

Design and development of Indian tsunami detection system

Tata Sudhakar^{1,3*}, Suriyakala C. D², Shijo Zacharia³

¹Sathyabama University Chennai, Tamil Nadu 600119

²Toc H institute of Science & Technology, Ernakulam, Kerala, Pin 692313

³National Institute of Ocean Technology, Pallikarani, Chennai, India, 600100

*Corresponding author E-mail: tata@niot.res.in

Abstract

India established first generation Tsunami Warning System in 2006. The first generation system was developed using indigenized data buoy technology and imported electronic systems. The second generation system is under development at National Institute of Ocean Technology, Chennai, India. This paper describes first generation system, design goals and novel system configuration of second generation system for Tsunami detection. It also reports indigenous second generation, laboratory testing and sea trial results. The Tsunami detection system may be enhanced redundancy.

Keywords: Tsunami; Tsunami Warning Systems; PSOC; Automated Test Rig; Detection Algorithm.

1. Introduction

India has more than 13000km long coastal line. More than 20% of population lives in Indian coastal area and majority of them are at less than 10m sea level. A tsunami warning system with fast response and accurate detection is essential to save the life of coastal population. The national calamity due to the December 26th 2004 Tsunami instigated Government of India to give high priority for establishing an Indian Tsunami Warning System. A Tsunami Warning System (TWS) detects tsunami events in advance and issues warnings to prevent loss of life and property. Tsunami is detected based on vital inputs from seismic measurements, tidal observations and bottom pressure recorder (BPR) measurements. The seismic sensor based TWS generates erroneous alarms due to the fact that all underwater earthquake may not produce Tsunami. Tidal observation based TWS generates warning only after arrival of tsunami to the coast. The BPR based system generates reliable warning information well in advance as they are deployed far away from the coast.

Tsunami occurred in Indian coastal regions couple of times in 18th and 19th century [1]. Given the rarity of tsunamis in the region and the country's scarce economic resources, the south Asian countries did not consider a tsunami warning system to be a high priority. The first generation Indian Tsunami Warning System (ITWS) for India was established in 2006 by with National Institute of Ocean Technology (NIOT) Chennai Ministry of Earth Sciences (MoES), in collaboration with Department of Science and Technology (DST), Department of Space (DOS) and the Council of Scientific and Industrial Research (CSIR) The first generation ITWS comprises a real-time network of seismic stations, Bottom Pressure Recorders (BPR), Data buoy and tide gauges to detect tsunamigenic earthquakes and to monitor tsunamis. The second generation of ITWS is focused on indigenization of subsystems of Bottom Pressure Recorder.

a) International Tsunami Warning System

The United States of America developed Tsunami Warning System after Aleutian tsunami of April 1, 1946. The warning systems

were intended for rapidly locating earthquakes in the Pacific region and developing a method to predict the arrival times of the Tsunami at various places. Other countries in Pacific such as Japan and USSR had also established national warning system by 1948. These systems have limited data recording capability and communication range [2].

Pacific Tsunami Warning System (PTWS) was formed by participation of several countries after the Chilean Tsunami in May 1960. The Alaskan Tsunami focused additional attention to the need for an International Tsunami Warning System. International Tsunami Information Centre and the International Coordination Group for Tsunami Warning System (ICG/TWS) were established at Hawaii in 1965. The participating countries and number of stations were increased over the years with more advanced instrumentation and communication systems. In September 1997, a DigiQuartz broad band depth sensor based integrated Tsunameter System was deployed by Pacific Environmental Laboratory. U.S. National Tsunami Hazard Mitigation programme has established six network stations by 2004 [3]. A deep water Tsunami surveillance System for Malaysia was deployed in December 2005 [4].

2. Data and methods

a) Principle

The BPR is deployed at deep sea, to the sea bed with dead weights and a buoyancy collar. The BPR is normally kept 50m above sea bed and the buoyancy collar keeps it vertical.

$$d = 10 * h\rho g \quad (1)$$

Where

d- Water column height observed by the BPR

h- Height of water column

ρ - Density of water column

g- Acceleration due to gravity

Since the BPR is fixed rigidly to the seabed, acceleration due to gravity is constant. The prediction uses only past 190 minutes

data. The sea water density is assumed to be constant. The pressure sensor is temperature compensated. Normally the BPR is deployed at more than 3000m depth. Hence high frequency signals are attenuated to minimum at BPR. The signals observed at sensor are mainly due to tide and other abnormalities.

