Self-Powered Wireless Ocean Monitoring Systems

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***Abstract*—Recently, underwater wireless sensor network (UWSN) has been emerged as one of the important research topics from the need for the conservation and exploitation of the ocean. Since underwater sensor nodes suffer from limited power source, in this paper, we have planned to design and implement self-powered ocean monitoring systems which generate renewable marine energy from a device at sea surface and share the energy with underwater nodes. As a first step of this objective, we have developed an acoustic modem for wireless communication and made experiments in a pond to verify the performance of the modem. In addition, we have supplied the power to the modem by harvesting solar energy with solar panels. Efficient energy management, movement of underwater nodes and energy transfer will be investigated as succeeding work.**

***Keywords*-Underwater Wireless Sensor Network (UWSN); Energy Harvesting; Acoustic Modem.**

I. Introduction

During the last few years, there has been a growing interest in observing underwater environments for scientific exploration and monitoring ocean currents and winds (Tsunamis) and some researchers have studied and developed the prototype of underwater wireless sensor network (UWSN) systems [1], [2]. The study on acoustic modem has also conducted by many research groups. Especially, Yan et al. [3] implemented a modem adopting orthogonal frequency division multiplexing and verified one-way communication in oceanic environments.

One of the open problems for UWSN is the limited power, since the devices of UWSN typically rely on batteries. Until now, researchers tried to resolve this problem by utilizing a finite energy efficiently as much as possible [4], [5]. Meanwhile, in case of autonomous unmanned vehicle (AUV), there was a trial for the vehicle to be equipped with solar energy harvesting module at the Beacon Institute for Rivers and Estuaries [6]. When the vehicle floats to the sea surface, it starts to generate energy by using solar panels on its back.

Recently, initial studies on wireless energy sharing between devices are investigated in various forms. Magnetic resonant coupling with coils has lots of attention due to its efficiency and working range. Photonics and modern electro-magnetics group at MIT has conducted theoretical analysis and experiments with coils [7]. According to the results, wireless energy transfer in the air was possible between two self-resonant coils having the radius of 30 cm. The efficiency for 60 watts transfer was 70 % and 40 % at 1 m and 2 m distance, respectively. Besides, magnetic induction, RF and optics are the candidates of wireless energy transfer in air in the spotlight.

Based on the thorough survey of the abovementioned existing work, in this paper, we suggest the concept of self-powered wireless ocean monitoring system which generates solar or wind energy from a device at the sea surface and transfers this energy to other devices in a wireless manner. It would be possible to observe oceanographic data and predict natural disasters such as tsunami and sea shock permanently with this system. As a first step of the target system, we design and implement an acoustic communication system operated by the renewable solar energy and make experiments in a pond.

The remainder of this paper is organized as follows. We first describe the big picture of the target system in Section II. The design of solar harvesting and acoustic transceiver are discussed in detail in Section III. In order to examine solar harvesting modules and estimate the performance of the developed modem, experimental results are provided in Section IV. Finally, in Section V, we give a brief summary and comments on further work of this paper.

II. Objectives

Fig. 1 shows the blueprint of a self-powered wireless ocean monitoring system. This system is comprised of four components for monitoring of underwater environments: sensor node, sink node, gateway and an onshore user. The basic operation of the system is similar to the normal UWSN. That is, when the user requires underwater sensing data, it queries to a specific sensor node via the gateway in downlink transmission and gets the wanted data in uplink data transmission.

The main differentiated points of the proposed system are power management, energy harvesting, actuator module of node and wireless power transfer module. The power management part on the gateway controls energy generation and consumption continuously for smart energy management. Also, renewable energy is generated from the gateway located at the sea surface and the nodes goes to the gateway and recharge the battery when it is needed. Also, Fig. 2 illustrates the block diagrams of node and gateway in detail. In the figure, the black dotted lines represent the data flow and the red solid lines means the power transfer.

