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Measurement of Longshore sediment transport in the coastal regions using Wireless sensor Network

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ABSTRACT

In this paper, we introduced a system using wireless sensor network suitable to measure long shore sediment transport in the coastal region over time periods. This wireless sensor system measures and quantifies the littoral sediment movement based on the empirical formula and the ocean physical parameters such as significant wave height, current speed, current direction, etc. This oceanographic sensor system includes microcontroller, hardwares and sensors interconnected with long and short range wireless modem. The microcontroller triggers the sensor with suitable sampling interval, process the data and send the data through GSM/GPRS to the receiving base station. The real time data processing, prediction and validation were done by collecting the multi data series of different location sensor nodes. The WSN system is experimented and tested in the lagoon of Kavaratti Island during February 2018. The purpose of this research is to acquire real time datasets with low cost to investigate periodic coastal morphology dynamic changes and sediment transport processes particularly during extreme events.

Key words: *Wireless sensor network, Longshore sediment transport, Oceanographic sensors*

Introduction

Climate change, industrial developments, population growth and globalization increase the complexities and challenges for coastal management in the 21st century. The coastal region is an energetic and fragile environment due to the influence of both terrestrial and marine ecosystems. It experiences a wide range of anthropogenic and natural pressures such as shoreline change, erosion/accretion and near-shore sedimentation. Hence, there is an increasing need to underst and, monitor the coastal ecosystem, morphology and predict the longshore sediment transport in terms how it is impacted by natural activities along the coastal region (Martini *et al.,* 2012). Also, there is a growing consensus, that large-scale sediment transport in the Indian coast is primarily controlled by anthropogenic and natural pressures (Mireille *et al.,* 2014). In recent years, some advanced studies were carried out by different researchers to find out the sedimentation in river bed and coastal region. The Abeywardana and colleagues (2009) developed the smart sediment particles to track the 3 dimensional trajectory to detect the sedimentation in river bed. Buschmann (2012) performed monitoring of sediment transport using the instruments such as acoustic Doppler velocimeter (ADV), turbidity meter and a pressure wave gauge. The primary goal of this research is to design and develop a low cost wireless sensor network system using hardware components and its associated appropriate sensors to measure continuously the

Longshore sediment transport. The real-time observation and monitoring can be done for different seasons in the coastal region even fully operational during storm surges and extreme environmental conditions.

The main goal of this design is to create a sensor network node using different oceanographic physical parameter measuring sensors in multiple sensitive areas. The main developmental objective is designing and developing a conceive setup that is wireless and can be easily relocated in order to respond quickly to emerging scientific demands. The system design builds up a controller system with network security, which is robust and reliable. In order to stay operational in the marine environment over a time period of several months, the sensor system is fabricated with sufficient protection against biofouling.

Methodology

Coastal Longshore sediment transport

Coastal Longshore Sediment transport is a complex, multidimensional and dynamic process that results from the interaction of coastal hydrodynamics and sediment particles. The longshore sediment transport (LST) process is conceptually simple and it depends on the physical oceanographic parameters based on the bed zone, physics of grain size variation and bathymetry. The erosion/accretion in the coastal region mainly occurs due to the high longshore sediment transport due to the longshore currents and the physical parameters such as tidal variation, currents, waves, sediment type and its grain sizes, bed steepness, breaking waveheight and surf zone width etc. The LST can be calculated using various method incorporating the grain size variations. The most acceptable findings for the LST is CERC formula (Shore protection manual, 1984) which also shows the relationship between beach slope and grain size. The formula explains that the sediment transport depend on wave height, wave period, wave angle, currents, grain size, suspended sediment load, bed load and the surf zone width.

According to CERC formula, the total immersed LST rate(I) is given by

$$I = \frac{K}{16\sqrt{\gamma_b}} \rho g^{\frac{3}{2}} H_b^{\frac{5}{2}} \mathrm{Sin}(2\alpha_b)$$

The constant 'K' is the empirical coefficient and it depends on breaking wave height or significant wave height, ρ is the density of sea water and ρs = 2.65 (quartz sand density), H_b is the breaking wave height, γ_b is the breaker index and α_b is wave angle at breaking.

