# FISH-LIKE SWIMMING PROTOTYPE OF MOBILE UNDERWATER ROBOT

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## Abstract:

*In this paper, authors present a new approach to the design of a mobile underwater robot inspired by a fish. They describe a prototype of a self-designed and a self-made mobile underwater robot called the CyberFish, which resembles fish in the way it looks and behaves. In the beginning, a short consideration on fish-like swimming is presented. Then the biological inspiration for swimming robots are described by means of comparison of robots parts to fish organs. In the next section authors focus on electronic control system as well as on applications written in C/C++ that are used to control the robot in three different modes.*


***Keywords:*** *robotic fish, underwater mobile robot, biological inspiration.*

## 1. Introduction

The drive of a mobile underwater robot is indisputably associated with various kinds of propellers. However, there is the lack of such solutions in nature. Thus, a more natural way of moving underwater seems to be worth taking into consideration while designing a robot which is going to be work in the water environment. There are more and more surveys on such kind of propulsion, carried out in many scientific centres around the world. H. Kim and *et al.* [6] studied the motion mechanism of real fishes and proposed the dynamic Lagrange's equations of a fish robot modelled as a four-link system. A similar approach is presented by L. Zang and *et al.* in [12], however the team focused on developing efficient diving mechanism, which uses pectoral fins and fuzzy logic controller. The main propulsion is also implemented as 4-section tail, driven by four servomotors. Above two papers refers to so called carangiform swimming whereas there are also many surveys on different forms (anguilliform, rajiform, gymnotiform etc.) of fish movement. Some of them are presented by K.H. Low in [8]. Author however considered a gymnotiform robot, which mimic a Black Ghost Knifefish. He presented several similar solutions as well as his own prototype of such a robot. The mathematical model of such propulsion is also described in the paper.

The main goals of the project described in this paper were to develop a concept, design and build prototype of a carangiform robotic fish equipped with proximity sensors, temperature sensor, wireless digital miniature video camera and wireless communication system. The maximal representation of a fish-like movement was, however, the most important priority for the authors. There were several assumptions to the project. Firstly, the construction should be cheap and easy to be built without using sophisticated materials and tools. Secondly, parts used to build CyberFish should be easy available. Thirdly, the robot should be able to operate autonomously as well as being controlled *via* computer. Taking into consideration these assumptions authors, in cooperation with colleague Dominik Wojtas, have studied fish movement and have tried to find ways of translating and transforming it into a mechanical device. Based on the findings and conclusions of the study, the 3D CAD model of CyberFish was created in Catia v5 system. The results of the computer simulation confirmed that the kinematics of the model was correct. The underwater robot was capable to swim like a fish. Therefore, the physical prototype has been built. The next step of the project was robot testing in the two thousand - litre tank. Tests showed that the proposed concept is correct and CyberFish swam like a real fish. Nevertheless, it was still much work to do. The main tasks concerned with developing electronic control system and software based on an appropriate control algorithms, which would give the robot the ability to be operated *via* computer or swim autonomously.

## 2. Biological inspiration

The concept itself appeared during studies of Automatics and Robotics at the Faculty of Mechanical Engineering of Cracow University of Technology. Authors were interested in making original bionic robot different from existing rolling robots created in the likeness of arachnids or crustaceans. The real challenge was to design and build underwater mobile robot. The first thought was to create a fish-like device. In that case the robot must not be driven by propeller but only by means of undulating movement of its "body".

### 2.1. Fish-like swimming

It is obvious that swimming is the most convenient way of moving underwater. In general, there are two types of fish swimming methods: BCF (body and/or caudal fin propulsion) and MPF (median and/or paired fin undulations) [3]. In the paper authors focused on BCF-like motion. The many kinds of fishes swim by means of wavy movement of theirs body and/or tail. The frequency and amplitude of those vibrations depend on the species (Fig. 1). Anyway, the force that pushes fish forward is a result of consecutive muscle contractions. When fish is swimming, water is pushed sideways and backwards. Forces, which act sideways, compensate each other whereas the force which pushes water backwards gives reaction that enables fish to move forward. The majority of fish species have two types of muscles. The white muscles give fish the ability to swim very fast and turn rapidly. The red muscles are used for smooth and gentle swimming without excessive fatigue. The types of muscles are named because of theirs colour [5].