The specific procedures for energy sharing of the system are as follows. First, solar module on the gateway keeps generating energy from the sun and charging a battery. Meanwhile, in the underwater, each smart battery charge controller continuously checks the residual battery power in the node. When detected a lack of power of its node, the controller reports the present

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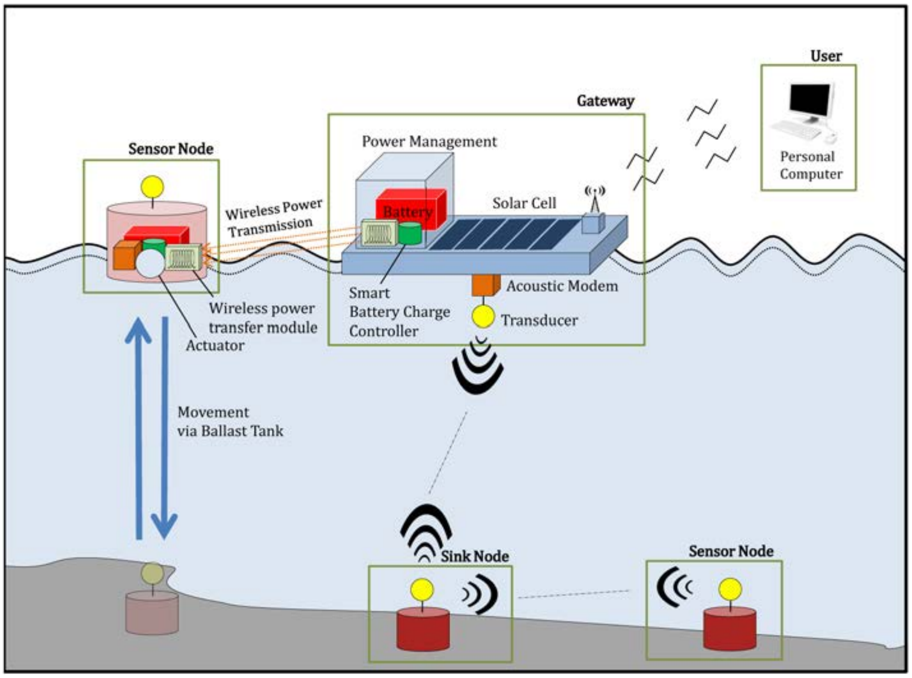

Fig. 1. Blueprint of self-powered wireless ocean monitoring system.

state to the gateway and sends a signal to a actuator module to move to the gateway. The actuator module consists of thruster and ballast which take in charge of the horizontal and vertical movements. After being arrived near the gateway, the battery in the node is charged wirelessly by two strongly coupled induction coils in wireless power transfer module. Since two resonant objects having the same magnetic resonant frequency have a tendency to exchange energy, these two coils make it possible to transfer a power. When the recharging is completed, the node goes back in underwater with the help of actuator module and starts acoustic communication again.

To realize this system, the following devices should be investigated.

1) Acoustic modem
2) Smart battery charge controller
3) Marine energy harvesting module
4) Actuators with thruster and ballast module
5) Wireless power transfer module

Among the five items, we have designed and implemented three devices: acoustic modem, smart battery charge controller and marine energy harvesting module. In further works, we will develop remaining two devices such as actuator and wireless power transfer.

III. A Prototype of Self-Powered Wireless Ocean Monitoring

A. Transceiver

In our previous work, several transceiver modules taking in charge of underwater wireless data transmission and reception have been implemented [8], [9]. Compared to the previous transceiver, amplification blocks in transmitter and receiver

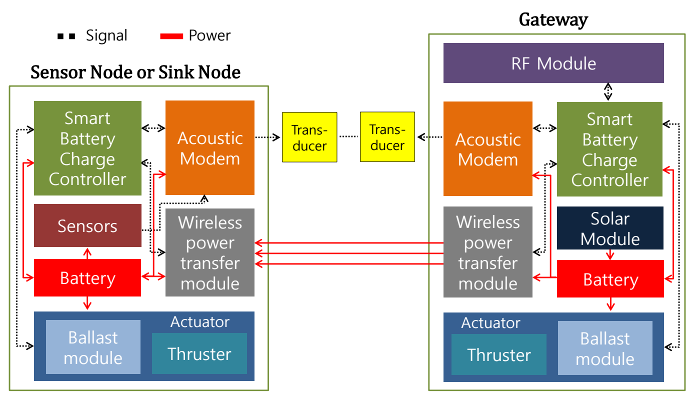

Fig. 2. Block diagram of gateway and node.

are reinforced and software coding is optimized for the performance enhancement in terms of working range and data rate. As shown in Fig. 3, the acoustic transceiver consists of digital board, analog transmission board, analog reception board and transducer. The detailed specification of the transceiver is summarized in Table I.

