Versatile Sensor and Communication Expansion Set for the Autonomous Underwater Vehicle MONSUN

Benjamin Meyer*, Christian Renner and Erik Maehle

Institute of Computer Engineering, University of Lübeck,
Lübeck, Schleswig-Holstein, Germany
**E-mail: meyer@iti.uni-luebeck.de*
www.iti.uni-luebeck.de

This paper presents a novel and modular way of an adaptable autonomous underwater vehicle called Monsun. The robot can be equipped with various hardware modules that feature sensor and communication capabilities qualifying it for a large number of mission tasks in the field of environmental monitoring. Having the possibility to adapt the robot by hard- and software components, the Monsun robot differs from most conventional AUVs.

Keywords: Underwater Robotics, AUV, Environmental Monitoring

1. Introduction

Extensive investigations of water bodies are of ever-increasing importance. With a view to conserving water resources regarding the steadily growing global population, environmental monitoring helps to preserve the indigenous species of flora and fauna. Autonomous underwater vehicles (AUVs) can help to provide data to a greater extent as conventional methods, but the existing robots are mostly too specialized to operate in different areas under changing conditions. The data has to be collected at many places over various time periods independently from external influences and weather conditions for each water body. For this, a platform is needed which easily is adaptable to outer influences and customizable for each special mission.

This paper presents the expansion set for the Monsun AUV [1] enabling it to adapt to various requirements and mission tasks which occur in the field of underwater monitoring. The set includes three types of expansion kits consisting of different hardware modules which can be attached to the robot via a number of docking points. Thus, a change of the sensor and communication capabilities is possible with a minimum of maintenance effort. This principle differentiates it in an important aspect from other AUVs.

2. Related Work

Due to the diversity of our planet and the resulting different operational areas, a variety of AUVs has been developed. Each robotic system meets a specific range of requirements, thus qualifying the robot for certain operational areas but eliminating it for others. As a result, very few AUVs are commercially manufactured and affordable. Most robots are too specialized or too expensive in construction for commercial manufacture and usage [2]. For the field of environmental monitoring, only a small number of vehicles is available. The University of Washington developed the Seaglider [3] for continuous, long-term measurement and the collection of oceanographic parameters. To achieve a long range and endurance, the focus of construction is on the minimization of the energy consumption, allowing the AUV to travel autonomously for months. However, the robot has to be precisely balanced and offers no possibility to change the system parameters and sensor devices in an easy way. Another relevant AUV is REMUS [4]. The main aim of development was the design and construction of an efficient and low cost AUV that is small and easy to handle. To meet the different requirements, several types of robots were designed differing in size and sensor capabilities. Recently, the Hydromea project was launched as a further development of the Serafina robot [5]. The AUV resembles Monsun in many ways, but like all other mentioned robots, it is not able to use expansion modules for more functionality.

3. Hardware Concept

There are numerous applications for AUVs but in nearly all cases, a specialized robot perfectly adapted to the desired behaviour is needed thus eliminating customizability. If at all possible, the exchange of, e.g., the sensor system is a complex issue due to the waterproof case of the robots. Cable ducts or mounting places are difficult to upgrade and the balance of hydrodynamic and buoyancy must be maintained.

Therefore, the Monsun robot is built in a forward-looking modular way, enabling it to exchange, e.g., full parts of the sensor system in less than five minutes. This enables task-specific configurations and a quick reaction to changing conditions. Currently, the so-called expansion set consists of eight extension modules that can be flanged at three different docking points at

