Remotely Operated Vehicle – Development process and system overview

Lars-Christian Boll, Philipp Stark & Marc Wörmann (Hochschule Bremerhaven)

Fachrichtung: Maritime Technologien, Studienphase: Bachelor, contact: marcwoermann@gmx.de, pstark@studenten.hs-bremerhaven.de, lars-christian.boll@boll-1.de

The main goals of the Remotely Operated Vehicle project of the University of Applied Science Bremerhaven were to realise a saltwater proof design for model making engines and to create a control system supported by open source software. Operations in saltwater of the Remotely Operated Vehicle failed in the past. Through the project the saltwater proofness and the control system were successfully realised. It was able to dive in a depth of 24 meter and to observe the sea floor.

Keywords: ROV, Remotely Operated Vehicle, saltwater proof, epoxy resin, microcontroller.

1 Introduction

For marine research and industry Remotely Operated Vehicles (ROVs) are inevitable. With their help it is possible to reach great depths and areas, without risking human life. Especially for marine energy they are used for the installation and maintanence of the support structures. Put simply a ROV is a waterproof casing equipped with a camera, thrusters for movement connected to a cable for live images and transmitting the steering signals. Often multiple sensors and measuring devices are mounted. ROVs and Autonomous Underwater Vehicles (AUVs) fall into the category of Unmanned Underwater Vehicles (UUVs), with the main difference of the ROVs being tethered to the surface, either by ship or on land. Whereas the AUVs are equipped with batteries and are pre-programmed for their missions. The ROVs are again separated in work class, special use and observation class, which our ROV belongs to (Robert D. et al., 2007). Studying maritime technology at the University of Applied Science Bremerhaven the group members took over the ROV project in September 2015. The ROV is designed to operate in a depth down to 50 meter and is equipped with a camera, sonar system, compass and CTD (conductivity, temperature, depth) probe. There are two main end housings installed, these include the interfaces, the camera and the electrical power supply. Also the mountings for the engines and the operation light were installed. By the time of the handover from the previous group, the ROV was not suitable for an operation. It was not possible to communicate with the hardware or to regulate the engines.

Multiple students founded the project in 2007 in order to monitor the underwater conditions. After being dismantled and put into storage for a few years, in 2013 the project was included in the course marine energy of the study degree maritime technology. Since then three student groups have worked over a period of two semesters each on the ROV. The main focus was to have a saltwater proof and functioning system. This goal was successfully achieved in May 2016. Before then it worked in fresh water and had multiple malfunctions in salt water.

From May 28 to June 4, 2016 the third workshop for marine energy took place at the Sven Lovén Centre in Fiskebäcksil, Sweden. The workshop provided students from Uppsala University, division for electricity, and students from the University of Applied Science Bremerhaven, division maritime technologies, the opportunity to exchange experiences and knowledge in the fields of marine energy systems. At this third workshop the ROV had its first successful test dives in the harbour. Moreover, on three expeditions with the research vessel Oscar von Sydow to the Wave Power Project Lysekil (Dolguntseva, I. 2016), the ROV operated in depths of 24 meter. It was possible to study the wave power generators and their condition, which are moored in the waters of Skagerrak.

Figure 1: The ROV (length, width, height; 60 cm, 50 cm, 40 cm) of the University of Applied Sciences at the Sven Lovén Centre in Fiskebäcksil, Sweden

During the two semesters the biggest tasks were to build saltwater proof thrusters and to install a new communication system. As the engines used, brushless direct current (DC) engines, which already proved their functionality in this project, a coating with epoxy resin was intended. The previous group had the same idea, but used very liquid epoxy resin. However the cable connections were not sealed properly. Therefore resin poured into the cable and after the hardening time the cable breaks occurred, which lead to shortcuts in saltwater. Learning from this, a whole procedure was improved.

2 Methods and Material

The ROV contains out of several devices for movement, communication, measurement and housing. Some parts are modified for the special requirements in seawater.