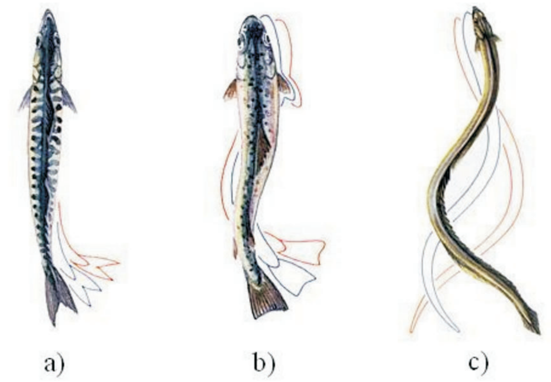


*Fig. 1. BCF fish motion a) mackerel, b) trout, c) eel [2].*

Strong muscles themselves are insufficient to perform underwater manoeuvres. The flexible and lightweight skeleton is also very important. What is important, fish skeleton does not carry whole weight of the fish because the buoyancy force compensates to some extent the force of gravity. Thus, the skeleton can contain hundreds of small bones and cartilages, which form with muscles a very flexible construction that helps fish to swim very efficiently.

Another very important fact is that the density of fish body is close to density of water. This gives the fish the ability to easy move vertically underwater by means of its swim bladder and pectoral fins. The swim bladder is a hydrostatic organ in the shape of a flexible thin-walled container, which can be filled with air thus changing buoyancy of fish. The size of the swim bladder depends on the species. Freshwater fishes have larger swim bladders than seawater fishes because of the differences in the density of fresh water and sea water [5]. In some kinds of groundfish and sharks there is no such organ [4]. Shark uses its pectoral fins to dive and emerge. Its body has higher density than water thus is unable to maintain depth. Shark uses dynamic lift of their pectoral fins so they sink when they stop swimming [10].

### 2.2. Robot's design

In order to build the prototype of fishlike underwater mobile robot, authors have to be acquainted with fish anatomy and its behaviour mentioned above. The first important goal was to design a mechanism which kinematics is similar to the undulating motion of a fish's body. The mechanism consists of four segments connected in series with the rotary kinematic pairs. The head - the biggest segment, two tail segments of similar size and tail-fin segment. First three of them contain drives. Next segment is driven by a servomotor placed in a previous segment. When the mechanism is in motion the proper rotation of each segment and appropriate synchronization of movement of segments create the effect similar to swimming motion of a fish. Computer simulation shows that such motion is really similar to fish motion. Figure 2 presents top view of the CyberFish 3D model in one moment of movement.

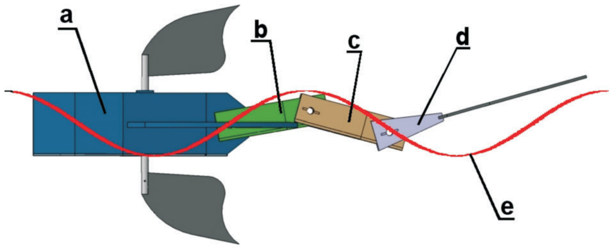


*Fig. 2. Motion of the proposed mechanism, a) the first segment the head, b) the second segment, c) the third segment, d) the fourth segment and the caudal fin, e) superimposed image of sinusoid.*

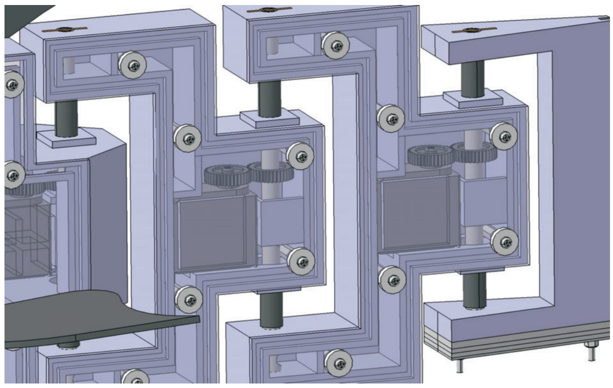

*Fig. 3. The transmission of the second and the third segment.*

Each segment is driven by micro servomotor. That solution is compact, cheap, and easy to control and gives high torque in comparison to its size. The transmission from the servo shaft to the segment axis is carried out by gear with ratio 1:1 (Fig. 3).