b) First Generation Indian Tsunami Warning System

The first generation ITWS was integrated with market available subsystems, Satellite telemetry system, Acoustic Release, Acoustic telemetry system and Data buoy. The BPR records the pressure at 15s interval. It transmits measured pressure data to data buoy by acoustic telemetry every one hour and during the Tsunami events. The acoustic modem on the data buoy receives the data from the BPR and transmits it via satellite telemetry to the data reception centre at NIOT Chennai. The data buoy and surface electronic systems were indigenously developed by NIOT. NIOT successfully deployed four BPRs in Bay of Bengal and two in Arabian Sea by 2007. The subsystems of first generation ITWS are shown in Fig. 1 and 2.



Fig. 1: Bottom Pressure Recorder.



Fig.2: Data Buoy.

c) Second Generation ITWS

The second generation system is focused on indigenization of subsystems with increased reliability and improved performance with low power consumption. The first generation systems were powered by solar energy. But solar powered systems frequently failed due to the harsh marine environment and vandalism. In order to improve the system reliability second generation systems are designed with power optimization and there by battery powered systems are realizable.

d) Design goals

NIOT indigenized various subsystems of Tsunami warning system. The design goals of BPR development programme are listed below:

- Development of rugged electronic system to withstand harsh marine conditions
- Increase the battery life of BPR and reduce number of deployments and maintenance cost.
- Design and development of underwater enclosure to house electronic systems
- Ensure the successful retrieval of BPR after two years from deployment
- Measure the sea level at every 15 seconds interval and predict it at every 5.25 minute time interval

- Data storage for two years
- Reduce the detection threshold level
- Reliable acoustic communication
- Every hour observation report in normal condition
- Transmits tilt parameters of the BPR during deployment.
- Transmits battery voltage under normal conditions
- In case of an event observation to be reported every 5 minute

e) System Description

Quartz based sensors are chosen because of their remarkable repeatability, low hysteresis and excellent stability. The Root Mean Square (RMS) noise level of pressure sensor is less than 1 part per million. The pressure sensor has 1×10^{-8} resolution and 0.01% accuracy (Frequency measuring system). It consumes only 1.6mA@6VDC. The pressure sensor output varies from 37 kHz to 45 kHz.

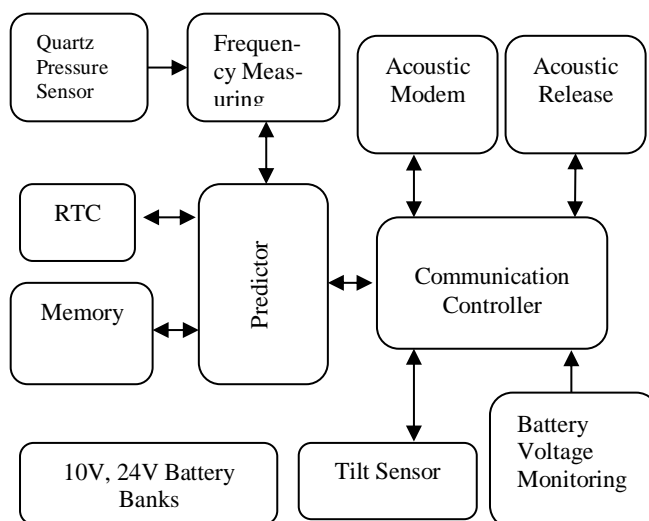


Fig. 3: Block Diagram of Second Generation ITWS.

The block diagram of the second-generation system is shown in Fig 3. The measurement system is normally disabled to reduce the power consumption. The measurement system samples the pressure signal at every 15 s interval. The observations are recorded in low power non-volatile random access memory. The predictor reads 10-minute average tide data from the circular memory and runs the detection algorithm at every 5.25 min. It compares the latest prediction with every observation. If the difference between observed data and prediction is more than predefined threshold level it triggers the communication controller. The communication controller uses acoustic telemetry (acoustic modem) to transmit the warning information. It transmits status information at every one hour under normal condition. The predictor needs to run only at 5.25min intervals but the communication controller is always in listen mode to receive the commands form the surface data buoy through acoustic modem. Hence they are implemented in two low power devices to reduce the power consumption. The predictor and communication controller is implemented in Field Programmable Gate Array (FPGA) configurable block of PSoC device (Fig 4). The RTC enables the measurement block at every 15s intervals. The overall power consumption of the system is reduced by selecting low power devices, high frequency devices operating at low frequency and partial power control of subsystems. Since overall power consumption is reduced, system is powered by Lithium thionyl chloride battery (Battery Banks). The system is recovered by activating acoustic release. The system has built in battery voltage monitoring circuit. The tilt sensor measures roll and pitch of the system. The system stores data in the internal flash memory.