2.1 Components

Figure 2 shows the basic components and wiring of the ROV. A power converter and a Laptop with a movement controller (Sony Playstation 3 bluetooth controller) are connected to parts onboard of the ROV. A cylindrical polyoxymethylene (POM) housing and a glass housing produced by Vitrovex protect the electrical devices. The main processing tasks are processed by an Arduino Mega Board (Arduino Mega 2560 Datasheet) as microcontroller. Three power supply devices manage the power distribution. The thruster engines are controlled by engine controllers inside the POM housing. The Ethernet camera and a camera servo are fitted inside the glass housing. An Ethernet switch provides the connection between the microcontroller, Ethernet camera and the laptop.

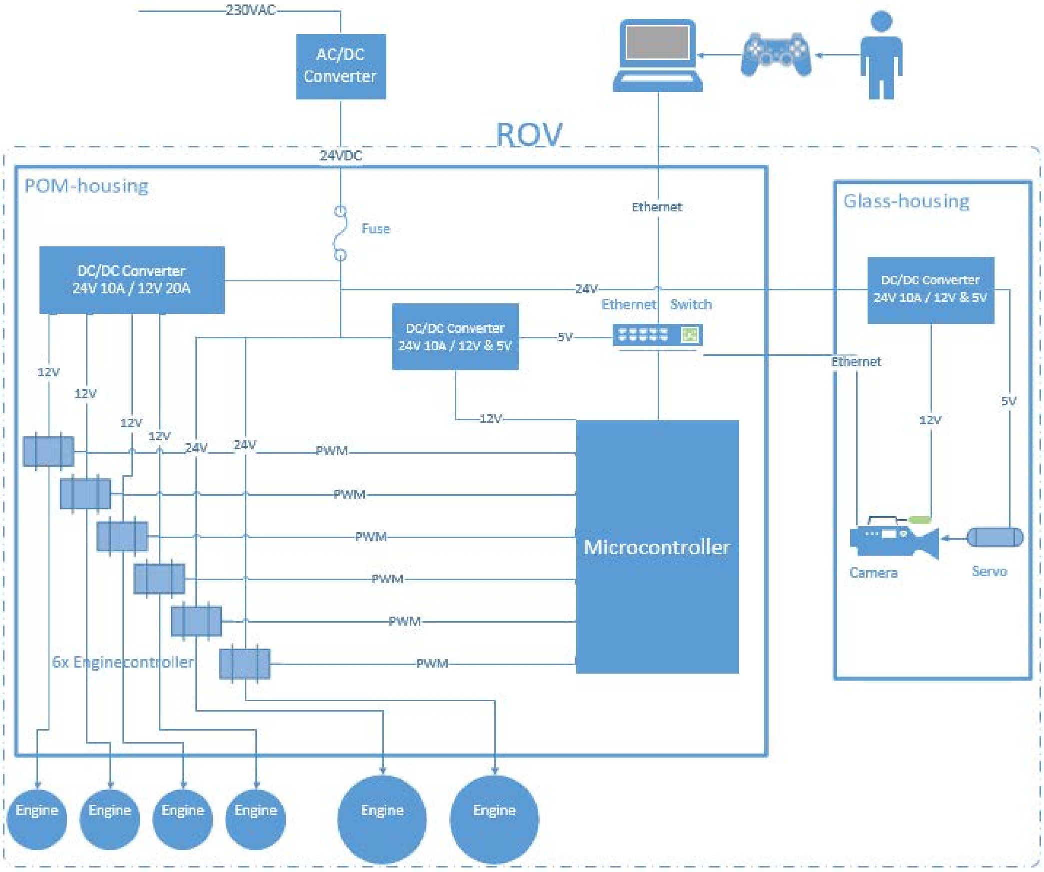

Figure 2: Basic Components of the Remotely Operated Vehicle

Housings

Two housings are fitted in the frame of the ROV. One housing, made out of POM, includes an Arduino Mega Board, the engine controllers, an Ethernet switch and two power supplies and protects them from water, corrosion and pressure. This housing consists out of a cover plate and a tube, which are connected together by a screw connection. The water and pressure solidity is provided by a double o-ring sealing. The electronical devices are mounted on the internal side of the cover plate. By removing the cover plate all electrical devices can be pulled out of the tube. This construction provides access for maintenance to all electrical devices. The second housing consists out of glass and is produced by Vitrovex. This special polished glass sphere houses the power supply, the Ethernet camera and a servomotor to adjust the angle of the camera. Due to the polishment visibility is possible through the glass with low fraction inside and outside the water. It also contains the connectors for the measurement parts, which are not yet connected to the running system.

Communication

The Arduino Mega Board as microcontroller is connected via the Ethernet switch to the laptop. A game controller, used by the operator, is connected to the laptop via bluetooth. The receiving input of each engine controller is connected to the Arduino Mega Board. The engines of the thrusters are connected to output of the engine controller.

Movement

The movement of the ROV is realized with six electrical outrunner engines produced by Robbe, because of an open thruster design no pressure housing and no radial shaft sealing is required. For the vertical movement, four Robbe Roxxy C35-30-14 with a maximum power of 270 W are installed. Two Robbe Roxxy C50-65-09 with a maximum power of 1400 W manage the horizontal movement. All engines need to be controlled by Robbe Roxxy BL-Control 900 engine controller. These engine controllers are working with pulse-width modulated (PWM) signals transmitted by the Arduino Mega Board.