Another important feature of fish anatomy is swim bladder, which is essential for depth control. Such an artificial organ was implemented in the CyberFish. It consists of two thin-walled silicone tubes sealed at one end. The tubes can be compressed and stretched by the additional servomotor and the special linking mechanism. Such a pumping mechanism can draw water through a hole in the bottom of the housing. Artificial bladder's servo is also used to change angle of pectoral fins by means of levers and ties. This allows currying out up-and-down motion of the robotic fish just like sharks do when they swim. Diving mechanism has also got the small additional weight, which moves forward while pectoral fins move up, and moves backward in the opposite case. This changing slightly the centre of gravity of the robot and allows the CyberFish to swim like a real fish. Diving mechanism is shown in the Fig. 4.

Based upon the 3D CAD model of the robot, the prototype has been built using PCV, acrylic, rubber, aluminum and stainless steel. The volume of the robot was estimated by Catia software and used to calculate buoyancy that allows the prototype to float in water rather than sink. The mass of CyberFish's body is 3.5 kg and the robot's density is slightly lower than the density of water. This solution enables the robot to change its depth using small changes in volume of the swim bladder. The CyberFish operating underwater is shown in Fig. 5.

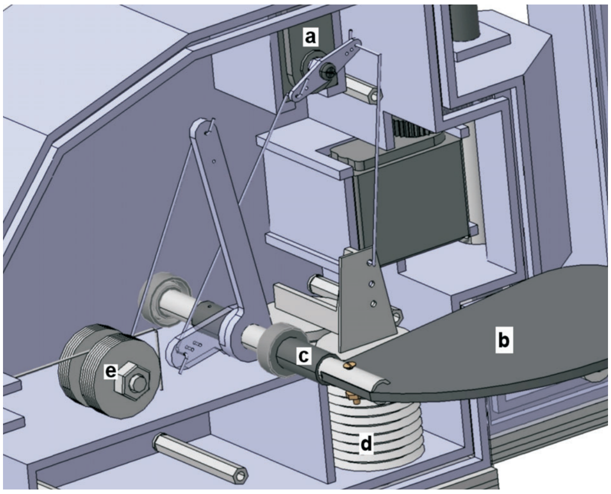


*Fig. 4. Diving mechanism, a) servo, b) pectoral fin, c) pectoral fin's axis, d) two silicon tubes, e) additional weight.*

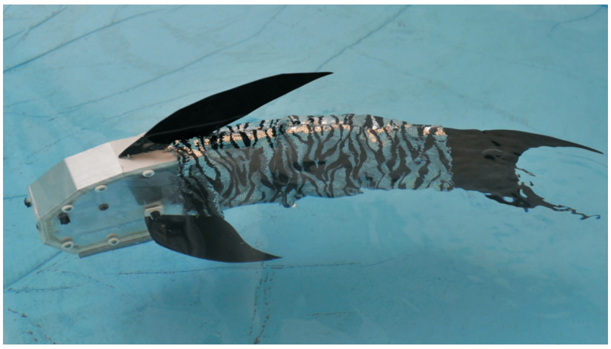

*Fig. 5. The prototype of fish-like mobile underwater robot - The CyberFish.*

## 3. Control system

The work on the control system has been carried out simultaneously with the building of the mechanical part of the prototype. The concept assumes three control modes: (1) autonomous mode, (2) manual control *via* computer equipped with wireless communication module and (3) tracking submersed object recognized in camera image by image recognition algorithm. In order to fulfil that assumption, the control system was divided into two parts. The low level control part is based on micro controller electronic board embedded in the CyberFish, whereas the high level control part is formed by an external computer with control software. The communication between these two parts is performed by means of exchanging messages, which are sent *via* wireless communication channel. The autonomous mode is fully implemented in embedded part of the control system, thus the robot need no extra device to operate underwater. In this mode, one of eighteen predetermined robot's activities is randomly selected at 15 seconds intervals. Four proximity sensors, mounted on the head of the CyberFish, are turned on. Thus the robot is able to detect and avoid obstacles. The autonomous mode can be turned on when no data is received from the computer for more than 60 seconds. If it is on and the robot receives messages, it immediately switches to the manual control.

The high level part of the control system is based on a specially designed computer software which gives an operator the ability to control the robot by clicking buttons or pressing keys on the keyboard. An image recognition algorithm is also implemented in the software. It recognizes red round object in the video received from the robot's onboard wireless video camera. Based upon the coordinates of the centre of the object in the image, algorithm sends messages to the robot in order to maintain the object in the middle of the frame.