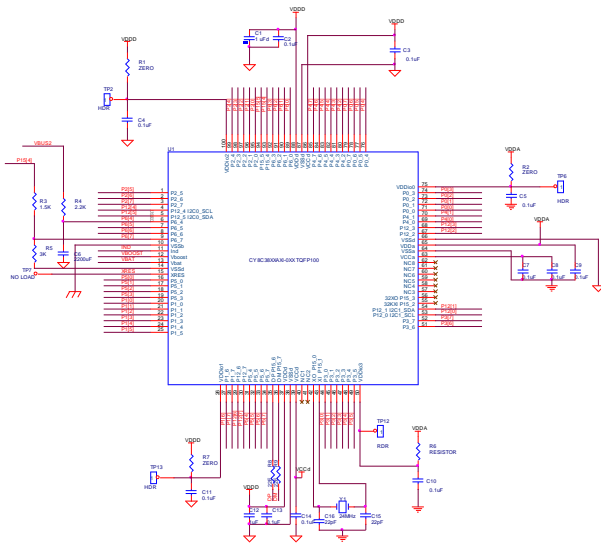


Fig. 4: Predictor and Communication Controller Implemented with PSOC Device.

f) Detection Algorithm

At present most of the BPR reported with Tsunami detection algorithm developed by Mojfield under NOAA's DART program [5-9]. In order to reduce expected error in prediction of pressure and complexity of the hardware a new detection scheme is used in this system. The power consumption is significantly reduced by simplifying the hardware complexity. The prediction error is reduced by reducing no of samples taken for calculating average value. The pressure measurement is taken at 15 s interval. The detection algorithm uses 1min averaged value. The predictions are updated at every 30 s interval.

The predicted difference from the datum

$$H_p(t^+) = \sum_{i=0}^{i=3} w_i H(t - i dt) \quad (2)$$

$$H(t - idt) = \frac{1}{4} \sum_{n=0}^{n=3} [h(t - i dt - 15 n) - h_{ref}] \quad (3)$$

Where:

$H_p(t^+)$: Predicted difference from the datum, updated every 30 s

$H(t)$: one minute averaged water column height

$h(t)$: Water column height measured at t^{th} sec

h_{ref} : Datum set by user after deployment of seabed electronic system

dt : 3600 sec (one hour)

w_0 : +1.02306621093750

w_1 : -0.03787050781250

w_2 : +0.01904238281250

w_3 : -0.00423808593750

The difference between predicted pressure and measures value is calculated by (3)

$$\varepsilon(t^*) = |h(t^*) - h_{ref} - H_p(t^+)|$$

t^* , t^+ : indicates different events.

If value of $\varepsilon(t^*)$ is more than predefined threshold, a Tsunami detection flag is set and the system enters in triggered mode. An extended triggered mode is followed with the triggered mode. The threshold value typically varies from 30mm to 50mm. It is fixed based on site parameters and historical tide and wave.

The prediction algorithm was developed in MATLAB. A prediction algorithm is validated with the Bay of Bengal BPR data recorded during January 2009.

g) Small range pressure Testing of Tsunami Detection System

The pressure sensor was immersed in water on an automated test rig. The water column height was decreased to 5cm in 10mm steps.

h) Full range pressure functional testing of the Tsunami Detection System

The Seabed Electronic system casing was subjected to 400bar pressure at hyperbaric facility at NIOT. The pressure sensor was kept in hyperbaric chamber and subjected to pressure. The underwater cable was terminated at the lid of the pressure casing and output was monitored in real-time. The casing was kept at 400 bar for one hour.

i) Testing on Automated Tsunami Test Rig

The pressure sensor was fixed on automated test ring. The automated test ring was pre-programmed with tsunami recorded data. Hence the pressure sensor undergone pressure functions of similar to a tsunami event. It was observed that the seabed electronics system runs in normal mode after deployment mode. The seabed electronics triggered by a tsunami event created by automated test ring (Fig 5).



