Underwater Sensors for Marine Applications


by Engr. Assoc. Prof. Dr Mohd. Rizal Arshad and En. Mohd. Norzaidi Mat Nawi

INTRODUCTION

The ocean covers about 71% of the earth's surface and the wide use of underwater sensors has contributed greatly to the success of exploration of the underwater world without endangering human lives. An underwater vehicle which requires minimal or no intervention of a human operator is also known as an unmanned underwater vehicle (UUV) and was developed in the early 70s. With the help of the underwater sensors in monitoring and performing environmental surveillance, the UUV makes the system completely functional by enabling it to move around flexibly, avoiding any obstacles. The installation of sensors has enabled the vehicle to make decisions according to the input while operating with minimal human supervision.

Power consumption, communication and operational cost are some of the most common issues involved when it comes to operating the underwater system in the open seas or in lakes. To overcome these problems, the miniaturisation and performance quality of the underwater system are required.

There are so many small areas which could not be explored as the size of the current UUV is too big, thus making it impossible for it to be operated within narrow spaces. The minimisation of UUV size is important and it depends greatly on the system integration which consists of sensors and circuitry. In order to achieve the miniaturisation and higher performance of the underwater system, a small-scale sensor which is high in efficiency and performance, yet low in power consumption while possessing a longer life span, is required.

In general, the sensor is divided into two categories, namely physical and chemical. Physical sensors are usually used to measure physical variables such as force, acceleration, pressure, temperature, flow rate, acoustic vibration, and magnetic field strength. Meanwhile, chemical sensors are usually used to detect chemical and biological variables including chemical concentrations, pH, binding strength of biological molecules, and interaction amongst proteins.

Underwater sensors are mostly physical sensors such as the acoustic sensors, optical sensors and flow sensors. Such sensors have been developed over decades using a variety of approaches. To improve the performance of sensors, various designs and materials are used. Many factors need to be considered when it comes to designing underwater sensors, such as water murkiness, water pressure, and the salinity effect which is quite different from a sensor that is operated on land.

THE DEVELOPMENT OF UNDERWATER SENSORS

The navigation and localisation of the underwater vehicle are a big challenge. Hence, various techniques for the estimation of the position and orientation such as an inertia, sonar and vision based systems have been developed. The sonar based system utilises the acoustic wave for communication and imaging in the underwater environment as shown in Figure 1. The sonar technology is most commonly applied in geophysical, geotechnical and environmental surveys. Minimisation of the size, improvisation of the performance and efficiency in energy consumption are some of the main challenges faced by researchers in acoustic micro design.

Figure 1: Sidescan sonar survey by UUV

Since the last decade, various acoustic sensors starting from the scalar-type sensor, which only measures pressure components, to the vector-type sensor, which measures both pressure and velocity component in acoustic field, have been designed. With the help of Micro-Electro-Mechanical Systems (MEMS) technology, a new structure has been developed where both capacitive type and piezoelectric type acoustic sensors have been successfully miniaturised. The purpose of MEMS is to miniaturise the devices by using silicon process technology which has led to the many different principles of sensing including electrostatics, piezoresistivity, piezoelectricity, thermal resistivity and bimetallic thermal bonding.

Another technique used in positioning the underwater vehicle is the vision based system. By using an optical sensor, this system offers many advantages in terms of cost and size compared to the acoustic designed sensor. The vision based system can also provide some important information such as the horizontal and vertical distance between the UUV and an object. Further more, optical information travels at the speed of light so that the bandwidth and latency of visual sensing are only introduced by the camera and for subsequent processing. However, this type of sensor has its limitation when it is operating under a poor visual condition. It could perform better near the ocean or lake floor. Moreover, there are many unresolved problems for the optical sensor such as motion estimation and non-uniform illumination.

Nowadays, the flow sensor is increasingly being studied to enable its implementation on underwater platforms. There are two types of principles applied in the conventional flow sensor, namely the thermal based hot-wire anemometry and Doppler frequency shifts. The principle of the hot-wire anemometer is based on the anemometer principle where it measures the flow rate by sensing changes in heat transfer through a small electrically heated hot-wire sensor. However, the disadvantage of the hot-wire anemometer is the energy management. The hot wire needs an accumulator with high density to produce a high current. Therefore, to improve the power consumption, the use of MEMS hot-wire is suggested.

The Doppler frequency shift measures the velocity by transmission and reception of signal. However, reducing the size of this type of sensor is the critical part because it consists of the transmitter and the receiver. With the help of MEMS technology, few researchers have successfully miniaturised the Doppler by the fabrication of integrated optics on a single substrate.

The development of the underwater sensors is still ongoing and many different designs have been proposed. In addition, a new approach has been found to improve the performance of the sensor including investigation of the mechanism inspired by nature or better known as bio-inspired sensor, while the use of new materials such as polymer is proposed.

BIO-INSPIRED SENSOR

A bio-inspired approach can provide ideas for new designs and capabilities, starting from the use of tongs and tweezers to genetic algorithms and autonomous legged robots. Table 1 shows a few examples of different mechanisms inspired by nature. Many researchers are trying to implement the function of nature to the underwater system and sensor. In the development of a bio-inspired flow sensor, the biological approach is a promising alternative to the conventional underwater sensor, which has encountered the current conventional flow sensor problems. The development of bio-inspired flow sensor has gradually increased in the past few years. For instance, a flow sensor based on the lateral line flow sensor in the fish's body is being investigated. Many species of fish and bacteria depend on the side of this system to monitor the flow fields for maneuvering and for survival under water.

