scheme.

For robot fish *RR-9* the following elements are used:

- radio transmitter type: 6 channel with 2 manipulators and inner microprocessor;
- outlet power 600 mW; a frequency range 40 MHz with modulation PPM/FM;
- radio receiver type: 6 channels with modulation PPM/FM; a frequency range 40 MHz; sensitivity 15 µV;

The general view of fish robot *RR-9*, having neutral buoyancy, with the radio management panel is seen in Fig. 6. It is necessary to carry a horizontal arrangement of the engine, management of a draught vector to constructive novelty of fish robot in the horizontal plane, new mechanisms of transfer of power on a tail fin. Proposed solutions are patented.

Fig. 6. The general view of fish robot *RR-9* (with the radio management panel).

As a result of the design, the following values of relative factors of weight ζ (take into account the mass equation) and also factors of perfection of construction for robot fish *RR-9* are received:

- $\zeta_{tc} = 0.15$; $\zeta_{ac} = 0.18$; $\zeta_{em} = 0.12$; $\zeta_{cs} = 0.05$; $\zeta_{cd} = 0.06$; $\zeta_{km} = 0.02$; $\zeta_{ul} = 0.42$;

- $1 = 0.15 + 0.18 + 0.12 + 0.05 + 0.06 + 0.02 + 0.42$
- $\varphi_{em} = 0.34$ W·g^{-1}; $\varphi_{ac} = 18.46$ mAh·g$_{-1}$; $\varphi_{\sigma} = 290$ cm; $\beta_c = 13.4$ MB·g^{-1}; $\varphi_t = 0.67$ m·s^{-2}.

From the analysis of resulted factors it is possible to draw following conclusions. The housing mass of this case ($\zeta_{tc} = 0.15$) makes 15 % from a total mass while at rocket designs it can reach only 3–4 %. Therefore, in future housings can be worked on − like thin-walled frame covered with a preliminary tension of cover.

In spite of the fact that for robot fish *RR-9* a modern lithium-polymeric accumulator is the energy source, its mass ($\zeta_{ac} = 0.18$) is large (18 % from the total mass). This limits range of swimming and demands working on more perfect accumulators, or the need of additional charge of accumulator during swimming.

The weight of useful loading equal of 42 % **(**$\zeta_{dl} = 0.42$) that gives the chance to place into housing various equipment − gauges, illumination and photographic devices, micro devices artificial intelligence (in the form of the onboard computer for storing of the collected information), realization of the adaptive set program for movement of the fish.

Other relative factors of weight ζ and factors perfection of construction (in view of the limited volume of robot fish *RR-9*) here are not commented. They may be useful for different experts for comparison of similar characteristics of other fish robots to solve the problem of a multi criteria optimization of a system [6].

V. Tests of Radio-Controlled Fish Robot

For recording experimental information in pool, the test bed contains: a computer measure complex with a digital storage oscillograph; a laser tachometer; an electronic chronometer; a digital multimeter; adjustable power supplies.

The digital multimeter measured values of pressure and a current for various motion modes of fin according to electric motor capacity. The contactless stroboscope fixes rotary vibrations frequency of tail under loading, both in air and in water.

The speed of movement of model center mass was defined with the help of a chronometer.

The resistance factor *Cx* of fish robot was experimentally found in an Armfield wind tunnel in the Institute of Mechanics (RTU). It was found as the draught force $T = Cx$ that was measured with constant swimming speed.

The obtained experimental data allowed calculations of efficiency of model as the relative power efficiency factor by the formula:

$$\eta = \frac{T \cdot v}{I \cdot U} \cdot 100\% \qquad (6)$$

or

$$\eta = \frac{T \cdot v}{N} \cdot 100\% \,, \qquad (7)$$

where: T − force of draught (N); v − speed of movement in water (m/s); U − voltage of electric motor (V), I − a current consumed by an electric motor (A), N − power consumed by an electric motor (W).

Dependence of swimming speed and draught on voltage of the electric motor is presented in Fig. 7. Power consumption and the general efficiency is shown in Fig. 8.