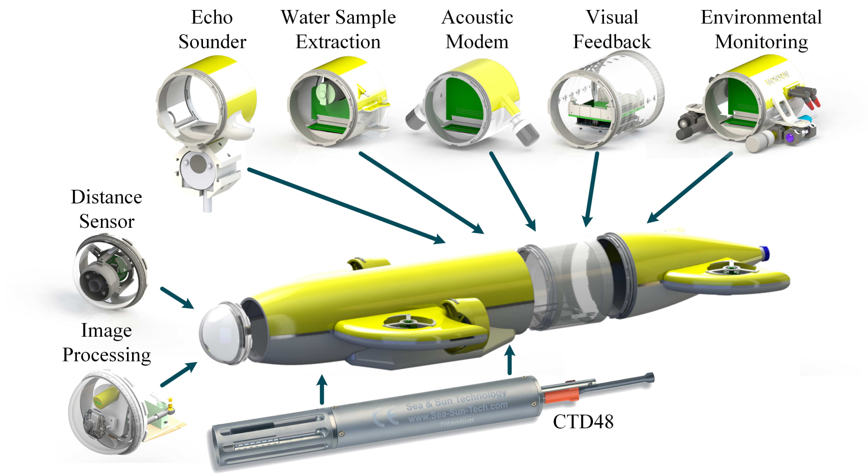

Figure 1. The modular hardware concept of the MONSUN underwater robot. It has three different docking points to flange various kinds of peripheral sensors and specialized devices. At the robot's front, the standard glass dome can be equipped with different distance sensors and a camera for image processing. At the bottom, an aluminium track system can be used to attach a professional CTD probe or additional weight packs for buoyancy. The most important docking point in the robot's centre serves to mount different kinds of devices for environmental monitoring, communication, and navigation.

the robot's hull (see Figure 1). At the robot's front, a glass dome with a small 60 mm bayonet closure can be equipped with, e.g., distance sensors and imaging devices. An aluminium track system at the bottom of the robot serves as position point for a professional CTD probe or additional weight packs. The main docking point in the centre of the robot is accessible by a 100 mm bayonet closure. The expansion modules can be installed without changing any robot parameters and the control unit of the robot detects the additional devices automatically. The modules have a neutral buoyancy in order to prevent a new tare process of the robot. In the following, the various parts of the expansion set are categorized and explained in detail.

3.1. *Navigation Kit*

One essential requirement for underwater navigation is the information about the distance to the surrounding landscape. Therefore, the expansion set currently includes three modules combined in the so-called navigation kit (see Figure 2). For long-range distance measurements, the echo sounder module can be implemented at the robot. It uses an Imaginex 852 Ultra-

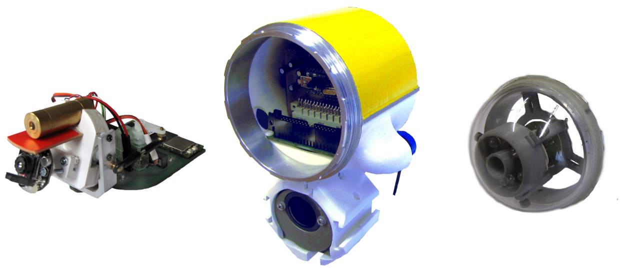

Figure 2. The navigation kit of the MONSUN underwater robot consists of three different devices for distance measurements. Left: pan-tilt camera unit with line laser for contour detection and short ranges, Middle: echo sounder expansion module for long ranges; Right: light-emitting distance sensor for short ranges.

miniature echo sounder, which can measure distances of up to 50 m with a range resolution of 20 mm [6]. Furthermore, the echo sounder can be attached at the module in two ways to measure the distance in the direction of travel or to the ground. Thus, it can be used to survey the erosion and depth development of inland water bodies. For short range distance measurements, the robot can be additionally equipped with two optical sensors. A low-cost light-emitting distance sensor consisting of a pulsing light source and a photo resistor has an operating range up to 20 cm. It can be used to prevent the robot from colliding with objects like other MONSUN robots or as emergency stop in front of obstacles. The second optical sensor which can be placed behind the glass dome is a self-sufficient image processing system. It consists of a 720 MHz Overo® Fire COM Gumstix module which runs a Linux Ubuntu operating system, a web cam on a pan-tilt unit, and a line laser. With the help of the light sectioning method, a contour can be measured with a range of up to 200 cm.

3.2. *Communication Kit*

Especially in the field of underwater robotics, a system with various types of communication capabilities is of great importance. This does not just facilitate the way to communicate between the robot and the user, but also enables formations of robot swarms. The communication kit encompasses two modules, a visual feedback module and an underwater acoustic modem (see Figure 3). The visual feedback module includes $13 \cdot 5$ RGB-leds in a transparent housing. The leds are controlled via an Arduino Uno controller and can be addressed individually. The emitted light has a wavelength of 465 nm for blue light and 525 nm for green light which is most suitable for