Measurement

For measurement and easier control underwater there will be a CTD, Sonar and a compass installed. These parts of the ROV are not connected to the microcontroller yet, due to the focus of the project group. The focus was to build a reliable and easy to handle functioning basis of a ROV.

2.2 Engine Improvement

Saltwater proof engines

As mentioned before engines from model making are used. Two models are chosen, different in power and dimensions. The engines get their main power supply over three cables located at the bottom of the engine. These cables have to be connected to the engine controllers. The horizontal engines are separately connected with an underwater, three-pin cable to the POM housing. On the other hand the small engines are not connected solitary. Two engines are combined to a pair. This pair is connected to the POM tube with a eight-pin underwater cable. Six of the eight-pins in the cable are used for each pair, so that two pins are not connected. These eight-pin cables were already available so that this conclusion is the most cost effective opportunity. The ball bearings pre-installed in the engines were replaced with selfmade bronze bush bearings.

Engine mounting

The horizontal engines (figure 3 & 4) are mounted on a steel bracket at the outside of the ROV (see also figure 1). First of all the steel bracket is prepared with a drill hole, in which a saltwater proof, three-pin plug is mounted. Between the bracket and the engine a middle section out of POM is mounted. It was lathed and has got a cylindrical, hollow form. The three cables of the engines are lead through the middle section and are then connected with the plug. This middle section and the whole engine will be filled with epoxy resin, so that there are no more moveable cable. An epoxy resin and an epoxy hardener by the brand Buehler are used.

The smaller engines are installed in a similar procedure. The first engine is also connected with an eight-pin, underwater plug. But the difference is that there is another drill hole in the middle section of the first engine. Through this hole there is a normal three-pin cable leaded to the second engine of this pair and sealed with cable passings. This cable connects the second engine with the underwater plug. The plug is connected with an eight-pin, underwater cable to the POM tube.