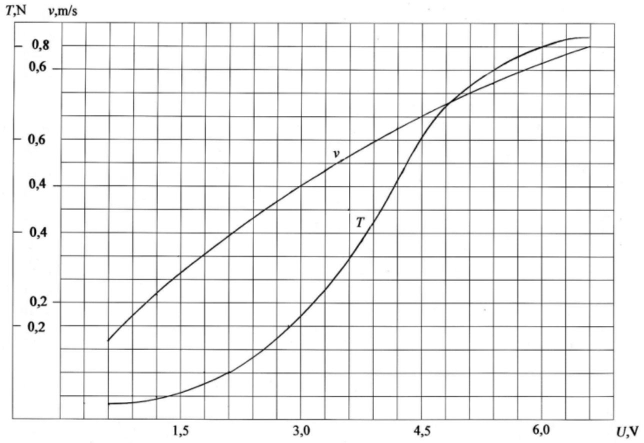


Fig. 7. Swimming speed *v* and draught *T* dependence as function of voltage *U* of the electric motor.

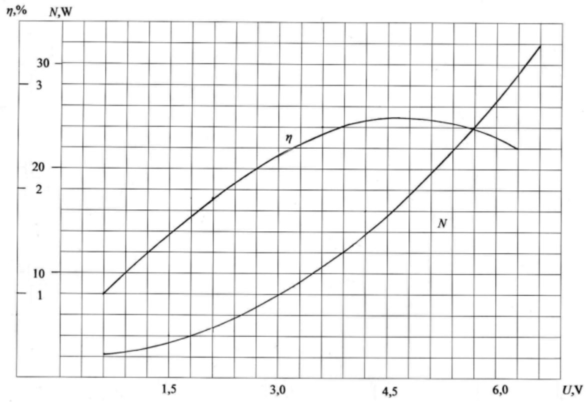


Fig. 8. Power consumption *N* and efficiency *η* dependence as function of voltage *U* of the electric motor. Extreme is in the region U = 4.8 V.

In process of increase of voltage *U*, draught *T* and speed *v* of swimming object also increase. But the increase of swimming speed also increases the power consumption.

Dependence of the general efficiency on speed has extreme character [12] as shown, for example, at Baikal harius (grayling) (Fig. 9).

Additional evaluation of efficiency in the field of an extreme of the general efficiency (U = 4.8 V) may be calculated by formula:

$$\eta_p = \frac{T \cdot v}{N_p} \cdot 100\% = 16.1\% ,$$

where N_p − the power transferred to the tail, which composes 7.3 % of electric motor power. It was defined as a power consumption difference in water with a tail and without a tail.

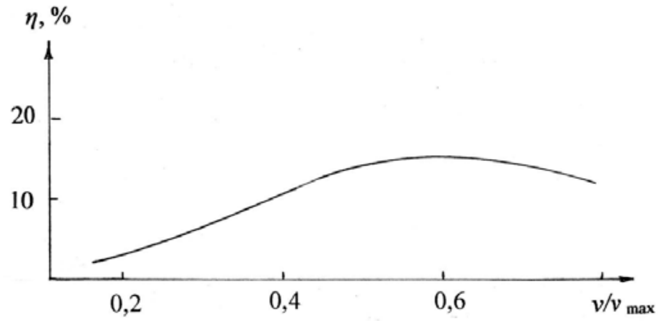


Fig. 9. Efficiency change *η* depending on the speed of Baikal harius.

Tests in Kish-lake have allowed to define the minimum radius of a turn to be 1.0 m and the depth of immersion near to the radio management panel to be 5 m. Duration of the time of swimming and speed were 0.5 h and 1.8 km·h^{-1}, accordingly.

VI. Experiments in Nature

Linear and square water tank was used for experimental indoor investigations of robot *RR-9* (Fig. 10 – Fig. 14). Additionally, outdoor experiments were made in Kish-lake (Fig. 15, Fig. 16). Some comments on floating and diving motion of robot *RR-9* in these experiments are given under pictures below.

Fig. 10. Neutral diving and floating ahead motion of robot *RR-9* in linear tank.

Fig. 11. Straight corners water tank with some floating devices. In the forefront is robot *RR-9* in neutral floating (before motion starts). Robot is controlled using three actuators: a tail frequency actuator for propulsion force generation, a steering angle exchange actuator and an up or down motion control actuator (by side fin rotation angle exchange).

Fig. 12. Start of the diving motion of robot *RR-9* in water tank. On the right side under water video camera can be seen.