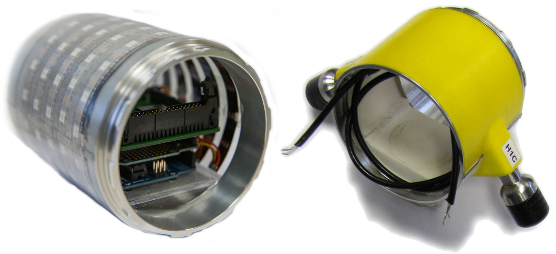

Figure 3. The communication kit of the MONSUN underwater robot consists of two different modules which can be implemented at the robot's centre. Left: The visual feedback module with a matrix of $13 \cdot 5$ RGB-leds which is used to visualize the internal robot state and to communicate with various blinking pattern. Right: The home-developed underwater modem for acoustic communication with a range of 50 m.

underwater applications due to the absorption capacity of long-wave light in water. [7] On the one hand the system enables the user to identify the internal robot state even from a distance, on the other hand it is able to distinguish between the robots in a swarm. Furthermore, various blinking patterns are implemented to perform a near field communication. To enable a mid-range communication of up to 100 m distance between MONSUN AUVs, we devised and built an acoustic modem. Our prototype fits in a 7 cm-module at the centre of the robot and features high modularity and online configuration. The modem is powered by the main supplies of MONSUN and consumes as little as 500 mW in idle mode; hence, the operation time of the AUV is hardly affected. We use two Aquarian Audio off-the-shelf AS-1 hydrophones [8] that cost at roughly €400 each. The cost of the remaining hardware sums up to €200 for components and circuit boards. Our current prototype achieves a data rate of up to 780 bit s^{-1} and operates in a frequency band from 50 to 75 kHz. It supports distance estimations by time-of-flight measurements. The required information about the sound velocity can be inferred from external sensors and empirical models (relying on depth, salinity, and temperature).

3.3. *Environmental Monitoring Kit*

Beside underwater inspections and the survey of water bodies, the environmental monitoring is one key application of autonomous underwater vehicles. The various environmental parameters can also be measured periodically in hard-to-reach areas which helps to understand existing biological

Figure 4. The environmental monitoring kit consists of three different modules which can be attached to Monsun. Top: a CTD48 multiparameter probe to measure parameters like pressure, temperature, and conductivity can be docked at the bottom of the robot, Left: The environmental monitoring module with sensors for pH, dissolved oxygen, conductivity, and temperature, Right: water sample extraction module to collect water samples for more precise laboratory tests.

processes. Therefore, the Monsun underwater robot can be equipped with an environmental monitoring kit consisting of three different devices (see Figure 4). At the bottom of a robot, an aluminium track system can be used to attach a professional CTD48 multiparameter probe especially designed for limnological measurements on lakes, rivers, and estuaries, but it can also be used in shallow water and an oceanographic range of up to 2000 m depth. It has its own power supply and measures pressure, temperature, and conductivity [9]. Beside that, the expansion kit includes a home-developed monitoring module, which can be attached to the robot's centre. It uses *Atlas Scientific* environmental sensors to measure pH, dissolved oxygen, conductivity, salinity, the number of total dissolved solids, as well as temperature. Together with the pressure information from the robot control, all parameters are used to perform miscellaneous compensations and optimizations to gather accurate digital environmental values. With the help of these two devices, monitoring as demanded in the European Water Framework Directive can be performed [10]. If the monitoring process reveals alarming environmental conditions, it can be necessary to investigate the water in more detail. Therefore, the environmental monitoring kit contains an expansion module for water sample extraction. It can be installed at the robot's centre, enabling it to collect 5 ml samples at a desired position and depth in the investigated area. More precise laboratory tests can hence be performed.