The total bulk volume LST rate 'Q' is given as

$Q = \frac{K}{16\left(\frac{\rho_s-\rho}{\rho}\right)(1-p)} \sqrt{\frac{g}{\gamma}} H_b^{\frac{5}{2}} \sin(2\alpha_b)$ where 'p' is the porosity

Using Kamphuis theory, it includes the calculation of total load but it also includes the effects of wave period, grain size and the beach slope. This can be applied to field real time observational data and it is expressed as

$$Q_u = 2.27 H_{sb}^2 T_p^{1.5} m_b^{0.75} D_{50}^{-0.25} \mathrm{Sin}^{0.6}(2\alpha_b)$$

Where, Q_u is the transport rate of underwater mass (Kg/sec), T_p is the peak wave period (sec), m_b is the beach slope from the breaker line to the shore line, and D_{50} is the median grain size (mm).

According to CERC formula, the empirical coefficient 'K' is expressed as

$$K_{(rms)} = 0.05 + 2.6 \sin^2(2\alpha_b) + 0.0096m + 0.007 \frac{u_{mb}}{w_s}$$

Where, w_s is the sediments fall speed, m is the beach slope, and U_{mb} is the maximum oscillatory velocity magnitude at breaking. The term 'm' constant is negligible in size so it is generally neglected. Hence, by using the validated empirical formula the Longshore sediment processes and transport is quantified.

Wireless sensor network (WSN)

The wireless sensor network(WSN) is the rapidly developing technology in the marine, ocean environment (Pathan *et al.,* 2006). The applications such as disaster management (Kaur *et al.,* 2012), landslide detection (Ramesh *et al.*, 2009), environmental monitoring (Zuo *et al.,* 2011) includes the WSN system in acquiring the real time data and communication. The ocean physical parameters in the coastal region differ from site to site and the observational location to be unique for all parameters. Hence the observational site for each parameter to be selected according to the characteristics of parameter with the sensor. So the sensor setup to be made in different sites depending on the parameter. Therefore, inorder to segregate the multiple datasets from the diverse sites within the limited area, wireless sensor network is required for continuous observations in the mesh network topology (Fig. 1).

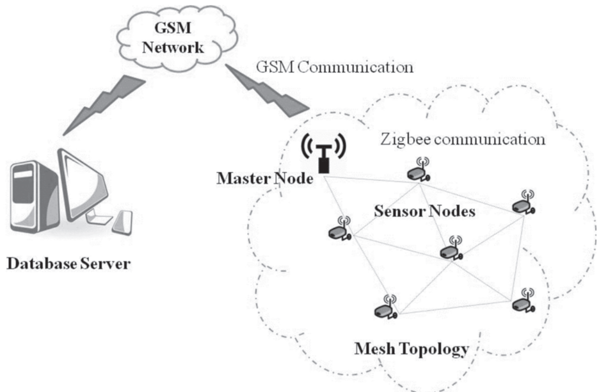

Fig. 1. Representation of network topology, GSM and Zigbee communications among the master and sensor node

The WSN includes a sensor setup at the diverse location with zigbee communication modem and microcontroller for internal datalogging, monitoring and transmission. Each sensor setup in diverse location is called as sensor node which measures the parameters wave height and periods, grain size, bed load, suspended sediment load, Wave angle, surf zone width and the wave current. Kennedy and colleagues (2014) implemented the instrument to measure the ocean waves using the solidstate sensors, microcontroller and communication devices with specific analytical algorithms. The sensor node is interconnected to other nodes and to the master node by using the mesh topology. Each sensor node consists of the processor, power supply unit, internal memory unit and the sensor unit which measure the physical oceanic observations.Compared to the wired system, the WSN provide a simple and economic for distributed sensor monitoring and controlling the deployed setup. The Fig. 2 show the components of the master node which controls over other node in triggering and the communication to the server. The master node processor controls the nodes function such as triggering the sensor for the suitable interval, making the burst signal, access to the sensor, communication control, algorithm execution, power energy management and the sampling rate.

