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A SMART HYDROPHONE FOR UNDERWATER ACOUSTICS

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ABSTRACT

The paper describes a network-capable smart hydrophone that, in addition to acoustic detection, also provides operational information and calibration data such as temperature and pressure. Such a hydrophone can store information such as sensitivity, capacitance, date of manufacture and/or a serial number. This data will be written at the time of manufacturing or in the field, or a combination of both. This additional sensor information can be multiplexed into a single output data stream. The hydrophone can also use the additional sensory information to self-compensate for variations in operating conditions, thereby providing more stable operational data. The paper will describe a smart hydrophne that will identify itself and its location on a network and will include multi-channel sensing capabilities, a built-in pre-amplifier, and possible data multiplexing. The paper will also discuss emerging smart transducer standards that involve a mixed-mode interface using two wires for power supply (phantom power) as well as time-shared analog and digital signals.

INTRODUCTION

Smart sensors process their own information thus providing increased value to the user. A smart sensor has the capability of making logical decisions and has capabilities for self-test and adaptive calibration as well as ease of set-up and use. The sensor may either act on information or pass it on just as raw data for further processing or do both.

There are many advantages in the application of smart sensors. The use of a smart sensor reduces or eliminates the need of a control infrastructure that would otherwise be needed to manage the system. In large systems, the need for cable and wiring reductions has become necessary. The implementation of smart sensors not only reduces cabling and weight, but also saves valuable resources and time with self-identification capabilities.

Even with a wide array of advantages, smart sensors are not yet extensively used. Often transducer manufacturers are reluctant to interface transducers to the largely varying, and fragmented control networks. The IEEE P1451.2 [1] proposes a standard which would enable transducer manufacturers to support the development of network-capable smart sensors and actuators which would result in faster acceptance and implementation of smart sensors into the market.

SMART HYDROPHONES

Hydrophones are used extensively in many applications that include geophysical surveys, surveillance, communication, and marine mammal and other research. Many different kinds of sensing elements are available for the manufacture of hydrophones. In the geophysical work, stringent physical and acoustical requirements narrow the field quickly [2] to piezoelectric materials.

In geophysical work, the need is for low-distortion hydrophones. The clarity of signals received plays an important role in the accuracy of interpretation of subsurface structures and the location of oil reserves. With increasing need for accurate prospecting and reservoir maintenance, a need for better hydrophones exists.

An intelligent or smart hydrophone is the integration of an analog or digital sensor, or actuator element, a processing unit, and a communication interface. A smart hydrophone transforms the raw sensor signal to a standardized digital representation. In many cases, the smart transducer is able to locally verify the control action and provide a feedback at the hydrophone interface. These considerations of low distortion and other considerations have established the need for a better hydrophone. This paper will describe such a hydrophone.

System Architecture

The development of the smart hydrophone comprises three parts. This is shown schematically in Fig. 1 and 2.

- A network independent part consisting of the hydrophone, pre-amplifier, and other sensors and related interfaces
- A network specific interface that enables effective communication between smart sensor and the network
- A network.

