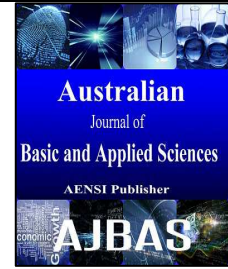




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### Underwater Wireless Sensor Networks- Challenges and Opportunities- A Survey

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#### ABSTRACT

Wireless Sensor Networks (WSNs) have recently been considered as potentially promising alternatives for underwater applications since they have a number of advantages such as unmanned operation, easy deployment, real-time monitoring, and relatively low cost. These networks have increasingly attracted a great deal of research and development attention. This paper aims to provide a comprehensive overview of the current research on Underwater Wireless Sensor Networks (UWSN), focusing on the current state-of-the-art techniques and further challenges and opportunities.

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#### INTRODUCTION

Wireless Sensor Networks (WSNs) have gained worldwide attention in recent years, particularly with the proliferation in Micro-Electro-Mechanical Systems (MEMS) technology which has facilitated several applications in underwater environments. These sensors are small, with limited processing and computing resources, and they are inexpensive compared to traditional sensors. These sensor nodes can sense, measure, and gather information from the environment and, based on some local decision process, they can transmit the sensed data to the user. Smart sensor nodes are low power devices equipped with one or more sensors, a processor, memory, a power supply, a radio, and an actuator. A variety of mechanical, thermal, biological, chemical, optical, and magnetic sensors may be attached to the sensor node to measure properties of the environment.

##### I. Overview:

Traditional use of oceanographic research vessels for monitoring underwater environments is very expensive and time-consuming process that has a low resolution both in time and space. For such environments WSN-based approach can dramatically improve the access to real-time data covering long periods and large geographical areas (Thiemo, V., *et al.*, 2007). According to Tateson *et al.*(2005), a WSN-based approach is cheaper than a conventional oceanographic research vessel. In a UWSN various kinds of sensors are used to monitor and measure

different physical and chemical parameters such as water temperature, pressure, wind direction, wind speed, salinity, turbidity, pH, oxygen density, and chlorophyll levels. Development and deployment of an adaptive, scalable and self-healing UWSN system need to address a number of critical challenges such as autonomy, scalability, adaptability, self-healing and simplicity (Yebra, D.M., *et al.*, 2004; Whelan, A., F. Regan, 2006). UWSN applications should take into account the following challenges different from those on land (Albaladejo, C., *et al.*, 2010):

(i) *Higher water resistance:* Sensor nodes of a underwater monitoring system require greater levels of water resistance;

(ii) *Stronger robustness:* A underwater monitoring system needs stronger robustness, since the underwater environment with waves, underwater currents, tides, typhoons, vessels, *etc.*, is aggressive and complex, and causes movement of nodes;

(iii) *Higher energy consumption:* Energy consumption is higher due to long communication distances and an environment in constant motion;

(iv) *More unstable line-of-sight:* The oscillation of the radio antenna can cause a more unstable line-of-sight between transmitters and receivers (Alippi, C., *et al.*, 2008).

(v) *Other problems:* There are also some other problems including the difficulty for deployment and maintenance of nodes, the need for buoy and mooring devices, sensor coverage problems (Cardei, M., J. Wu, 2006), and possible acts of vandalism.

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There have been a few literature reviews on Wireless Sensor Networks for underwater environment monitoring. Albaladejo *et al.* (2010) provided a comprehensive review of the research and development of oceanographic monitoring using wireless sensor networks and pointed out the challenges and difficulties of WSNs for oceanographic monitoring. This paper is intended as an update and extension of Albaladejo *et al.*'s review Albaladejo *et al.* (2010) based on recent developments in this area during the past five years. The limitations and challenges of wireless sensor networks for environmental research were discussed in (De la Piedra, A., *et al.*, 2013). They reviewed several WSN applications such as water ecosystems, forest monitoring, precision agriculture, wildlife observation, disaster prevention and urban monitoring.