### 3.1. Hardware

The core of the robot's electronic control board is the Atmel Atmega 32 micro controller clocked by 8 MHz crystal. The typical application of the Atmega micro controller

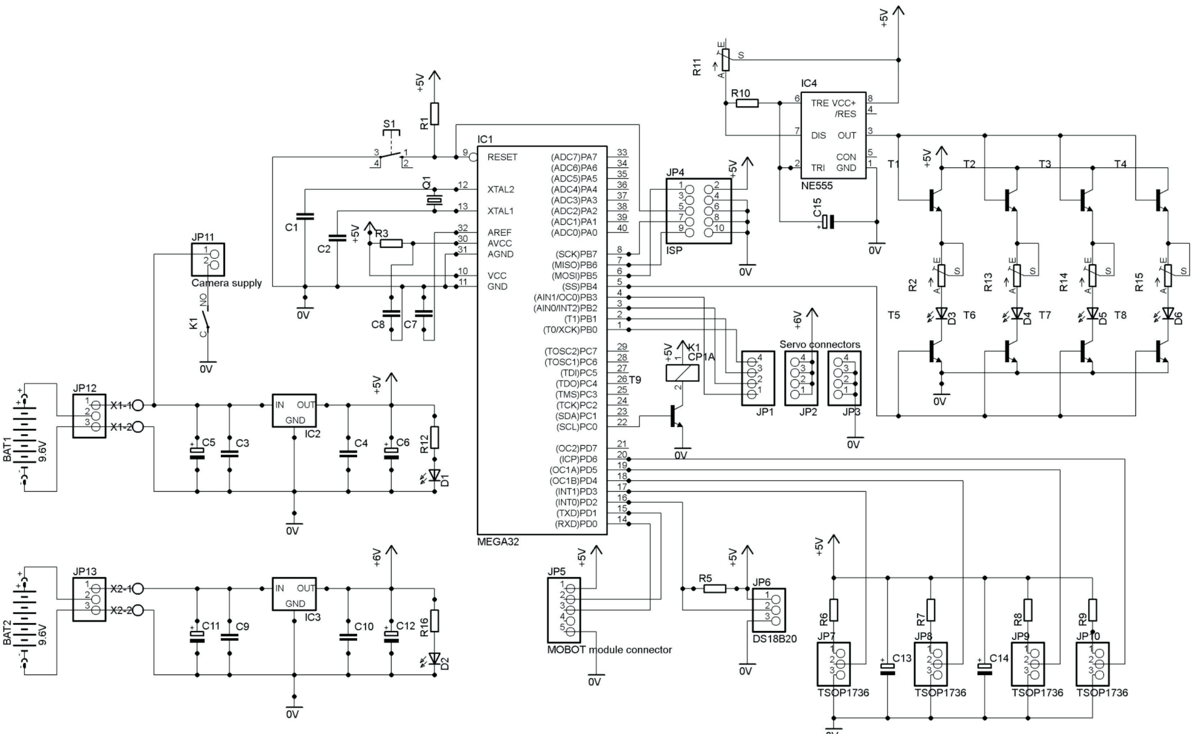


*Fig. 6. The complete scheme of the robot's electronic control board.*

which can be found in [1], was enriched with: two stabilized power supplies, NE555 timer to generate proximity sensors carrier wave signal, transistor keys used to modulate proximity sensors signal, connectors used to connect the radio communication module, servo motors, DS18B20 digital thermometer, IR detectors, video camera and programming socket. The complete scheme is shown in Fig. 6.

Several parts of the scheme need to be commented. First of all robots proximity sensors are built with four TSOP1736 IR detectors, which need the appropriate input signal. The signal consists of packets of 30 pulses with the frequency of 36 kHz with approximately 9 ms gap. The 36 kHz square wave is generated by NE555 timer. This signal is modulated by the appropriate signal from micro controller with the use of set of transistor keys (T1 - T8). Such a modulated signal is send by IR diode and if it reflects off the obstacle, TSOP detects it and sets a low state on its output.

