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A simplified signal analysis algorithm for the development of a low cost underwater echo-sounder

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A B S T R A C T

In the literature survey, most of the signal analysis techniques for underwater acoustic information rely on complex mathematical models, which are impractical for a small real time application such as an underwater echo sounder. The purpose of this work is to introduce a modified signal process algorithm which can be easily implemented into a microprocessor and to determine the distance an obstacle from a moving underwater vehicle. This simplified acoustic signal analyzer uses a series of 'mask shading', '3-time majority' and 'echo-duration threshold' signal process steps to increase the accuracy of distance measurement for the self-developed underwater echo sounder. Experiment result shows that the proposed algorithm can ignore the erroneous signal cased by environment noise at sea and transient noise from the circuit board. This work has been proven valuable when used with an auxiliary solar-powered boat to measure the slurry accumulation at a local An-Ping Harbor in southern Taiwan.

1. Introduction

In the world of automation and robotics, the surrounding environment is a challenge for any autonomous vehicle to navigate due to the presence of stationary and moving obstacles. The vehicle must be able to sense the obstacles and to determine a path around them so as to avoid collision. An ultrasonic sensor system is widely used in industrial applications to measure object distance both in air and in water. This technique is particularly useful for the underwater environment because light and RF signal are attenuated over shorter distance, and application based on RF signal at subsea level is minimal. Typically, for underwater acoustic applications, frequency range is less than 300 kHz. To date, many autonomous underwater vehicles (AUVs) use high end sonar system for distance detection at the expense of cost. For application at shallow water region such as Taiwan Strait between Taiwan and mainland China, low cost sonar system for collision avoidance application has its economic advantage over its expensive counterpart.

The operation principle of an acoustic sensor system is based on the measurement of the time of flight (ToF): the time for an ultrasonic wave traveling from a transmitter to the receiver after the signal being reflected from the target. Different techniques can be used to generate ultrasonic waves. Among them, continuous wave [1] and pulse-echo techniques [2–4] are widely used. In continuous wave methods, the accuracy is dependent on the measurement of phase shift between the transmitted and reflected wave, and in general a complex hardware is recommended. The pulse-echo technique uses a short train of signals generated enabling the same transducer to be used both as a transmitter and as a receiver. Although this method is simpler and cheaper than the continuous wave method, but it suffers from poor resolution when echo-pulse has been attenuated. This situation can be worsen when the environment moves to undersea level because higher attenuation rate caused by

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water. It therefore requires signal processing algorithm to improve the accuracy of the pulse-echo method. To name a few of these algorithms: Marioli et al. [2,3] use a cross-correlation function of the transmitted and the received echo signals to determine the time of flight (ToF) information. ToF is closely related to the maximum of the cross-correlation function and its sampling interval. Cai and Regtien [4] propose another method called the self-interference method by sending two pulse trains of waves delayed by a given time using a piezoelectric transducer. These two pulse-trains interference each other, and by measuring the zero of the received echo envelop, the time of flight can be calculated. The accuracy is determined by the transducer's resonant frequency, fluctuations in the acoustic velocity and change of environment temperature. Barshan [5] discussed ToF measurement using threshold, curve-fitting, sliding-window, and correlation methods regarding fast processing for accurate range measurements. An A/D converter having 1 MHz sampling frequency is required for the afore-mentioned application, and which is not suitable for low cost underwater acoustic application. Recently, Egana et al. [6] proposed 1-transmitter/2-receiver system to manage the return echo envelope in order to have an accurate ToF data. This method demonstrates possible application in open air environment, but it is still questionable for subsea application. It is also suggested by Heale and Kleeman [7] that the use of local digital signal processor (DSP) has the advantage to obviate the data communication problem to a central computer. Kuc [8,9] uses the coincidence detection algorithm to eliminate the reverberation of artifacts in a confined corridor area. In his studies, two sensors are used to act as the binaural sonar, and the echo responses are represented as the pseudo-action potentials (PAPs). Sonar image is mapped from as many as 24,000 PAPs. Due to the lengthy scanning process, it takes about 1 min to complete each scan and this method is not suitable for our application.