This paper provides a comprehensive review of recent developments in the related fields, discusses major technical challenges, and identifies future research directions. The rest of the paper is organized as follows: Section 2 briefly describes fundamentals of WSN-based underwater environment monitoring systems. Section 3 reviews some related projects, systems, and technologies. Section 4 highlights various challenges and opportunities including oceanographic sensors protection, advanced buoy design, energy harvesting system design, and WSN-based system stability and reliability. Section 5 provides some concluding remarks.

#### A. Application Areas:

WSN-based underwater environment monitoring has a broad coverage including a number of application areas: water quality monitoring, ocean sensing and monitoring, coral reef monitoring, and underwater fish farm monitoring. Different application areas require different WSN system architectures, communication technologies, and sensing technologies. Under water quality monitoring system is usually developed to monitor water conditions and qualities such as temperature,

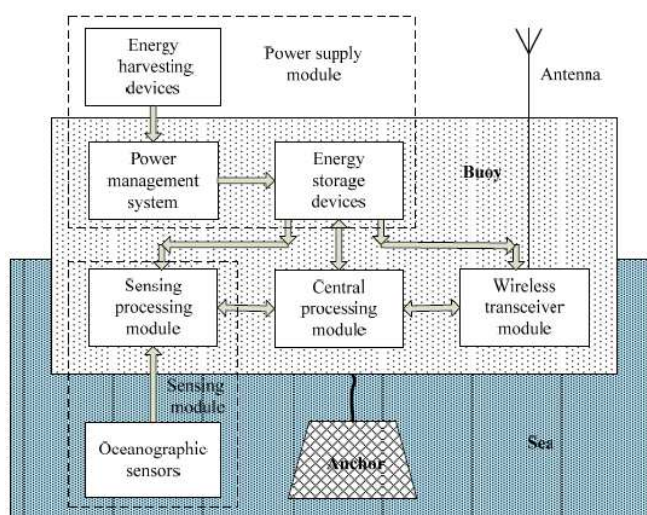
pH, turbidity, conductivity and Dissolved Oxygen (DO) for ocean bays, lakes, rivers and other water bodies. An ocean sensing and monitoring system is used to monitor ocean water conditions and other environmental parameters. A coral reef monitoring system is normally installed to monitor coral reef habitats using an autonomous, real-time and *in-situ* wireless sensor network. An underwater fish farm monitoring system is developed to monitor water conditions their temperature and pH, and accurately quantify the amount of fecal waste and uneaten feed for a fish farm.

#### B. General Architecture for UWSN Systems:

Figure 1 shows the architecture of a general sensor node in a UWSN system. It usually includes a buoy device to protect the electronic devices against water. A monitoring wireless sensor node normally consists of the following four main modules (Giuseppe, A., *et al.*, 2009):

- (i) A sensing module for data acquisition;
- (ii) A central processing module for local data processing and storage;
- (iii) A wireless transceiver module for wireless data communication;
- (iv) A power supply module for energy supply.

A sensing module is usually composed of several probes and sensors (with associated amplifiers and A/D converters) to sense and monitor the physicochemical parameters of underwater environment. A central processing module normally includes a CPU and memory to process and store the collected data. A wireless transceiver module mainly consists of a RF transceiver and an antenna to send the collected data and receive instructions from the sink node. A power supply module consists of rechargeable batteries, power management system and energy harvesting devices such as solar panel, wind energy, tidal power, and seawater generator. The buoy has an anchor device in order to prevent it from moving due to waves, underwater currents, wind, tide, *etc.*



**Fig. 1:** General architecture of an UWSN sensor node

The energy options for sensor nodes usually include batteries, capacitors, heat engines, fuel cells, and energy harvesting. Sensor nodes are normally battery power operated in most application systems. However, the use of a battery in sensor nodes has a number of disadvantages (Knight, C., *et al.*, 2008):

(i) When the network size increases, replacement of depleted batteries becomes wasteful and time-consuming.

(ii) The batteries have limited energy that limit the life time of the sensor nodes.