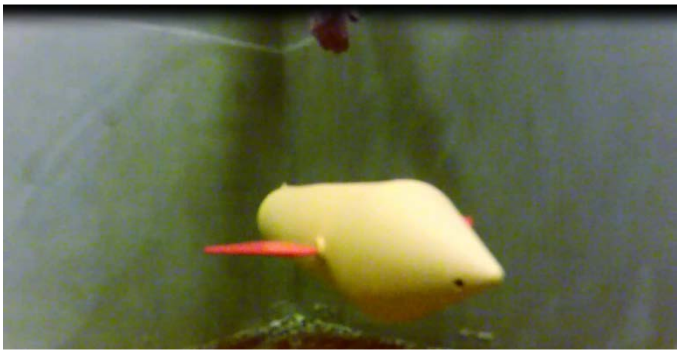


Fig. 13. Robot *RR-9* moves underwater horizontally inside the straight corners water tank.

Fig. 14. Robot *RR-9* moves up with a left turn in water tank corner.

Fig. 15. Outdoor experiment with robot *RR-9* in the Kish-lake. It can be seen how the robot takes the left turn in itself caused water surface waves.

Fig. 16. Diving motion of the robot. It can be seen that robot moves very efficiently by generation of local water waves.

VII. Conclusion

In this report the design of a diving or floating underwater robot with an effective mass distribution is discussed. Using it optimal parameters of the robot are found, and then it is designed, manufactured and experimentally tested at Riga Technical University. It was that found out that the swimming speed of the robot with total weight of 1.5 kg is $0.5\ \text{m}\cdot\text{s}^{-1}$. Linear and square water tanks were used for experimental indoor investigations of robot *RR-9*. Additionally, outdoor experiments were made in Kish-lake.

Acknowledgement

This work was carried out within the framework of the International European project «Robotic Fish Locomotion and sensing». As a result, the design and manufacture managed to get a cheap and technologically simple radio controlled micro robot, which according to its technical characteristics is comparable with foreign models.

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Semjons Cifanskis, Jānis Vība, Vladimirs Jakuševičs. Radiovadāms zivs robots RR-9
Rakstā aplūkoti zivs robota tehniskie parametri, kas iegūti, izmantojot sastādošo elementu masu eksistences vienādojumu. Tas ietver relatīvos svērtos koeficientus, kā arī agregātu un sistēmas pilnveides koeficientus. Aprakstītas zivs robota konstrukcijas īpatnības ar izstrādāto radiovadības sistēmu brīvdabas izmēģinājumu apstākļos. Izveidotajā zemūdens zivs robotā izmantoti zemūdens organismu pārvietošanās principi, kuru pielietojums varētu atrisināt daudzus – gan civilos, gan militāros – uzdevumus: lielu zivju koncentrāciju atklāšanu un to vietu norādīšanu zvejas kuģiem; kuģu zemūdens daļu pārbaudes inspekciju bez nirstošiem ūdenslīdējiem; okeānu straumes ātruma mērīšanu dažādos dziļumos; minerālvielu meklēšanu jūras un okeāna dibenā; nogrimušu kuģu karkasu un mīnu meklēšanu. Atzīmēts, ka, reklamējot savu produkciju, daudzi uzņēmumi sniedz tikai informāciju par produkta „ekstremālo" tehnisko raksturojumu, kas neļauj novērtēt tā tehnisko izcilību, kā arī nedod iespēju izvērtēt produkta attīstību kopumā un dot atziņu par tā zinātnisko vērtību. Šajā darbā visas esošās specifikācijas savienotas vienā objekta elementu masu vienādojumā, kas parāda, ka dotajā tehnoloģijas līmenī nevar izveidot zivs robotu, kam piemīt visas ekstrēmās īpašības visos vēlamajos kritērijos. Zivs robota projektēšanā piedāvāts salīdzināt izstrādātās konstrukcijas, lietojot relatīvos elementu masu koeficientus un agregātu vai iekārtu pilnveides koeficientus. Kopumā tie dod pilnīgāku priekšstatu par radītā robota praktisko attīstības līmeni. Saskaņā ar tehnisko uzdevumu darbā atrisināts uzdevums, kā radīt efektīvu zivs robotu ar šādiem parametriem: kopējais svars – ne vairāk par 1,5 kg (mikrorobots); kravnesība – vismaz 30 % no kopējā svara; korpusa garums – aptuveni 0,5 m; peldēšana ātrums – nav mazāks par 1,5 km/h; un peldēšanas pagriezienu rādiuss – vienāds ar diviem korpusa garumiem.