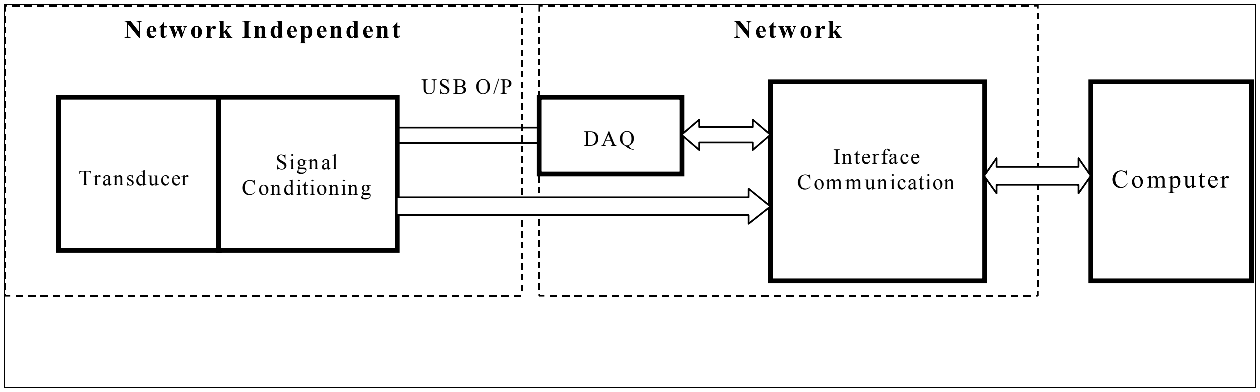

Figure 1. Smart hydrophone system artitechture

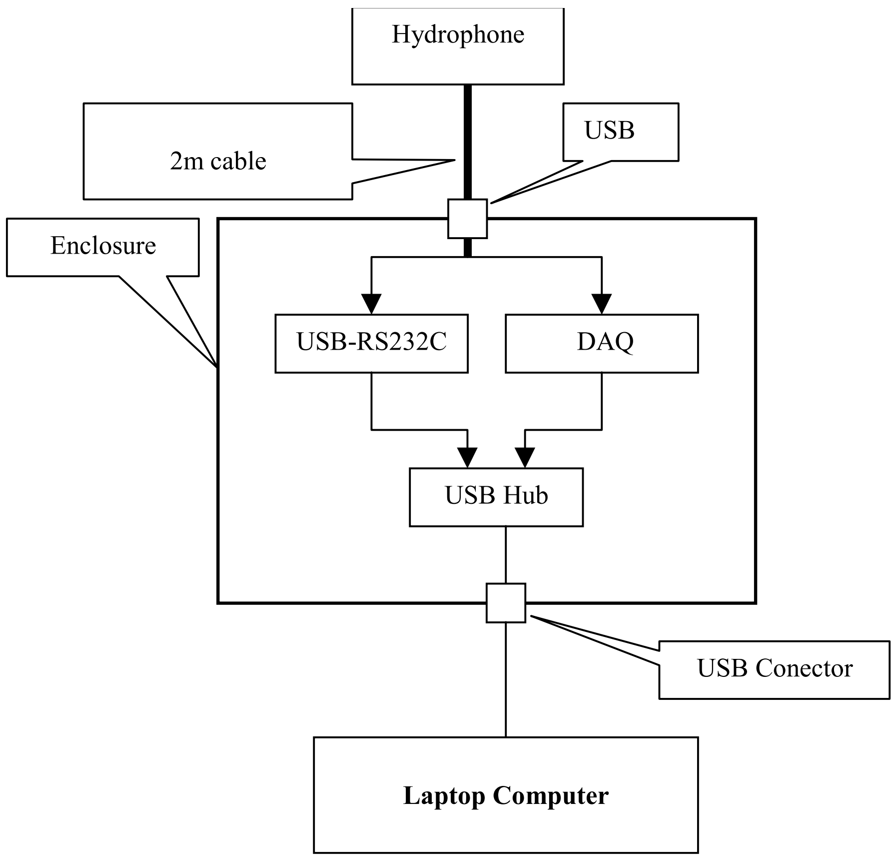

Figure 2. Network interface setup

<u>Network Independent Components</u>

Piezoelectric materials are extensively used in the fabrication of hydrophones. These materials are processed such that they generate a voltage when subjected to stress. These materials are usually made from a material known as lead zirconate titanate or PZT. PZT tubes are extremely hard and strong and have deep-ocean capability. PZT materials are available in different grades and Navy Type II material is the most commonly used for hydrophone manufacture due to its large piezoelectric coefficients.

The analytical expression for acoustic sensitivity of the end-capped design was derived by Langevin [3]. The key assumptions and in this expression [4] are:

- Dimensions of the cylinder are small compared to wavelength. The velocity of sound in water is approximately 1,500m/sec, and at the highest frequency considered (5,000Hz), the wavelength is 0.3m. The proposed maximum dimensions of 25mm diameter and 25mm long for the device are considerably smaller.
- The inside surface of the cylinder is completely shielded from the external acoustic pressure. Two rigid end caps satisfy this condition.

The acoustic sensitivity of the end capped cylinder is given by the equation

$$(V/P0) = - \{(b/(1+\alpha)\} [(1-\alpha)\ g_{33} + (2+\alpha)\ g_{31}], \quad (1)$$

where V is the open circuit voltage, P_0 is the applied external pressure, g_{33} and g_{31} are piezoelectric voltage coefficients of the material, a is the inner radius, b is the outer radius, and $\alpha = (a/b)$.

Sensitivities are normally expressed in decibels. This is done using the expression

$$M = 20 \log (V/P_0) \text{ dB ref } 1V/\mu Pa. \quad (2)$$

In development of the smart hydrophone, we selected an end-capped hydrophone. The hydrophone uses a ceramic tube with a 25mm outside diameter and a 1mm thick wall and 20mm high. Assembled, this hydrophone exhibits a sensitivity of -193.5dB ref 1V/μPa.

Two components are integrated into the hydrophone: an on-board Dallas Semiconductor one-wire EEPROM memory chip and an SA12 preamplifier. The EEPROM memory chip has a capability of storing up to 1024 bits of information. This chip was used to both write and retrieve data about the hydrophone. Each EEPROM chip has its own unalterable and unique 64-bit ROM registration number that is factory lasered into the chip. The registration number is used to address the device in a multidrop one-wire network environment. Using the EEPROM has allowed us to program information such as capacitance, sensitivity, operating depth, and temperature into individual hydrophones.

The SA12 amplifier integrated into the hydrophone is made by Sensor Technology. The SA12 is a phantom-power amplifier offering very low power consumption. Its voltage sensitivity is fixed and is independent of cable length or capacitance. Its low output impedance allows signals to be transmitted over long cables through harsh environments with virtually no loss in signal quality. As well, the two-wire system accommodates standard low-cost coaxial or other two-conductor cables.