(iii) Batteries have environmental contamination and disposal issues since the chemical composition of a battery often involves toxic heavy metals.

It is therefore necessary to explore energy harvesting techniques to supply energy for sensor networks. Energy harvesting methods include photovoltaic, fluid flow, temperature gradients, pressure variations and vibration harvesting. In terms

of their efficiencies and reliability, the most outstanding energy harvesting at the moment is photovoltaic (Knight, C., *et al.*, 2008).

### C. Sensing Parameters and Sensors:

The sensors nodes respond to changes in their environment by producing an electrical signal in the form of voltage, current, or frequency (Cesare, A., G. Cristian, 2008). In a underwater monitoring system, physical sensors are used to measure parameters such as temperature, humidity, pressure, wind speed and wind direction while chemical sensors are used to sense parameters such as salinity, turbidity, pH, nitrate, chlorophyll, dissolved oxygen (DO), *etc* as shown in Table 1. The right choice of sensors depends on the deployment area, measurement range, accuracy, resolution, power consumption, and intended deployment time.

**Table 1:** Common underwater environment monitoring sensors

Sensors	Monitoring Parameters	Range	Accuracy	Power Supply	Unit	Manufacturer
SBE 16plus V2	Temperature	-5 to +35 °C	±0.005 °C	9-28 V	°C	Sea-Bird Electronics
GT301	Pressure	0 to 60	< ±0.5% of FRO	24 V	bar	Kongsberg Maritime
SBE 16plus V2	Conductivity (Salinity)	0-9	± 0.0005	9-28 V	S/m	Sea-Bird Electronics
OBS-3+	Turbidity	Mud: 5000-10,000 mg/L Sand: 50,000-100,000 mg/L	0.5 NTU	15 V	NTU	Campbell Scientific
PS-2102	pH	0 to 14 pH	±0.1	N/A	pH	PASCO
YSI 6025	Chlorophyll	0 to 400 µg/L	0.1 µg/L	6 V	µg/L	YSI
ISUS V3	Nitrate	0.007 to 28 mg/L	±0.028 mg/L	6-18 V	mg/L	Satlantic
SBE 63	Dissolved oxygen (DO)	120% of surface saturation in all natural waters	0.1	6-24 V; 35 mA	mg/L	Sea-Bird Electronics

Underwater acoustic communication technologies can be a good choice for data collection and exchange among underwater sensors (Jiang, Z., 2012; Jiang, Z., 2008; Zhu, Y., *et al.*, 2013). Generally, the longer the range a radio module, more will be energy consumption. The choice of wireless communication technology depends on the amount and frequency of the transmitted data, transmission distance, and amount of available energy.

## **II. Research Challenges and Opportunities:**

During the recent years wireless sensor networks have been widely applied to terrestrial areas, and some of these deployments have achieved satisfactory performance. However, the application of WSNs in underwater environment monitoring is still in its infancy, and most WSN-based systems are purely experimental (Albaladejo, C., *et al.*, 2010). This section discusses a few of the challenges for underwater environment monitoring including oceanographic sensors protection, advanced buoy design, energy harvesting system design, and system stability and reliability.

### **A. Oceanographic Sensors Protection:**

In underwater environments, there are over 4000 organisms related to fouling problems (Yebra, D.M., *et al.*, 2014). According to their sizes, organisms can be classified into micro-organisms (or so called biofilms, slimes, and micro-fouling) and macro-fouling (Delauney, L., *et al.*, 2010). Biofouling development on a sensor surface is subject to several chemical, physical and biological factors such as pH, dissolved oxygen, temperature, light, location depth, conductivity, organic material and hydrodynamic conditions. When oceanographic sensors are immersed in seawater, they are susceptible to biofouling problems which often lead to the long-term accuracy issues of underwater environmental sensor measurements. Since the underwater environment is aggressive and the seawater is corrosive, oceanographic sensors should take appropriate fouling protection measures. The biofouling protection for oceanographic sensors may be divided into three techniques (Delauney, L., *et al.*, 2010) according to their different actions as listed below.

