Measurement 47 (2014) 475–482

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Data acquisition and processing at ocean bottom for a Tsunami warning system

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ARTICLE INFO

Article history:
Received 17 March 2013
Received in revised form 31 August 2013
Accepted 17 September 2013
Available online 25 September 2013

Keywords:
Bottom Pressure Recorder
Tsunami Early Warning System
Data acquisition
Data processing
Detection algorithm

ABSTRACT

The design and development of a Bottom Pressure Recorder for a Tsunami Early Warning System is described here. The special requirements that it should satisfy for the specific application of deployment at ocean bed and pressure monitoring of the water column above are dealt with. A high-resolution data digitization and low circuit power consumption are typical ones. The implementation details of the data sensing and acquisition part to meet these are also brought out. The data processing part typically encompasses a Tsunami detection algorithm that should detect an event of significance in the background of a variety of periodic and aperiodic noise signals. Such an algorithm and its simulation are presented. Further, the results of sea trials carried out on the system off the Chennai coast are presented. The high quality and fidelity of the data prove that the system design is robust despite its low cost and with suitable augmentations, is ready for a full-fledged deployment at ocean bed.

1. Introduction

Tsunami waves are a natural phenomenon originating in the ocean primarily due to seismic motions of the sea floor. Their mechanisms of generation and peculiarities of propagation in the ocean have been dealt with in detail earlier [1]. Its potential for causing widespread havoc and destruction has been well demonstrated in December 2004 when it wiped out more than 250,000 human lives in a single day. Since then efforts to establish a reliable early warning system for Tsunamis have been gathering more attention worldwide.

Bottom measurements of the ocean level based on pressure sensors have been established to be an extremely promising and reliable means of operative Tsunami forecasting. Systems based on this have been operational and their configuration, design and development [2–4] and commissioning [5] have been described in several previous publications. However, they do not discuss the specific requirements of the data acquisition and processing part. Neither do they go into sufficient details of the implementation aspect.

The design of a data acquisition and processing circuitry for the Bottom Pressure Recorder (BPR) of a Tsunami Early Warning System (TEWS) is described in detail here. The special requirements of the system design are high performance in terms of noise-free resolution (for faithful capture of extremely low amplitude events) and low power consumption (for deployable battery powered operation). The circuit implementation of the data acquisition part for meeting these are brought out. Some of previous works [6,7] that deal with this involve elaborate and complex schemes which are not amenable to low power consumption or cost.

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http://dx.doi.org/10.1016/j.measurement.2013.09.036

Further, the data processing part is dealt with where the primary requirement is to detect 'events' of significance with sufficient fidelity. This has to be carried out in presence of a variety of background 'noise' signals such as those due to periodic phenomena like tidal waves and aperiodic ones such as high frequency random fluctuations. One such algorithm is discussed and simulation results are shown to establish its efficacy. Previous literature [8,9] does not establish the versatility of the algorithm by way of either simulation or experimentation.

The significance of simultaneously achieving high resolution along with low power consumption for the data acquisition circuitry for such an application is evident from several of previous publications. For example the performance characteristics for the system explained in [3] lists the measurement sensitivity as less than 1 mm in 6000 m which translates to about 0.2 ppm. Further the powering scheme used therein along with battery capacity figures indicate an operation lifetime of about 4 years. It is also reiterated that this is based on several assumptions about the number of events and the volume of data. The various data reporting modes described therein are also techniques adopted to conserve the bandwidth and thereby power consumption. Such system-level characterizations with similar results form the core of several other papers such as [10,11] also.

Marine seismology is another area where a lot of stress is laid on data acquisition system performance in terms of S/N ratio and ENOB. [7] and [12] are typical examples of previous work in this area which discuss circuit optimization, high frequency noise rejection and PCB design optimization strategies and the performance results obtained for the seismometer after adopting these. The work outlined in this paper and the enhancements planned for the future have also been motivated by the results given therein.

Extensive characterization and performance evaluation of the system described here have been carried out by lab-level testing. Sea trials have also been carried out deploying the system to a depth of 150 m in Bay of Bengal off Chennai coast. The results of these tests in the form of acquired sensor data are presented. Finally, the aspect of low cost of the system implementation is also brought out which makes it especially attractive in the context of indigenous deployment and maintenance by developing countries.

2. Design

2.1. Requirements

The triggering events for a Tsunami are seismic activity such as earthquakes, plate tectonics and volcanic eruptions in the deep oceans [1]. The main cause of destructive Tsunami is the sharp vertical displacements of parts of seafloor due to these. This in turn leads to the vertical displacement of water column directly above the location of the event. The waves thus produced propagate and gather in amplitude as they move to landmass and finally lash the sea-shore with destructive energy.

For an effective Tsunami warning system, the waves need to be detected as near the source as possible since this enables the earliest warning and maximum time for preparations towards disaster mitigation. However, the amplitude of the water column displacement in open ocean, even in the case of catastrophic events, is usually limited to a few millimeters. This is very small when compared to the depth of the ocean, which runs to around a few thousand meters. It is this small amplitude along with characteristic long periods that renders these waves imperceptible in the open ocean. The challenges in implementing a data acquisition and processing system for Tsunami detection by deep ocean pressure measurements also arise primarily from this requirement.

A BPR works on the principle of detecting the pressure variation at sea-bed due to overlying water column. The configuration of pressure sensors that are suitable for such an application have been dealt with in detail in previous works [10]. Here the use of a conventional absolute pressure sensor of integrated diaphragm type construction for this purpose is demonstrated. This sensor was designed for a full-scale range of 400 Bar for deployment up to a water depth of 4000 m.

The surface amplitude of Tsunami wave is estimated to be not less than 4 mm for it to have sufficient strength on reaching the shore. This necessitates the detection of a pressure signal as small as 4 mBar over a static signal level of 400 Bar. Thus the ensuing data acquisition circuitry requires to have a resolution of around 1 ppm. These in turn translate to an Effective Number of Bits (ENOB) of $\log_2(10^{-6})$ i.e. 20 bits and noise levels as low as 2.5 μV when working with a reference voltage of 2.5 V and a single supply voltage of 5 V.

Similarly for the data processing part, the pressure signature of a 'significant' and 'relevant' event has to be captured faithfully. This function has to be performed against the background of a 'sea' of unwanted signals that may be periodic as well as aperiodic in nature. These consist of tidal activity that have long periods in the range of 12 h. In addition to this, short-term local disturbances of periodicity around 1 min may also be present. It is meaningful to assume that a random noise in high frequency ranges may also be super-imposed over these to account for the sensor and electronics noise as well as rapid local fluctuations of the sea level due to factors such as winds and ships passing nearby. The data processing circuit has to run the prediction algorithm that can flag a signal of interest in this background without fail and without a false alarm.

Further to the functional requirements as outlined above, the circuit design should meet certain constraints that are specific to the application. Low power consumption is the primary one among these due to the battery powered operation and the necessity for deployment at ocean bed. Thus, incorporation of advanced power conservation features such as sleep mode of operation and optimization of communication protocols are essential for long operational life of the deployed hardware. A low cost of implementation is also highly desirable especially in the context of necessity for fresh deployment once the existing hardware is depleted of power or damaged. This is especially so for developing countries those are having