System Design Consideration

In this research, the main focus for the electronic hardware system design deals with features of high efficiency, highly robust and low cost design. Inorder to work even in the adverse condition, the system is to be highly robust, less weight, compact

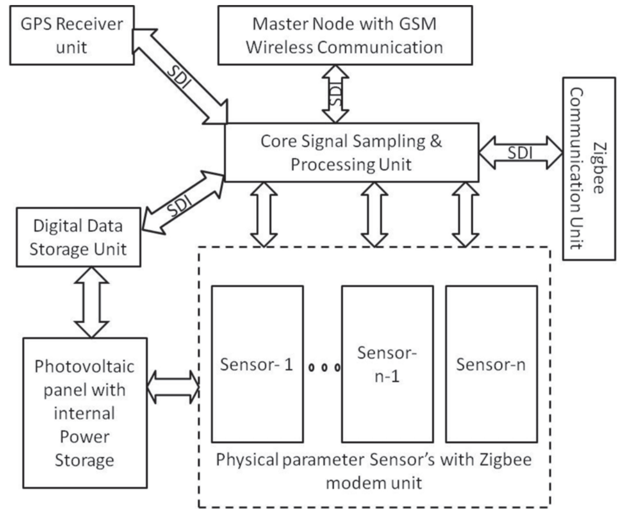

Fig. 2. The schematic block diagram for the hardware and software architecture of master and sensor node components

type with high performance and against biofouling because of the ocean environment. The deployment of sensor networks in real world application is also increasing day by day. Although there are many sensor networks currently in use, there are many difficulties in maintaining these systems in the long run. However the wireless sensor networks are self-reconfigurable and they require low maintenance. Moreover, developing the system for sediment transport requires hardwares and softwares, making the communication link from measuring sensor to on-shore server with low power consumptions. The software system includes the development of application domain by using schedules and processing algorithms (Maraiya *et al.*, 2011).

The main hardware system selected for data collection and communication is the ATmega microcontroller having a pulse width modulation output and 16Mhz crystal oscillator. The figure 2 shows the hardware and software architecture using block representation. Furthermore, for communication the Zigbee long range modem 900Mhz is used within the sensor network area (Patel *et al.*, 2013) and the GSM Network modem (Jinoj *et al.*, 2012) is used in master node for the long range communication towards the server of receiving end data storage (Fig. 3).

Microcontroller programming and synthesis

The microcontroller programming for the wireless sensor network includes sensor data acquisition and sampling, wireless networking and data communication among nodes, computational algorithm and low power signal processing (Fig. 2). The master node and all the sink node sensors are deployed in the suitable area of interest with the communication capability. The multiple sink nodes are within the network to carryout its task.

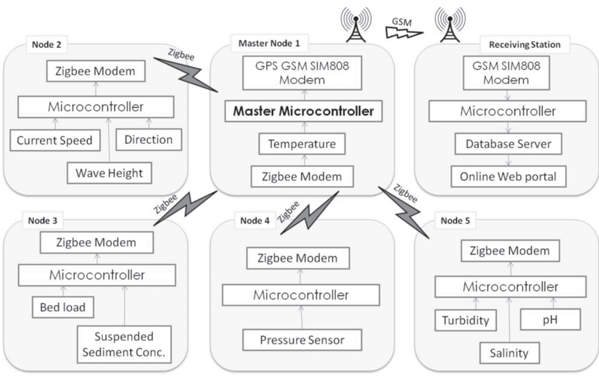

Fig. 3. Detailed master and sensor node components showing the sensor parameters

The mesh topology programming were used within the nodes for interconnection with the unique timestamp identity inorder to avoid redundancy and consistency. The low powered wireless nodal communication for discovering and tracking the route among the multiple sensor node is possible by only efficient programming. Using the unique identity time stamp, each nodes transmits the data after the sensor data collection. Each sensor nodes is active only during the sampling period and becomes inactive other than the sampling period. The mesh topology is adopted for interfacing the wireless sensor network which reduces the data loss among the nodes.

The master node microcontroller is programmed with the commonly accepted CERC formula (Shore protection manual, 1984) formula for the longshore sediment transport. The CERC theory deals with the relationship among the grain size and beach slope. The physical oceanographic parameters such as significant wave height, wave period, wave breaking, sediment type and its grain sizes shows the dependence on LST rate.