(i) *Wiper mechanisms*: It is an effective mechanical method as long as the sensor head has a suitable shape for wiper cleaning and the wipers are in good condition.

(ii) *Copper corrosion mechanisms*: A copper corrosion mechanism protects the sensitive sensor head effectively, but the protection mechanism is not easy to apply to existing sensors and the cost is relatively high.

(iii) *Chlorine evolution mechanisms*: This technique uses bleach or chlorine generation by seawater electrolysis. Moreover, this protection

mechanism can be easily adapted to existing sensors relatively low cost.

Besides the above mentioned three biofouling protection techniques, there are some other interesting methods which promise effective results coming from research laboratories (Whelan, A., F. Regan, 2006; Manov, D.V., *et al.*, 2004). However, it is very difficult to implement these methods in the real sea environment. Biofouling protection for oceanographic sensors should take into account six aspects: low cost, low power consumption, easy to install on existing sensors, no or low impact on measurement precision and the environment, long lifetime and robustness against aggressive conditions. Therefore, researchers and manufacturers should further study and explore the biofouling protection mechanisms for underwater environmental sensors.

### **B. Advanced Buoy Design:**

Considering the underwater environment is aggressive and complex, it is very crucial to design an advanced flotation device (buoy) for a underwater environment monitoring system. A buoy normally consists of a wireless sensor network node (CPU, sensors, radio, and batteries), an energy harvesting module, underwater sensors and a mooring system. For example, Pirisi *et al.* (2013) proposed a special energy harvesting buoy which can effectively use sea wave energy conversion as a power source and has potential applications in underwater environment monitoring. Albaladejo *et al.* (2010) designed a multisensory buoy system which can be effectively used for shallow underwater environment monitoring. The design and deployment of an advanced buoy for underwater wireless sensor networks should take into account the following requirements: low cost, waterproof, strong stability, energy harvesting, and mooring system.

(i) *Low cost*: A underwater environment monitoring system using wireless sensor networks is usually composed of a large number of sensor nodes. Therefore, each buoy device needs to be low cost.

(ii) *Water tightness*: In order to protect the stability of underwater environment monitoring system and prolong its lifetime, its electronic devices must be in a waterproof housing to avoid water damage.

(iii) *Strong stability*: As the underwater environment is aggressive and complex, the monitoring system should have a strong stability against adverse atmospheric conditions.

(iv) *Energy harvesting*: Since it is not convenient to replace the batteries deployed on the underwater surface and the sensor nodes, which are far away from the land and are power-hungry, it is necessary to consider the use of energy harvesting to reduce system maintenance requirements.

(v) *Mooring system*: Due to tides, waves, underwater currents, wind, *etc.*, an anchor is required on the seabed in order to avoid the movement of the buoy devices.

Besides the above mentioned requirements, the buoy mechanic design should meet a number of requirements including the buoy visibility with bright yellow color and a warning light for maritime traffic, the use of environmentally friendly materials, the connection of several sensors, and the reasonable antenna height for the better communication propagation.

### C. Energy Harvesting System Design:

The energy supply of a wireless sensor network is generally provided by batteries which have limited energy (Alippi, C., *et al.*, 2008). In addition, in underwater environment monitoring systems, wireless sensor nodes are often deployed in unapproachable sea surface areas, and they are mostly planned for long-time operation, therefore, it is not convenient to replace the sensor batteries. Moreover, underwater sensor nodes (sink nodes) have high energy consumption due to the use of long-range wireless communication protocol (GPRS). In order to reduce system maintenance requirements effectively, there is a clear need to design an energy harvesting system which uses renewable energy source such as solar (Thiemo, V., *et al.*, 2007), tidal power (Pirisi, A., *et al.*, 2013), or wind energy (Hsu, C.L., 2010; Seah, W.K.G., *et al.*, 2009). Some energy harvesting devices have been designed and developed to prolong the lifetime of underwater environment monitoring systems. For example, (Thiemo, V., *et al.*, 2007) developed a solar energy harvesting device which is composed of two solar panels behind the electronic equipment with an inclination of 45 degrees in an opposite direction. In order that one battery is always being charged while the other is always being discharged, a power management system of a low-power Maximum Power Point Tracker (MPPT) circuit was developed and used for wireless sensor networks in (Cesare, A., *et al.*, 2011) and (Cesare, A., G. Cristian, 2008). To design an advanced energy harvesting system for underwater environment monitoring, it is necessary to consider the following three aspects; energy harvesting devices, power management system, and energy storage devices (Cesare, A., *et al.*, 2011).