Fig. 5: Automated Test Rig

j) Sea Trial

The sea trial of the system was carried out in July 2011 on board ORV Sagar Nidhi at a depth of 1900. The BPR is deployed at 1900 m and the surface buoy with satellite communication was deployed near to BPR. The Fig 6 shows the system deployment.

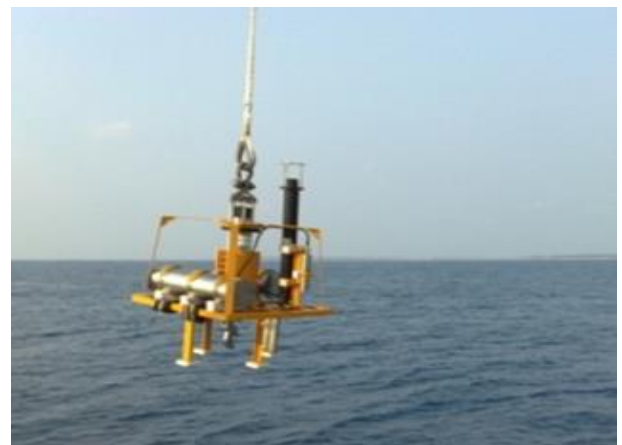


Fig. 6: BPR Deployment from ORV Sagar Nidhi.

3. Results and discussion

a) Simulation of prediction algorithm

The prediction algorithm was developed in MATLAB. A prediction based on sample data from Bay of Bengal BPR was analysed. Fig 7 shows the difference between predicted data and measured. The prediction for 16 hrs and its observation are presented in Fig.8. It is observed in the normal mode the prediction was within 20mm.

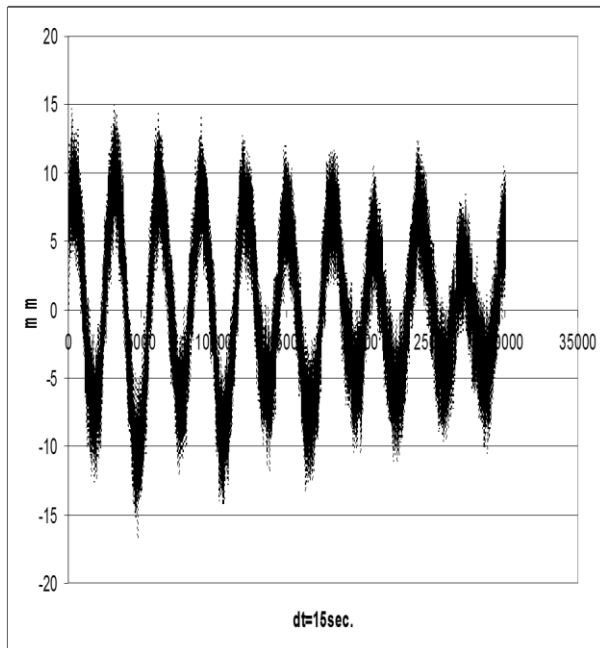


Fig. 7: Difference between Prediction and Observation.

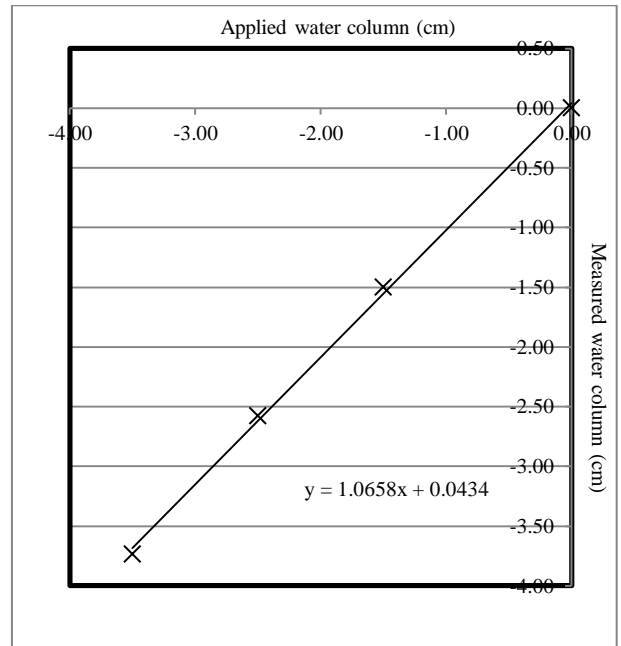


Fig. 9: Response of the Tsunami Detection System for Small Range.