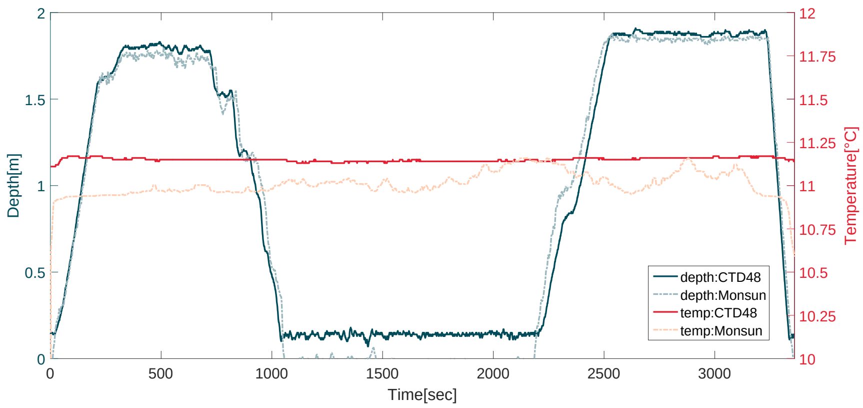

Figure 5. Results of a comparative measurement of two modules from the environmental monitoring kit. The CTD48 was contrasted with the home-developed monitoring module for Monsun during experimental runs in the Baltic Sea in October 2015. The blue lines illustrate the measured depth of the robot while traversing a mooring in Sassnitz harbour and the red lines display the measured temperature.

4. Experimental Results

The entire system was tested during experimental runs in the Baltic Sea in October 2015. The experiments included several test runs with various robot configurations to test modules of the communication and environmental monitoring kit. A Monsun robot traversed various corridors in a mooring of Sassnitz harbour and the coastal area defined by determined GPS positions. In particular, the robot dived at various positions in desired depths to measure the local environmental parameters. Figure 5 shows the result of a comparative measurement of two modules of the environmental monitoring kit. During two thirds of the run, the robot dived up to 2 m deep and measured the parameters periodically. The overall medium difference between the measured depth of the two devices is 9.979 cm, explainable by the local distance of the sensor mounting points at the robot of 10 cm. This can be seen in the middle of the run, where the robot is moving at the surface and only the CTD48 is submerged. However, the results of the measured temperature are different. While the CTD48 delivers a smooth and fine-grained temperature reading, the sensor at the monitoring module shows divergent results. The mean temperature difference between the two devices is 0.1345 °C. Summarising, the experiments prove that the environmental measurements deliver usable data concerning the European standards and are feasible while the robot moves at various depths. The

CTD48 can be used, if very precise measurements are necessary whereas the home-developed monitoring module is useful for long-term investigations.

5. Conclusion

This paper described the new expansion set for the AUV Monsun. Three different types of sensory kits were shown and possibilities for various missions were illustrated. The individual hardware modules expand the usability of the system and make a heterogeneous swarm of Monsun vehicles possible. The robot was tested during experiments at the Baltic Sea which show the advantages of the system even under difficult conditions caused by waves and currents. The next steps are the development of additional expansion modules containing a more powerful main processing unit and imaging devices as well as test runs with a swarm of three Monsun AUVs to increase the monitoring capabilities of the whole system.

References

[1] B. Meyer, K. Ehlers, C. Isokeit and E. Maehle, The development of the modular hard- and software architecture of the autonomous underwater vehicle Monsun, in *ISR/Robotik 2014 - 41st International Symposium on Robotics, 6th German Conference on Robotics, VDE Verlag, Muenchen*, 2014.

[2] M. Dunbabin and L. Marques, Robotics for environmental monitoring, in *IEEE ROBOTICS AUTOMATION MAGAZINE*, 2012.

[3] L. Techy and K. Morgansen, Long-baseline acoustic localization of the seaglider underwater glider, in *American Control Conference*, 2011.

[4] J. Farrell, S. Pang, W. Li and R. Arrieta, Chemical plume tracing experimental results with a remus auv, in *OCEANS 2003. Proceedings*, 2003.

[5] F. Schill and A. Bahr, Hydromea `http://www.hydromea.com/`, Accessed: 2016/01/19.

[6] Imagenex, Model 852 ultra miniature digital echo sounder `http://www.imagenex.com/Downloads/What_s_New/852_Echo_Sounder/852_echo_sounder.html`., (2016), Accessed: 2016/01/15.

[7] F. Schill, U. R. Zimmer and J. Trumpf, Visible spectrum optical communication and distance sensing for underwater applications, in *Proceedings of ACRA*, 2004.

[8] Aquarian Audio Products, Acquarian Audio hydrophones `http://www.aquarianaudio.com`, Accessed: 2016/01/15.

[9] Sea and Sun Technology GmbH, Cdt 48 memory probe `http://www.sea-sun-tech.com/fileadmin/img/pdf_sea/CTD48.pdf`, (2016), Accessed: 2016/01/15.

[10] European Parliament and Council, Water framework directive 2000/60/ec, in *OJL 327*, 2000.