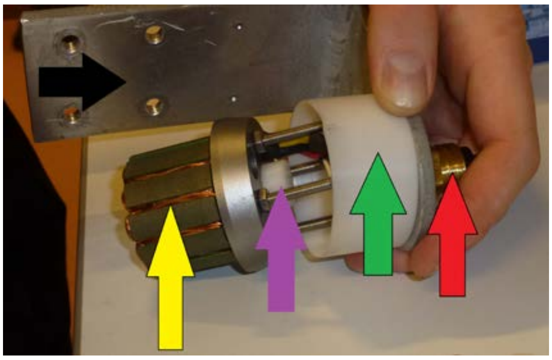
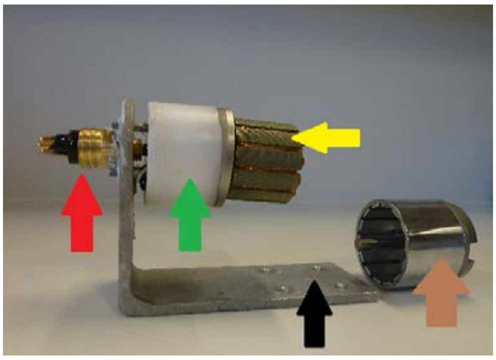

Figure 3 & 4: Horizontal engine during assembly.

In figure 3 and 4 the horizontal engines are shown in their finished arrangement before the filling process. Figure 5 shows one vertical engine pair. Pictured are the steel bracket (black arrow), the underwater plug (red arrow), the middle section (green arrow), the engine (yellow arrow), the bearing (purple arrow) and the outrunner (brown arrow).

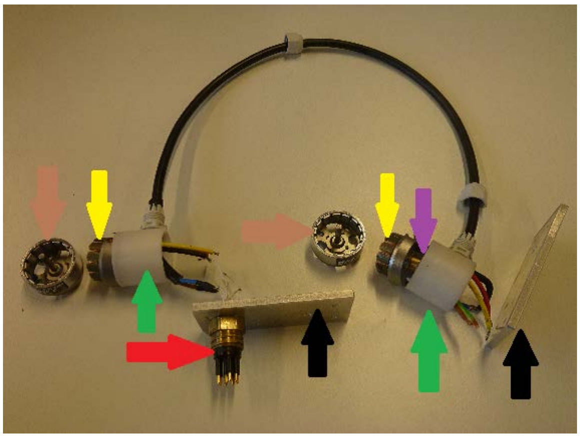

Figure 5: Vertical engine during assembly

Filling process

After pre-assembly, the filling process can be started. For this process a hollow cylindrical mold in POM is needed, placed around the stator of the engine. The mold is constructed for a 0.1 mm gap between mold and engine. After the filling process there should be a 0.1 mm layer on the engine. Also there is a stub out of POM used to protect the bearing hole

while the process.

Figure 6: Epoxy resin filling process

Figure 6 shows a horizontal engine during the filling process. As shown the mold fits accurately the engine and the stub seals the bearing hole. During the process the assembly is placed in a vacuum chamber several times. This should help to lead all the resin into the middle section until it is completely filled and to suck out the air bubbles. After revision when the middle section and the molding form are filled, the resin can cure.

2.3 Movement control with an Arduino Mega Board

For the movement of the ROV it is necessary to drive the engine controller of each engine. The engine controller can be driven with PWM signals. A receiver of radio-controlled systems normally generates these signals. Radio controlled systems connot be used, because of the low range of radio waves inside the water. The solution for a control system is an open source microcontroller like the Arduino Mega Board connected with an Ethernet cable to a computer. This microcontroller can generate PWM signals on several outputs, it also provides enough RS232 interfaces for the measurement devices.

Flow of data

Figure 7 shows the data flow for the movement instructions. The game controller is connected via Bluetooth to the laptop. A program on the laptop is processing the data, which are transmitted from the game controller continuously. It transmits these data directly to the Arduino Ethernet Shield, which is mounted on the Arduino Mega Board. The data strings are unpacked and provided for the program, which is processing on the Arduino by the Ethernet shield. This program transforms the values into adjusted PWM signals and sends it to the engine controller. With the information taken from the PWM signals the engine controller set the desired voltage for the engine.