B. Smart Battery Charge Controller

As shown in Fig. 2, smart battery charge controller at gateway is connected to five components: RF module, acoustic modem, actuator, wireless power transfer module and battery. In this work, we have implemented controller communicating with RF module via RS-232, acoustic modem via SPI and battery.

The software processed at the controller of gateway is depicted in Fig. 4. MCU measures battery voltage level

Fig. 3. Implemented acoustic transceiver.

TABLE I
SPECIFICATION OF ACOUSTIC TRANSCEIVER

Feature	Description
MCU	ARM9 (Cortex-M3)
Transducer	Omnidirectional
Resonant frequency	74 kHz
Interface	UART
Data rate	1 kbps
Power Consumption	3 W
Modem size	70 x 35 mm ($\phi\times$H)

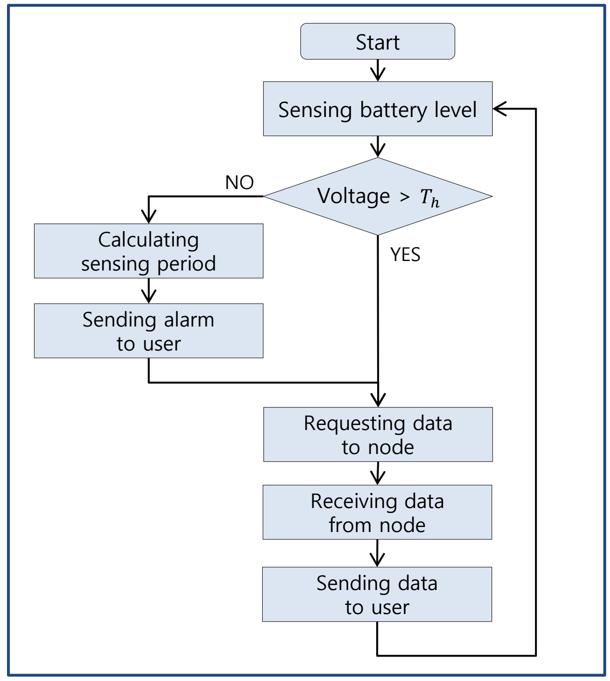

Fig. 4. Flow chart of software of smart battery charge controller at gateway.

periodically and compares it with a predetermined threshold T_h. If the voltage level is less than T_h, it computes sensing period to save power consumption and sends alarm command to the user. Then, the gateway requests data to nodes and receives sensing data from nodes. After forwarding the data to the user, it returns to the original state again.

C. Solar Energy Harvesting Module

The capacity of solar energy harvester should be determined by the following values:

1) the amount of power consumption of a device per day
2) the required amount of solar energy per day
3) the total required amount of solar energy per day considering a natural loss factor.

Since most of battery power is consumed at acoustic modem and actuator among several modules loaded in the sensor or sink node, the two modules are only considered for the capacity calculation of an energy harvester without loss of generality.

First, the amount of power consumption at acoustic modem per day is simply calculated by multiplying the power consumption of acoustic modem by hours in use per day. With the assumption that the acoustic modem operates during 20% in time in order to send data in underwater, the amount of power consumption per day becomes

$$3 \cdot (24 \cdot 0.2) \quad = \quad 14.4 \ WH. \qquad (1)$$

For actuator, if we assume that it consumes 60 watts and operates 5 minutes per day, the amount of power consumption at actuator is given by

$$60 \cdot \frac{5}{60} \quad = \quad 5.0 \ WH. \qquad (2)$$

TABLE II
THE AMOUNT OF POWER CONSUMPTION AND HARVEST

Comsumption		Harvest
Acoustic modem	Actuator	
3 W	60 W	20 W

From (1) and (2), total power consumption per day at each node is equal to 19.4 *WH*. Here, the result provided in [10] is used for the reference of power consumption at an actuator of wireless remotely-operated vehicle.