Two sets of stabilized power sources are used to eliminate interference caused by DC servos motors. Servos are supplied from the separate 6 V source whereas other devices are supplied from the 5 V source. Each source is supplied from Ni-MH 9.6 V 2700 mAh battery. Connectors JP12 and JP13 are used to either connect charger (pins 2 and 3) or supply the system (shorting pins 1 and 2). The miniature wireless video camera mounted in the front of the robot and connected to JP11 is supplied directly from batt1 by K1 relay. This enables the operator of the robot to turn the video camera on and off depending on the needs. The video signal from the camera is received by the computer with the use of video camera receiver and a USB TV tuner. The receiver gives a composite video signal on its output, which is then transferred, to the USB TV tuner, which works as an image-capturing device.

The wireless communication module MOBOT RCRv2 type A is connected to USART port by the JP5 connector. The micro controller communicates with MOBOT by asynchronous serial transmission, which parameters are as follows: 56 kbps, 8 data bits, 1 stop bit, and no parity. Another MOBOT RCRv2 type B module is connected to PC *via* USB and communicates with type A module by using 433 kHz radio signal.

The DS18B20 digital thermometer is connected to the micro controller by means of one-wire interface using PD2 line. The temperature sensor is located near the dorsal fin of the CyberFish.

### 3.2. Software

The micro controller software has been written in C using the WinAVR development environment and avrgcc compiler. Setting WinAVR to work with the compiler was made with help of information presented in [7]. Compiled code was written to the device by means of STK200 serial programmer and PonyProg 2000 application. The program consists of various functions like initialisation of: timers, USART module and one-wire interface, which are called before the main control loop. When the program enters