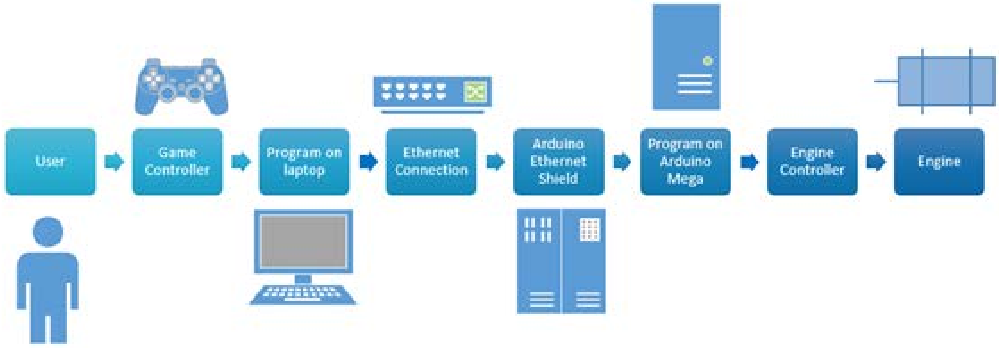

Figure 7: Movement data processing of the ROV

Pulse Width Modulated Signals

Figure 8 shows different PWM signals. These signals have square waves with an adjustable pulse width and a constant period (Rossmann, 2014). The pulse width is adjusted by a digital controller, which creates square signals while switching between on (5 V) and off (0 V). By changing the duration time of switched on position the pulse width is changed (Hirzel, 2016). The shortest on duration time for radio controlled receiver for engine controller is 1 ms. The longest on time is 2 ms. With changing the pulse width between 1ms and 2 ms the engine controller can set the rotation and the power proportional from 100 % clockwise to 100 % counterclockwise. When the pulse width is 1.5 ms wide the power is set at 0 %.

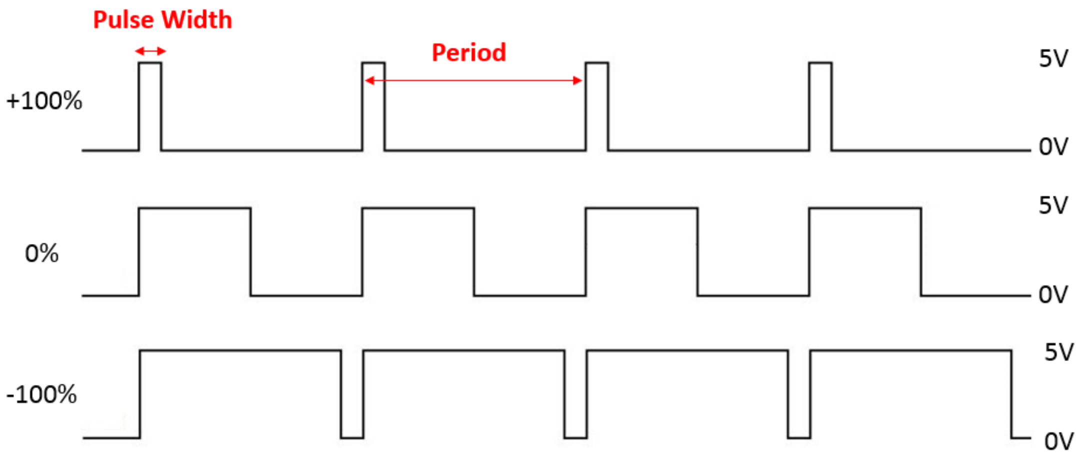

Figure 8: Pulse width modulation

Modulation of PWM Signals for Brushless Controller

The incoming data on the Arduino Mega Board are four values between 0 and 255. For each movement axis there is one value: Forward and backward, turn left and right, up and down and the camera movement. If an incoming value for an axis is 0, the PWM signal on the output has to be the minimum pulse width, which is required for the engine controller. If the incoming value is 255 the pulse width has to be the maximum. The range between 0 to 255 of incoming and minimum to maximum pulse width of outgoing signals is linear. Normally these values can be transformed by the library running on the Arduino Mega Board. The library is incompatible with these kind of engine controller, because of the required range of the minimum and maximum pulse width is not 1 ms and 2 ms. The pulse width of the signal has to be remodelled. By connecting an oscilloscope to the output of a radio-controlled receiver, which is working with the engine controller, it is possible to measure the required maximum and minimum pulse width. With these informations, it is possible to find emperical factors to calculate the right pulse width from the incoming data. With this factors it is even possible to justify each engine and engine controller to synchronize all engines build in the ROV.