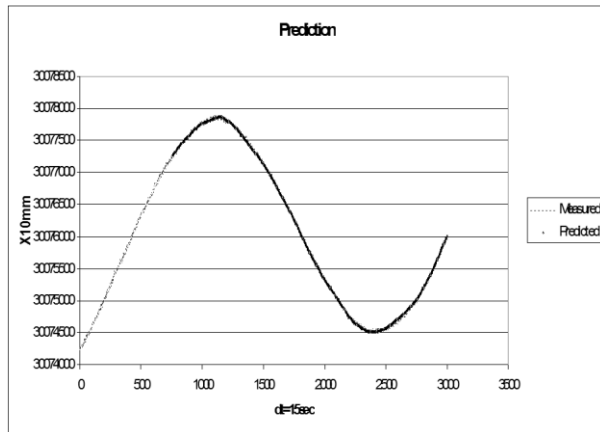


Fig. 8: Measured Data and Predicted Data.

b) Small range pressure Testing of Tsunami Detection System
 The response from the seabed electronic system was monitored on host port. It is observed that the pressure sensor output varies linearly. The response of the pressure sensor is shown in Fig 9.

c) Full range pressure functional testing of the Tsunami Detection System

The pressure sensor was kept in hyperbaric chamber and subjected to pressure in steps. It is observed that the pressure sensor output varies linearly (Fig 10). No physical damage or water ingress is observed in this test.

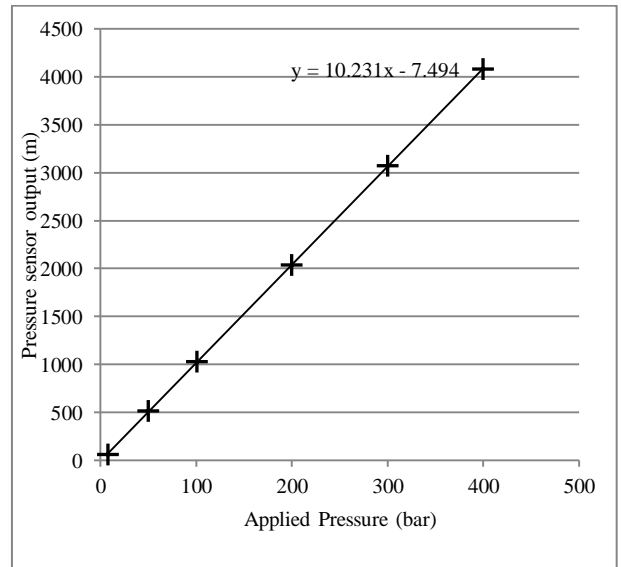


Fig. 10: Functional Testing of Pressure Sensor Full Range Pressure.

d) Testing on Automated Tsunami Test Rig
 It was observed that the seabed electronics system runs in normal mode after deployment mode. The seabed electronics triggered by a tsunami event created by automated test rig (Fig 11). The system was triggered in two events.

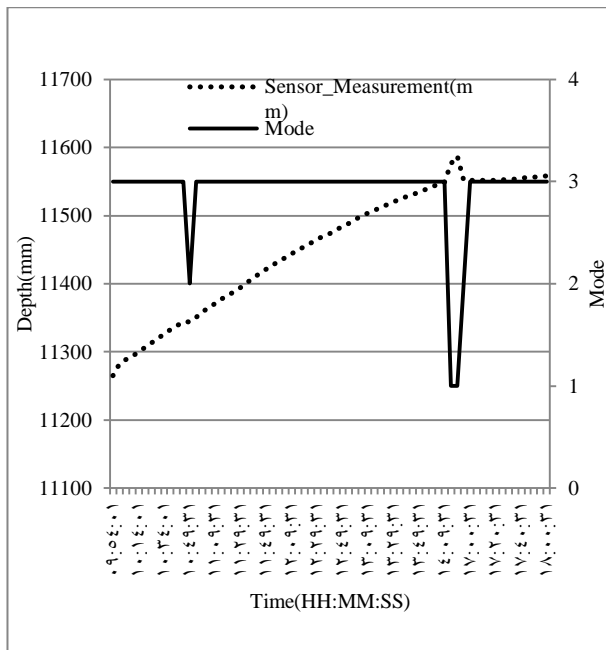


Fig. 11: Response of the System on the Automated Tsunami Test Rig.

e) Sea Trial

The data from BPR is received at shore station at NIOT. The system was functioned in Tsunami mode on deployment (Fig 12). The system was in normal state after initialisation period. It is observed that the system recorded the tidal wave. Data gaps were observed due to break in underwater acoustic communication.