Since the hours exposed to sunshine is 3.5 hours in average, the required amount of solar energy per day can be predicted by dividing the amount of power consumption per day at a node by the sunshine hours, which is written by

$$19.4/3.5 \quad = \quad 5.5 \ W. \qquad (3)$$

Also, by considering the typical loss factor of 1.2, the total required amount of solar energy per day becomes

$$5.5 \cdot 1.2 \quad = \quad 6.6 \ W. \qquad (4)$$

In order to recharge the three nodes simultaneously in the worst scenario in Fig. 1, the solar panel should harvest at least 19.8 watts. From these reasons, solar energy harvesting module which generates 20 watts is selected for the implementation of the system. Table II shows the consuming power at a node and the harvested power at the gateway of this system.

IV. PRELIMINARY EXPERIMENTS

The developed acoustic modem, battery controller and solar energy harvester are verified the functionality in a pond. Fig. 5 illustrates the test scenario at the pond. As shown in the

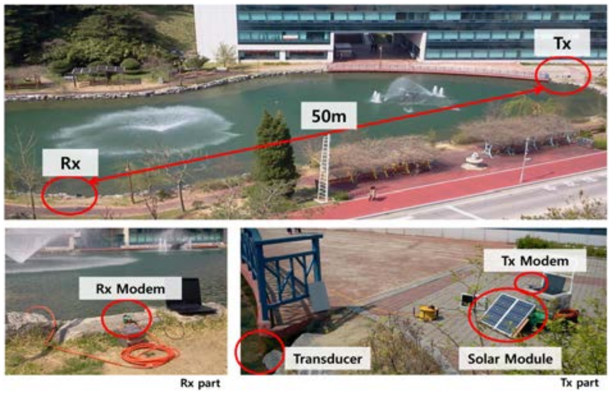

Fig. 5. Experimental environment.

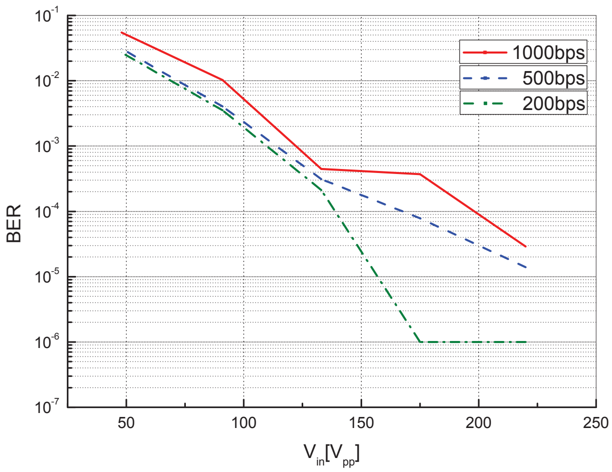

Fig. 6. Bit error rate with respect to input voltage and data rate.

figure, solar panel is connected to the transmitting modem and generates power. The receiving modem is placed on the other side at the distance of 50 meters from the transmitter. For the ease of experiments, only transducers are submerged to the pond. Predetermined data pattern is transmitted sequentially at the transmitter and the bit error rate (BER) is measured at the receiver.

Fig. 6 represents the bit error rate with respect to the input voltage of the transmitting transducer V_{in} and the data rate. According to the result, BER is improved by the increase of V_{in} at a given data rate. This is because if V_{in} is increased, the signal strength of received signal is also increased which make it easy for MCU to extract the transmitted signal from the corrupted signal by noise and multipath. Also, it is observed that BER degrades by increasing data rate which means both noise and multipath affect more and more for shorter symbol duration.

V. Conclusions and Further Work

In this work, we have proposed the concept of self-powered wireless ocean monitoring system which could be operated semi-permanently. Five core technologies have been distinguished for the target system. Furthermore, a simple underwater communication system equipped with solar energy harvester and battery controller has been developed and tested in a pond.

As succeeding work, we are planning to address the following topics. First, we will make more experiments in various marine environments to deploy acoustic modem with solar energy harvesting module. And, we will also develop wireless power transfer module and actuator and verify the feasibility of the self-powered wireless ocean monitoring systems.

Acknowledgment

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