3 Results

The ROV project was a scucces and the intended aims were achieved. It was possible to dive down to 24 m depths and to observe several wave generators. The coating process was successful and the engines are salt-water proof. After the curing time and removal of the mold, the stator is covered with a thin layer of epoxy resin but with small air pockets occurred. After some operations the engines were not running synchronous and there a grinding marks on the sealing of the stator. Furthermore, it was possible to steer the ROV, adjust the camera and receive the camera images. Sometimes, in irregular periods, the camera loses connection and it needs to be updated. While driving the engines with more than 50 % power the whole system shuts down abnormally, because the power converter reaches it limit of 30 A. After restarting the main AC/DC converter it was possible to control the ROV again. In the first test dive in fresh water in the laboratory there were no leaks and the system was functioning. The trim of the ROV was not levelled and it had a great downforce. On the first field tests in the North Sea the ROV proved to be saltwater resistant, but wasn't trimmed correctly again. The water current had major impacts on the stability of the ROV. The cable sank and was also torn away by the current. Long dive times resulted into an increasing downforce of the ROV. During the dives it was difficult to know the exact distance, the bearing and the depth.

Figure 9: Expedition dive to the bottom of a wave energy converter of the Wave Power Project Lysekil

4 Discussion

The results of the moulds were satisfying. The air pockets do not have a big impact on the engines. Actually for the function of the engine the iron core with the lacquered copper does not need to be coated. As it is intended to dive in saltwater this needs to be done for a sustainable solution and prevent it from corrosion. To prevent the spot of the air pockets from corrosion the stators of all engines need to be greased with vaseline before every dive. This also helps to reduce the friction of the rotor. Because the bronze bearings, middle sections and moulding forms were lathed manually, the accuracy of them vary. Therefore marks on epoxy coat of the stator and different efficiencies are the result. The programming code of the Arduino was adapted to the different engines controller and engines. They start turning at the same input signal of the controller, but each thruster runs on a different electrical start current. The reason for the abnormal shutdown is, that the main AC/DC converter on the surface is shutting down while working with more than maximum efficiency, by driving the engine thruster with more than 50 % power. To prevent this failure temporary, the maximum power of each engine was decreased to 40 % power. To fix this sustainable the power supply device has to be replaced by a powerful one. The connection loss of the camera cannot be explained yet. It might be possible, that the camera software is faulty or the camera becomes too hot. To correct the downforce, foam pieces were cut and installed. They were placed correctly to adjust the trim at the same time. Due to the density of saltwater is higher than fresh water, therefore the trim was corrected by additional weight. The reason for the increasing down force, when the ROV was submerged for long times, was the polysytrol foam, which soaked water. During the first test dives from the wharf, it was already realized, that an exact localisation is difficult, without any instruments as sonar, CTD and compass. In most dives the biggest help was to reach the ground and orientate from there. When too much cable was in the water, the ROV had problems to move. Cable on the seafloor slows the ROV down or prevents it from moving. This also results from the reduction of the engine power. Furthermore, the bronze bearings are more resistant to corrosion than the original ball bearings.

5 Conclusion

The main problems were fixed and the goals are successfully reached. The saltwater proofness is realised and a new reliable controlling system is installed. So the ROV of the University of Applied Science Bremerhaven is ready to dive in saltwater. The tasks for the future will be to connect the CTD probe, compass and the sonar. Other student groups will continue these tasks.

6 Acknowledgement

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