Although lots of literatures can be found for distance measurement in open air condition using time of flight technique, there is not enough information discussing the distance detection in the subsea environment. Nguyen [10] has done a fundamental discussion on the design of an active acoustic sensor system for an AUV, but gives no information regarding to the signal processing for his echo sounder. Therefore, the aim of this work is to develop a compact and low cost sonar system using the modified time of flight algorithm for accurate distance detection, which can be also used as a range founder for a moving AUV at subsea condition. We avoid the complexity of mathematical formulation, and propose the simple idea of a series of 'mask shading', '3-time majority' and 'echo-duration threshold' signal process algorithms to accommodate the characteristics of the underwater acoustic transducer and subsea noisy environment. The signal process algorithm is modified from the coincidence detection method for easy implementation. By using an underwater transducer, a complete echo sounder system is achieved when the simplified algorithm is uploaded into a micro-processor based interface circuit board. The entire system is compact in size and is powered only by battery, which is suitable for space limited application such as an underwater vehicle. This system has also been implemented into an auxiliary solar-powered boat to measure the slurry accumulation at a local harbor after the Morakot typhoon (2009.8.5) which caused tremendous economical loss in southern part of Taiwan.

In this paper, the overview of the system hardware will be first given. The proposed signal process algorithm for operating in a microcontroller will be also discussed in details. Experiment results at various testing environment have been shown that the system is simple and reliable, and it is possible to be used for AUV application in the future. Finally, we demonstrate the proposed system operating on an auxiliary solar-powered hydrological survey ship and showing how it effectively measures the slurry accumulation at a local harbor.

2. Hardware implementation

To transmit a pulse train of waves and to receive its echo signal, the ultrasonic transceiver, LM1812 from National Semiconductor [11], is used throughout this work. During the early phase of development, a LabVIEW interface is used for sending the key-in signal for pulse transmission, and a data acquisition card is used for digital input of the echo information, Fig. 1. The LabVIEW-based LM1812 simulator, Fig. 2 is also written to simulate the functionality of the transceiver. When the simulator receives a key-in signal from the controller, it also automatically responses with one set of pre-set digital acoustic information to the data acquisition unit. The clock in the CPU measure the time of flight information and the proposed LabVIEW signal process algorithm takes care of the information. The LM1812 simulator can be used as a redundant check for the self-developed sonar system. During each testing, the echo information is recorded and can be played back to insure the accuracy of the sonar system.

The schematic architecture of the micro-controller based sonar detection system can be realized as in Fig. 3. The Propeller chip has eight processors (cogs) which can operate simultaneously, either independently or cooperatively, sharing common resources through a central hub. A USB interface is for program uploading into the controller, the OP amplifier and the MAX232 provide the required TTL voltage level while communicating between the LM1812 and the Propeller microprocessor. This mini computer board also includes three motor controller ports for future control of underwater vehicle. A realistic PCB arrangement is shown in Fig. 4. In this paper, TC-2111 from RESON operated at 200 kHz is used as the transducer for emitting/receiving underwater acoustic signal. Synchronization is done by the Propeller microcontroller, and it calculates the on-chip clock ticks from key-into the end of signal acquisition. The remaining DI/DO of the chip can be arranged for applications such as PWM motor control,

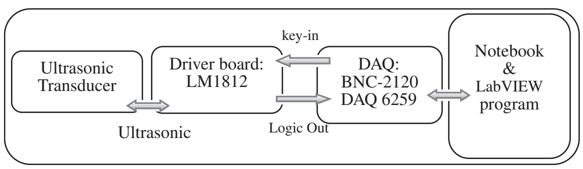

Fig. 1. Schematic diagram of a PC based sonar detection system.