A typical sensing system including an SA12 amplifier and ordinary two-conductor cable is shown in Fig. 3. Decoupling of the data signal occurs at the output stage of the signal conditioner. The 2.2 μF capacitor shifts the signal level to essentially eliminate the sensor bias voltage. The result is a drift-free AC mode of operation. Optional DC-coupled models eliminate the bias voltage by use of a DC signal level shifter.

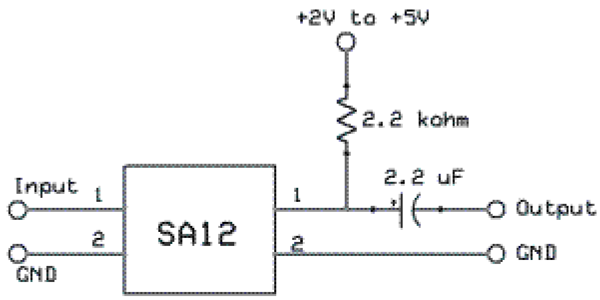

Figure 3: SA12 amplifier output circuit configuration

Network Specific Interfaces

The software involved in the network specific interface involves a data acquisition system (DAQ). In the present work, software provided by the hardware manufacturer is used to configure the device. In order to access data from the hydrophone, a DI158 DAQ [5] system was used. This system has the capability to record data with 12-bit accuracy at rates up to 14,400 samples/second. The system incorporates USB connections, which connect directly to the interface requiring no external power.

The hydrophone is integrated with the system using a USB connector. The USB connector is also the source of power to the system. As seen in Fig. 3, the network is connected to the hydrophone in the network specific interface.

Network

The network of our smart hydrophone system consists of a computer (laptop) with the LabVIEW software [6] installed and a USB interface. In our system, all hardware on the DAQ board is controlled directly through LabVIEW. This National Instruments software is an emerging standard in visual programming based instrumentation control systems. LabVIEW is programmed with a set of graphical icons that is designed for data acquisition, data analysis, and instrument control.

LabVIEW programs are called virtual instruments (VI's) because their appearance and operation emulate actual instruments. A VI has two main parts: the front panel, which is the interactive user interface of the VI and emulates the front panel of a physical instrument and the block diagram, which is the VI's source code, constructed in LabVIEW's graphical programming language.

SYSTEM CONFIGURATION AND MEASUREMENTS

Communication between the network and hydrophone is controlled through the programming of LabVIEW software program. The VI interface is shown in Fig. 4. Hydrophone calibration was done using common standards. This calibration data is entered into the EEPROM module of the system (Fig. 4). In all further hydrophone tests, the smart hydrophone was used as the test hydrophone. A standard SensorTech SQ03 calibration hydrophone was also used for comparison purposes. In all cases the measurement recorded are within 0.5dB of the standard hydrophone data.

The hydrophone has been assembled, tested, and works as was expected. It can be seen from Fig. 4 that the critical calibration parameters are recorded and provide the information as needed to the system. This information is also available as ASCII delimited files for further integration into programming and system interfaces. It is important that the system needs to be maintained as we add more sensors on the sensor-specific interface. Additional work needs to be done in terms of speed of data acquisition, specifically to the read/write program. Fig. 5 shows the complete system configuration.

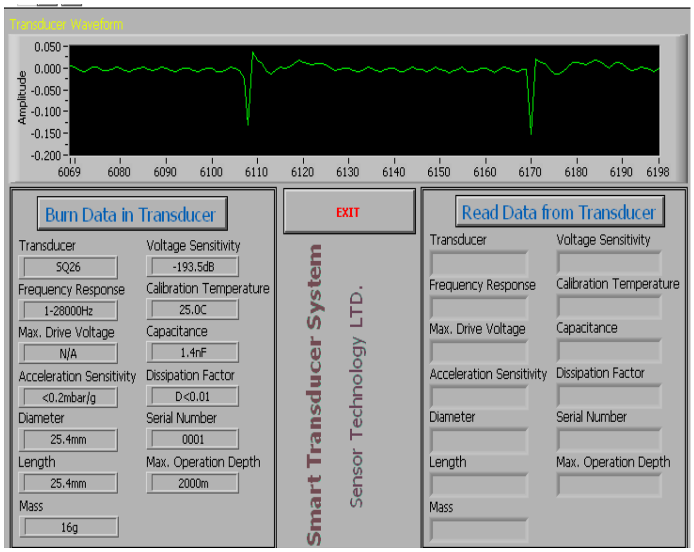

Figure 4: Smart hydrophone interface screen

Figure 5: Smart hydrophone system set up

FURTHER WORK

The smart hydrophone would be of further benefit with added components. Further work includes the addition of a temperature sensor as well as a pressure sensor. These changes would possibly entail power, DAQ, and channel modifications as well. Both the DAQ and the interface are capable of handling more sensors. Further work would be to investigate the multiplexing of multiple units in the system set up.

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