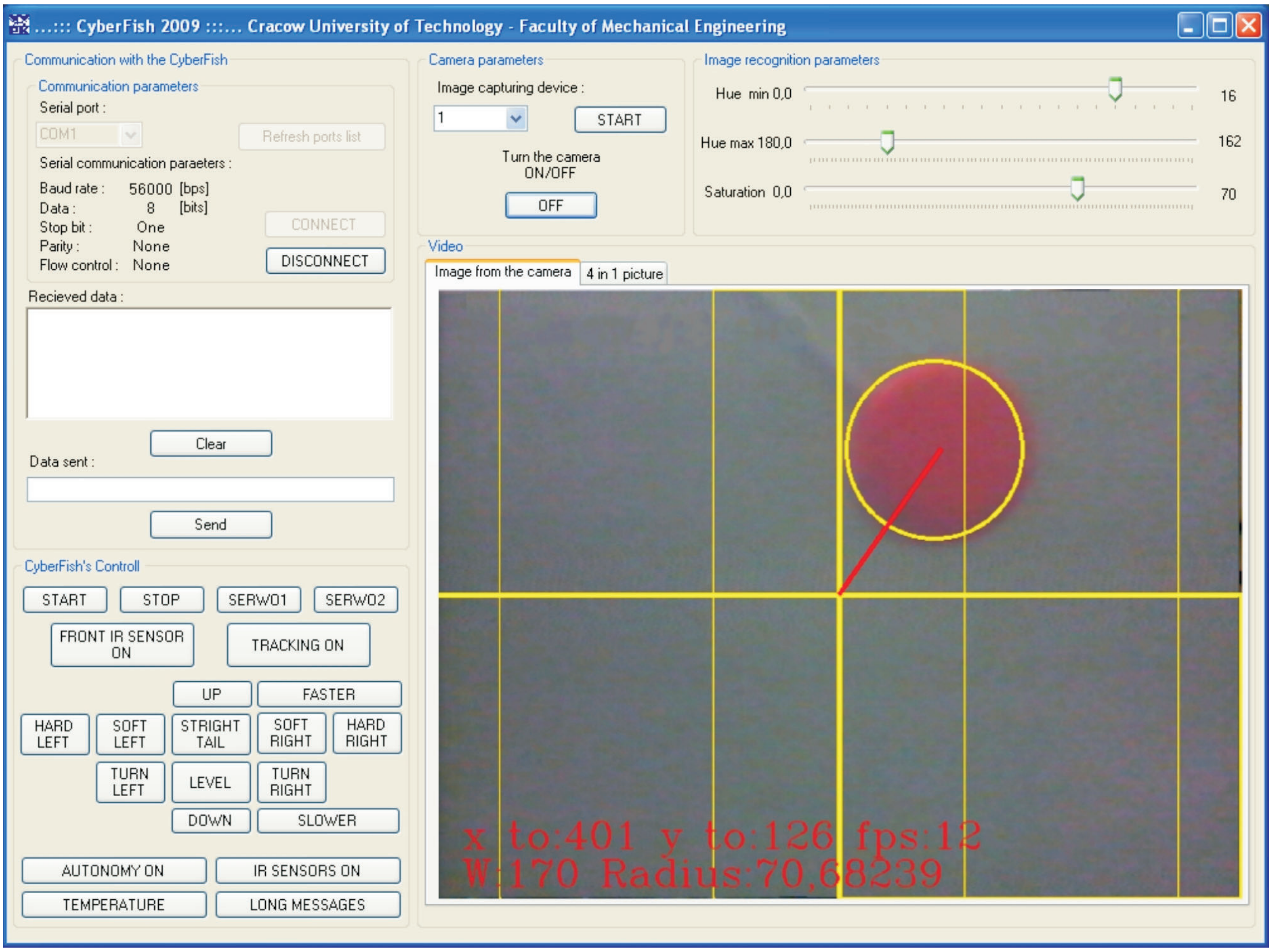


*Fig. 7. The robot's control application window.*

the main loop, function used to analyse messages is being called. It compares incoming messages received from the USART to messages stored in memory and then the appropriate action is being performed. Moreover, message of confirmation is sent back to the computer. If no message is received from USART within the 60 seconds and the autonomy flag is set, the autonomy function is being called. The robot switches to the autonomous mode described previously in the paper. Sending and receiving messages are performed in the USART interrupt handlers.
PWM signals are software generated within the timer interrupt handler. This is because Atmega32 is not equipped with a sufficient number of independent PWM channels to control four servomotors. There is a set of various functions, which are being called after receiving a message. These functions adjust the duty cycle of PWM in order to achieve appropriate servo movement and synchronization.

The micro controller program also contains functions used to handle communication with the DS18B20 temperature sensor and a function to receive signals from proximity sensors.

PC computer application has been written in C++ by Dominik Wojtas using the Microsoft Visual Studio 2008 development environment. OpenCV and EmguCV free computer vision libraries were used to build an image recognition application, which is further used to tracking submersed red round object by the CyberFish. The application itself is a single window form (Fig. 7), which contains several areas:

- communication parameters settings area,
- a text box used to send and receive messages (control commands),
- a set of buttons to control the robot,
- image recognition parameters settings area,
- a frame grabbing device settings area,
- a video screen with the resolution of 640x480 pixels on which the underwater view (as well as detected object) is displayed.

The image recognition algorithm was developed with the help of information contained in [11]. Images received from a capturing device are the algorithm's input data whereas commands used to control the robot are the output data. The algorithm consists of six major steps:

- capturing image,
- image processing,
- frame binary conversion using appropriate threshold,
- morphological operation of closing and opening to fill gaps in the image of the object,
- calculating coordinates of the centre of the object in the image,
- coordinates analysis during fixed time intervals.

Based upon coordinates analysis of the centre of the object in the image, appropriate commands are being sent to the CyberFish in order to maintain the object in the middle of the frame. If the result of the analysis locates the object in the left side of the screen during fixed time interval, „turn left“ command is being sent. A similar situation is observed when result of the analysis locates the object in the right side of the screen. If the result of the analysis locates the object in the middle of the screen, in the so-called "dead zone", there is no reaction from the control system. Taking into account problems with maintaining undisturbed signal from the onboard video camera at the greater depths, authors resigned from implementing up-and-down control in this control mode. Therefore, tracking submersed object by the robot works only when the CyberFish swims just below the surface of the water. Using more expensive and sophisticated wireless video camera should allow to implement up-and-down control in this control mode.

## 4. Conclusions

After several months of work on Master of Science Thesis in Automation and Robotics at Cracow University of Technology, the CyberFish has finally been made. The robot was designed so that it could be built using the cheapest materials and widely available tools and parts. Financial constraints did not allow for the implementation of sonar system or sophisticated video camera, which could operate at greater depths or at low light intensity. However, with the use of popular and well-known solutions, it was possible to build a unique underwater mobile robot, which has been tested in 2000 litres pool. Despite the difficulty of sealing, construction, manufacturing and logistics problems and bugs in the software, the aim of the project has eventually been achieved. The CyberFish represents an original underwater craft that can be drive without propeller. This solution seems to be more efficient or even irreplaceable if the device is going to operate in rushes or seaweed. Any further development would require funding that allows to create an underwater robot performing various functions, ranging from analysis of water pollution, ending the stand-alone water penetration in the search for missing items or people.

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