According to CERC formula, the total immersed LST rate is given by

$$I = \frac{K}{16\sqrt{\gamma_b}} \rho g^{\frac{3}{2}} H_b^{\frac{5}{2}} \mathrm{Sin}(2\alpha_b)$$

Where, K is the empirical coefficient and it depends on the breaking wave height or the root mean square wave height.

The total bulk volume LST rate is given by

$$Q = \frac{K}{16\left(\frac{\rho_s - \rho}{\rho}\right)(1-p)} \sqrt{\frac{g}{\gamma}} H_b^{\frac{5}{2}} \sin(2\alpha_b)$$

Here, H_b is the breaking wave height, ρ - density of sea water, ρs = 2.65 (quartz sand density), γ_b is the breaker index, α_b is wave angle at breaking and p is the porosity

Prototype Implementation

The figure 4 shows the prototype implementation and field deployment of master node at Kavartti Island. Each sensor node has the buoy with the builtin canister and the electronic circuit connections for the sensors. The special technical considerations for buoy buoyancy is done for the sensor node. The sensor and the housing of electronics in each node may differ based on the sensor parameters.

Experimental Results

The prototype is implemented with a master node and sensor node which is shown in Figure 4. The real environment experiment is made by deploying the WSN setup at the Kavaratti lagoon,

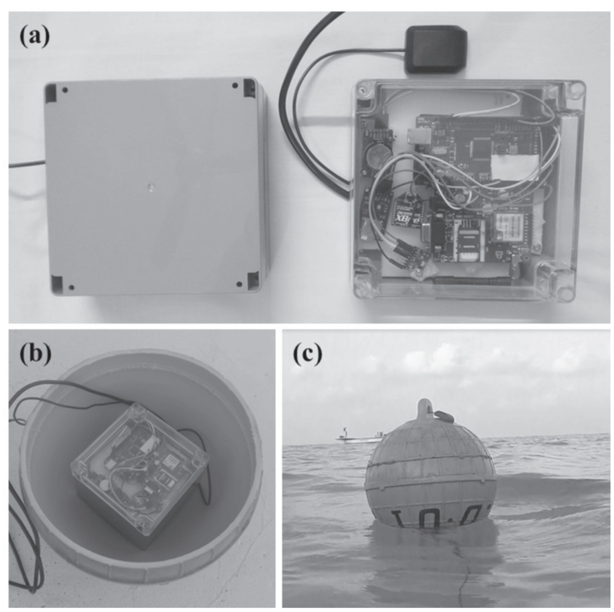

Fig. 4. (a) Prototype implementation of sensor and master node, (b) Housing of master node within the floating buoy, (c) WSN master node at the deployment site (Kavaratti Lagoon)

Lakshadweep Islands (Fig. 4). The system is programmed with the interval of 15 minutes for the continuous multi sensor data collection and the real time data acquisition using the WSN network. The inter-nodal communication and the long range communication using GSM communication is good during the experimental period. The experiment gains the experience of the marine environment in installing the system and to get the initial datasets from the environment. The deployment location is close proximity to shore within the lagoon area for the easy access to sensor node and the master node. The Figure 5 shows the significant wave height (m) and wave direction (radian) observed during the experimental period. The Figure 6 shows the sensor parameters observed using sensor nodes for the parameters sea surface temperature, surface currents(cm/s), Bed load and turbidity. From the experimental observation, the volume rate of longshore sediment transport(Q) on the particular