(i) *Energy harvesting devices*: An energy harvesting device is responsible for harvesting energy from the ambient environment. According to the characteristics of available ambient energies, we should choose appropriate energy harvesting devices and should consider how to install the energy harvesting devices.

(ii) *Power management system*: A power management system can intelligently manage the batteries to be charged and discharged at separate intervals of time. An ideal power management

system can prolong the lifetime of batteries and easily store more energy for the system.

(iii) *Energy storage devices*: Energy storage devices normally adopt the rechargeable batteries. Usually, the energy capacity of rechargeable batteries is larger than daily system energy consumption and daily harvesting energy in order to store energy and permit the system to supply power even in case of bad weather (Cesare, A., *et al.*, 2011). Given the aggressive and hostile underwater environment, in order to harvest and use more reliable renewable energies, we can envision a hybrid harvesting energy system for underwater environment monitoring in the future, which can use several renewable power sources such as solar, tidal power, seawater generator, and wind energy.

### D. System Stability and Reliability:

During the past decade, the system stability and reliability problem of wireless sensor networks has been widely studied in order to measure physical parameters correctly and effectively, as well as to prolong the lifetime of the system dramatically. AboEIFotoh *et al.* (2005) studied the reliability and message delay for cooperative wireless distributed sensor networks subject to random failures. Egeland *et al.* (2009) analyzed the reliability and availability of wireless multi-hop networks with stochastic link failures. Qureshi *et al.* (2011) presented a methodology using a topology control mechanism for the reliability evaluation of a WSN. Silva *et al.* (2012) proposed a methodology based on an automatic generation of a fault tree to evaluate the reliability and availability of wireless sensor networks in typical industrial environments. Considering the aggressive and complex environment, it is very important to analyze the system reliability in a underwater environmental monitoring system using wireless sensor networks. Therefore, the research on the reliability of a WSN-based underwater environment monitoring system should take into account the following aspects.

(i) *Battery life issues*: As mentioned above, underwater sensor nodes (sink nodes) consume more energy than other kinds of wireless sensor nodes. Therefore, the battery life issue always affects the system reliability.

(ii) *Communication relay issue*: The communication relay affects dramatically the system reliability, when some nodes fail or simply disappear.

(iii) *Severe environment conditions*: The underwater environment always has external interference from ships, fishes, and birds, and has severe weather conditions such as waves, underwater currents, tides and typhoons. Such severe environment conditions further influence the system reliability.

### Conclusions:

During the last decade, monitoring of the underwater environment has attracted a great deal of research and development attention. Wireless sensor networks are a highly promising technique for monitoring underwater environments because of their advantages of easy deployment, real-time monitoring, automatic operation, and low cost. This paper presents a state-of-the-art survey of applications of wireless sensor networks in underwater environment monitoring. It first describes fundamentals of WSNs-based underwater environment monitoring, including application areas, a common WSN architecture, general sensor node architecture, sensing parameters and sensors, and wireless communication technologies. Then, it reviews the related literature according to different projects, systems, applications, network routing mechanisms, algorithms, approaches and techniques on underwater environment monitoring based on wireless sensor networks. From this survey, it is evident that there are still a few interesting challenges and opportunities on development and deployment of wireless sensor networks for underwater environment monitoring, including oceanographic sensors protection, advanced buoy design, energy harvesting system design, and system stability and reliability.

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