The biological lateral line system consists of canals neuromast and superficial neuromast. Both canals and superficial are composed of hair cells which are embedded in the gelatinous cupula. When the fluid passes through the neuromast, it will cause cupula displacement and the hair cells will induce a neuron signal. Based on this principle, different sensor designs have been discussed by a few researchers at the University of Illinois at Urbana-Champaign since year 2000. Figure 2 shows the hair cell sensor inspired by the fish lateral line. The bio-inspired flow sensor is one of the passive sensing systems where the power consumption required to run the system is low but with an improved lifespan for certain operations that require longer running time such as monitoring activity of some habitats. This system also helps to minimise the size of UUV which enables it to perform this simple task and reduces the cost of operation.

Table 1: Representative mechanism and underwater applications inspired by animals

Inspired by	Mechanism	Underwater Applications
Fish and cricket	Hair Cilium	Flow detection
Fish	Neuromast	Hydrodynamic imaging around vehicle
Jellyfish	Morphology and Propulsion	Autonomous underwater vehicle
Plankton	Communication	Underwater wireless sensor network
Dolphin	Swimming Behaviour	Maneuverable underwater vehicle for short-distance echolocation
Rats and Etruscan Shrews	Whisker	Tactile sensing in underwater environments

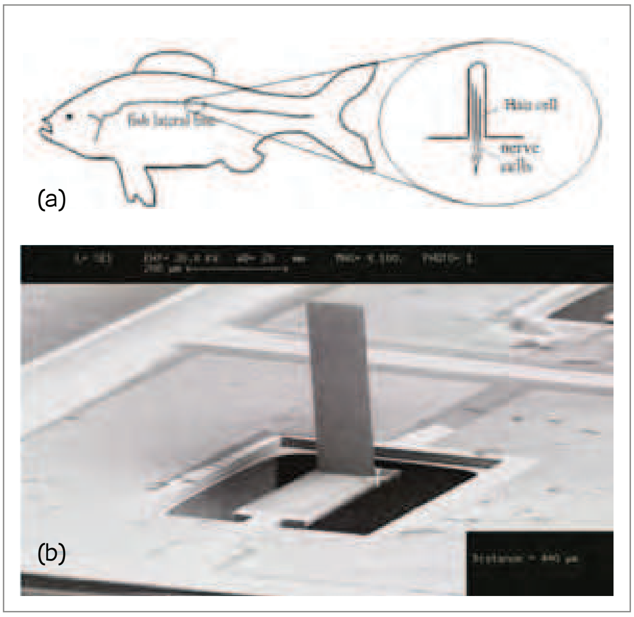

Figure 2(a) Hair cells in the lateral line system; (b) SEM for the artificial hair cell sensor (Fan, 2002)

POLYMER BASED SENSOR

Recently, polymer material has been found to have higher compatibility as compared to other previously used materials. It can provide greater advantages, especially in mechanical yield strain than commonly used silicon. Most of the polymer materials are easy to deform and they are suitable to be used to form the membrane or smart skin for the sensor. Polymer material can also be used for different purposes including as substrates, adhesion, packaging and coating. The acquiring cost for many polymer materials is significantly lower while the fabrication process can be accomplished outside the cleanroom confinement and is easier to handle. Polymers also allow the researcher to design the sensor with a simpler structure and fabrication process such as casting and molding. Table 2 shows the different types of polymer and applications in sensors.

Table 2: Representative Polymer Materials and Applications

Types of Polymer	Applications
PDMS	Microfluidic channels, pump and valves
Parylene	Microfluidic
Liquid crystal polymer	Flow sensors
Su-8 epoxy	Artificial hair cell sensor
Acrylics	Microfluid channels
Polyimide	Sensor substrates, microfluids

Generally, the polymer is used in a microfluidic condition where it is integrated with a sensor. The microfluidic plays an important role in leading the small-scale device to integrate with a different number of applications because of their potential in chemical and biochemical engineering. It is required to handle and process the small amounts of fluid. In addition, smaller channels improve resolution and enable the reduction of the overall size of the device, but it also makes the detection of small vessels to be more challenging and more sensitive to adsorption. The commonly used material in microfluidic is PDMS because it can be easily attached to the glass, making it a user-friendly material that allows the user to create any types of geometry using mold-replication technology.

OPPORTUNITIES AND CHALLENGES

There is a significant challenge yet to be solved. Some major problems with the underwater sensor include the size, material and the efficiency of the sensor. The underwater sensor is important for the autonomous vehicle to survive the underwater environment especially for monitoring and navigation. The variable of the sensor with different purposes demand researchers to explore the underwater world which has become more challenging. The underwater sensor technology needs to be further improved to increase the role of the sensor in assisting the underwater vehicle.

The advancement of MEMS fabrication technology helps the researcher to improve the current conventional sensor and has led to some new trends pertaining to the use of sensors. More research in the future will need to leverage on these advantages to develop nano-scale technology, which is quite new compared to micro technology. In fact, it is necessary to explore and understand the bio-inspired sensor in underwater sensing in future researches. The mechanism inspired by nature is more unique and suitable to implement in various types of applications. The new materials such as polymer have the potential to be integrated with MEMS, where currently the implementation of polymer in MEMS application is relatively small as compared to other materials. Future work is required for the development of underwater sensors, especially in the effort to look for new materials, structures and sensing principles. ■

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