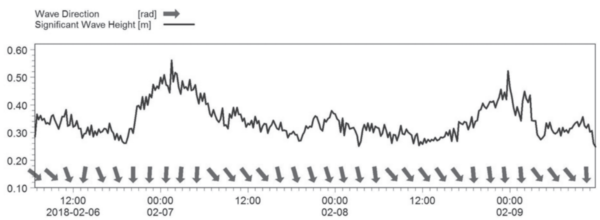

Fig. 5. The wave data collected using the WSN instrument during February 2018

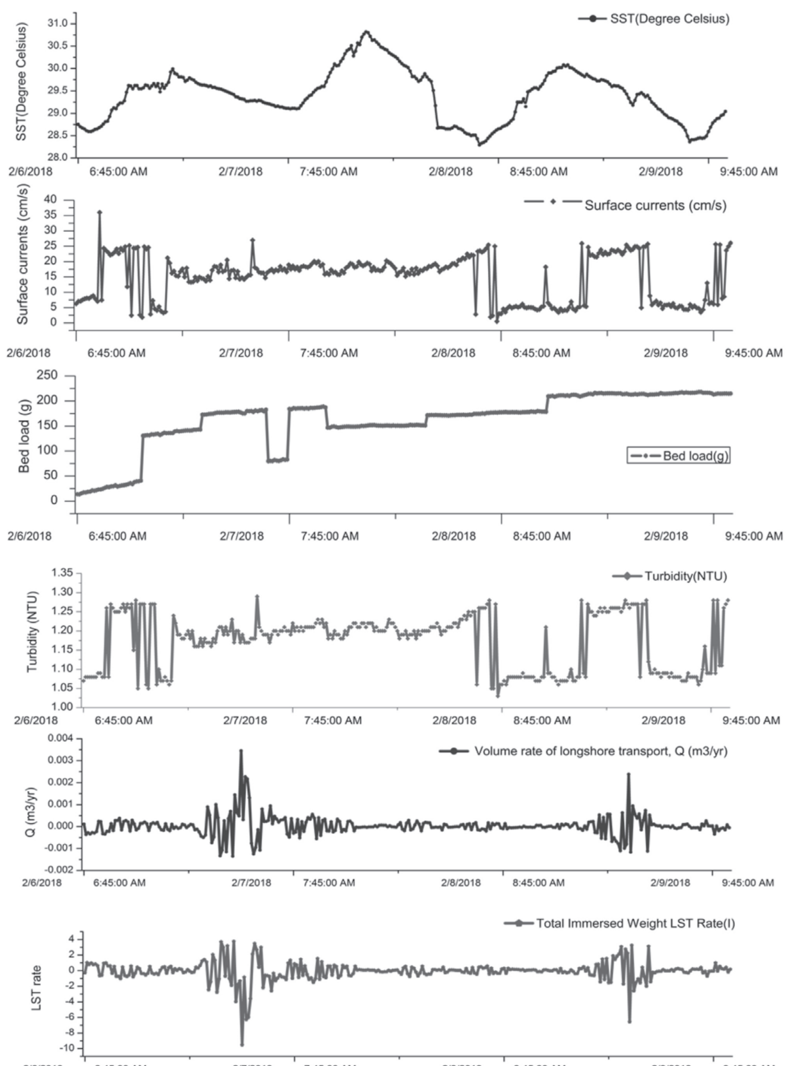

Fig. 6. Longshore sediment transport (LST) and other datas collected during the experimental deployment at Kavaratti Lagoon

location is within maximum 0.0037(m^3/yr) and minimum -0.0016(m^3/yr). Moreover, the total immersed weight LST rate(I) is in between 9.2 to 3.1 at the west coast of Kavaratti. The LST rate for the west coast is very low due to less wave action within the lagoon.

Future Scope

The experimental results obtained from the deployment site (Fig. 5 & 6) of the real ocean environment shows that the WSN system worked well. The system is producing the satisfying result throughout the field testing period. However the algorithm for programming the sampling rate and burst interval to be modified for the continuous measurement. Some major constraint in this research is creating robust housing for the microcontroller boards, calibration of the sensors for regular interval, and optimizing the power consumption. Moreover, some limitations such as processing limitation, communication channel using satellite and the biofouling is to be considered to make the system viable for the future.

Conclusion

In this research, we have proposed a low cost sensor system for longshore transport of sediments in the coastal region even during extreme events. The integration of the ocean physical and chemical parameters may results in long term monitoring with the continuous real time data acquisition through Zigbee modem and GSM networks. The special consideration of preventive measures for the sensor bio-fouling to be taken care so that the sensor holds good accuracy. During the observational period, the volume rate of longshore sediment transport(Q) is in between 0.0037(m^3/yr) and -0.0016(m^3/yr). As a result of testing the hardware and software performance, the system is stable and satisfactory. Proper periodic maintenance, calibration and removal of bio-fouling improve the system to work for a long period. The simultaneous observations of the oceanographic parameters from the different nodes of entire coastal region help us to investigate the real time LST rate for the future prediction. This design and implementation of the system in future should be upgraded into robust type with good battery life and buoyancy which withstands high waves and tough marine environment.

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