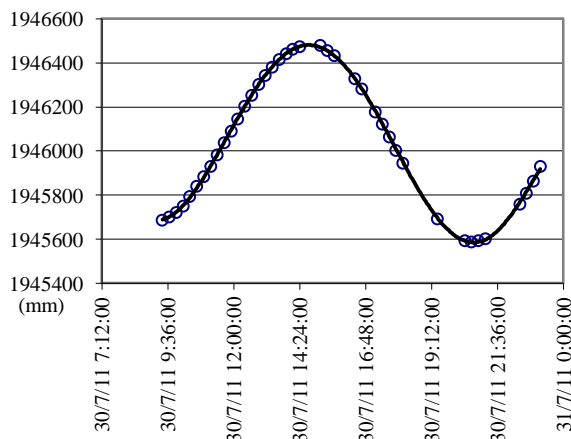


Fig. 12: Data Received from the Systems.

4. Conclusion

This article described international Tsunami Warning Systems. The first generation Indian Tsunami Warning System is integrated with market available subsystems. The second generation system is focused on indigenization of subsystems with increased reliability and improved performance with low power consumption. The design goals of the second generation system are reported. The second generation system consists of predictor and communication controller. The predictor and communication controller is implemented in FPGA configurable block of PSoC device. In order to reduce expected error in prediction of pressure and complexity of the hardware a new detection algorithm is used in this system. The algorithm is simulated in MATLAB and validated with the Bay of Bengal BPR data recorded during January 2009.

The system was tested for small pressure ranges on an automated test rig. The Seabed Electronic system casing was subjected to 400bar pressure at hyperbaric facility at NIOT. The seabed electronic system is tested on automated test ring. The sea trial of the system was carried out in July 2011 on board ORV Sagar Nidhi at

depth of 1900m. The system was in normal state after initialisation period. It is observed that the system recorded the tidal wave. The Tsunami detection system may be enhanced redundancy. The Tsunami prediction algorithm may be implemented in low power FPGA based signal processing hardware system.

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Authors profile



Mr.Tata Sudhakar received Master degree in Electronics and Control from Sathyabama University, Chennai. Has experience of 30 years in different oceanographic institutions. He received National Geo Science Award for excellence of the Ministry of Mines, Govt of India in the category of Disaster management for the contributions to the establishment of Indian Tsunami warning system. Presently he is

heading technology development group at National Institute of ocean technology, Chennai, India. He has filled four patents and has about 15 research papers.



Dr.C.D.Suriyakala is an Engineering Graduate in Electronics and Communication Engineering from Manipal Institute of Technology, Manipal, Did Masters MS in Electronics & Control from BITS, Pilani& M.S (By Research) from Anna University, Chennai & completed PhD in Software Agents for Communication with a total experience of 24 years which includes teaching as well as research. At present, She is associated with Department of Electronics & Tele communication Engg., SNGCE, KOLENCHERY. Sponsored projects (NRSC& DRDO), more than 100 publications in refereed conferences and journals added credit in career - research area is in wireless communication & software Agents .Member of professional Society like IEEE, ISTE, and Fellow member of IETE & IE.



Dr. Shijo Zacharia is a member of the Institution of Electronics and Telecommunication Engineers, New Delhi. He received Ph.D. in faculty of Information and communication engineering from Anna University Chennai in 2017. He joined in the Department of Ocean Engineering, IIT Madras, in 1997 as research staff. He joined in the department of Structural

Integrity, National Aerospace Laboratories Bangalore, as Technical Staff in 2000. Since 2001 he has been with Department of Ocean Electronics, NIOT Chennai, as Scientific Staff. He was the recipient of the Exemplary Performance Award by NIOT, Chennai in 2010 and Best Employ award by Ministry of Earth Sciences, New Delhi in 2012. He has coauthored over twenty publications and applied for five patents. His current research interests include wireless sensor networks, embedded system, development of low power instrumentation, and sonar systems.