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Research Article

GeoSense: A Multimode Information and Communication System

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Recent technological developments allowed to envision the low-power (solar power) and low-cost (open hardware) sensor devices (Agrisens/FieldServer/Flux Tower/FieldTwitter) with multimode (ZigBee/WiFi/3G/WebGIS) information and communication technologies (ICTs), a model in which is christened as GeoSense. Integrating these multimode and multi-level communication systems with distributed ambient sensory network location-based service (LBS) is a challenging task, which could be a potential technology for monitoring various natural phenomena. This integrated model is introduced to provide and assist the rural stakeholders with real-time decision support system (DSS) with dynamic information and modeling services for precision agriculture through GeoSense cloud service. This GeoSense research has been experimented in semiarid tropics in India under Indo-Japan initiative on multi-disciplinary ICT program.

1. Introduction

ICT is playing an important role in all walks of life in the knowledge society, including the rural systems with the revolutionary IVR and mobile telephony; (aAQUA [1], e-sagu [2], and FAS [3]). Geographical ICT (LBSs) and geocomputation is one of the important systems to solve a few dynamic open solutions in various rural development activities. This combination of ICT and GIS helps the remote rural stakeholders in a more interactive, integrated, and coordinated manner (distribution collaboration) in [4]. Another important ICT is SN, which is designed to detect physical/environmental events or phenomena, collect and process data, and transmit sensed information to the interested hub routing/server/users. Basic features of sensor networks in [5] are

(i) self-organizing capabilities;

(ii) short-/long-range broadcast communication and multi-hub routing;

(iii) dense deployment and cooperative effort of sensor nodes;

(iv) frequently changing topology due to fading and node failures;

(v) limitations in energy, transmit power, memory, and computing power.

These characteristics, particularly the last three, make sensor networks different from other well-established communication wireless ad hoc or mesh networks such as GSM or WLAN, which are based on a fixed network infrastructure, unattended and self-organizing. These so-called wireless adhoc and sensor networks open a wide range of communication and applications in [6]. The idea of mesh networking is not new but has been suggested for some time for wireless Intra-/Internet access or voice communication in [7]. Similarly, small computers, and sensors are not necessary; it has to be innovative/new parts for every new experiment. However, combining small sensors, low-power computers and radios make for a new technological platform that has numerous important uses and applications. Although sensor networks are networks of computing devices, they are considerably different from traditional data networks. The first difference is that the sensor networks with severe energy, computation, storage, and bandwidth constraints. The second difference is their overall usage scenario and the implications it brings to the traffic and interaction with the users. Typically, in traditional networks, users are connected to a node (or group of nodes) and require a service from another node. This two-communication model describes the overwhelming majority of traditional network traffic. The network acts as a medium bringing the two parties together. The interaction model is also straightforward. The user interacts directly with the user or service at the other end. Certain actions from the user will produce certain data transfers to and from the other end. Sensor networks, on the other hand, are less like networks (i.e., they loosely connect independent entities and more likely distributed systems). SN nodes tightly collaborate to produce information-rich results. The users are seldom interested in the readings of one or two specific nodes but will be interested in some parameters of a dynamic physical process. To achieve this efficiently, the nodes must form an application-specific distributed system to provide the user with solutions.

Novice agriculturists have started realizing the importance of this dynamic sensor network in its many processes, particularly in precision irrigation (PI), where one has to take decision at the right time/place/amount of water. In India, a few attempts have been made to collect real-time dynamic crop, weather, and environmental parameters using WSN technology to help/improve/assess the agricultural potential in the semiarid tropics: studied the feasibility of WSN, named Community based management of natural resources through sensor networks (COMMONSense net), in the semiarid region of India, which focuses on the design and implementation of a sensor network for agricultural water management with special emphasis on the resource-poor farmers of semiarid tropical (SAT) zones [8]; Centre for Development of Advanced computing (C-DAC) [9] works on ubiquitous agriculture using WSNs called U-Agri, with main emphasis on WBAS for groundnut disease/pests; A system, called Agrisens [10], uses a combination of wired and wireless sensors to collect sensory data (e.g., soil pH, soil moisture, soil temperature, etc.) through single-hop or multi-hop communication to a central node (Stargate) gateway [11]. Data is processed and stored in a structured database in the stargate to provide useful information to the farmers, which in turn helps to improve crop productivity and take a few control actions on irrigation through a web portal for data stream management system with which farmers along with agricultural experts and enthusiasts can interact with each other for better decision making. In [12], the authors worked on the ambient temperature, wind velocity, ambient humidity, soil moisture, and leaf wetness using Agrisens (a mote-based WSN) technology to calculate the evapotranspiration and leaf wetness of the vine yard in Nasik, Maharashtra, India to forecast grape diseases.

However, combination of Geo-ICT (location-based and geocomputation) and SN (a proximal distributed sensing units pertaining to weather, crop and soil parameters under microclimatic conditions) are promising real-time information gathering and dissemination technologies towards developing solutions for majority of the agricultural processes on a real to near-real-time basis. Realizing the importance of this integration in agriculture systems, a multidisciplinary collaborative project has been taken up to develop a real-time DSS, called GeoSense, to assist REC (farming community indirectly) through various ICTs to solve a few open solutions on PA aspects (irrigation, crop yield modeling, pest management, energy flux, and climate risks) [13]. The above research work is being carried out in the SAT region of India, where precision agriculture is one of the major solutions in improving rural livelihoods. GeoSense is an integrated distributed collaboration model with Geo-ICT (dynamic real-time information and communication) and WSN; christened as GeoSense. The WSN communication systems deployed/used to meet the information needs of the rural extension community are Agrisens [14] developed by SPANN Lab [15], IITB and FieldServer [16] developed by NARC [17]. These sensing devices consist of multiple detection stations (sensor nodes), each of which is small, light-weight and portable, and contains microcontroller/processor, transceiver, and power service. The transceiver, which can be hard-wired or wireless, receives commands from a central computer and transmits data to peer computers (Intra-/Inter-net). The power for each sensor node is derived either from the electricity or from a battery that has been charged by solar power (solar panels).

1.1. Specific Development Differences from Existing Related Systems. Rural/farming community needs timely real-time information/assistance, preferably in real-time, to combat the current climate aberrations. Geographical information and communication technologies (Geo-ICT) (combination of GIS and ICT for location-based services and geo-computations for decision support) and sensor network (SN) (a proximal distributed sensing units pertaining to weather, crop and soil parameters under microclimatic conditions) are promising real-time information gathering and dissemination technologies towards developing solutions for majority of the agricultural processes through sensor web enablement. Realizing the potentiality, an attempt has made to interlink Geo-ICT and sensor network to develop a real time decision support system in precision agriculture. Table 1 describes the specific development/functionality/facility difference between exiting related systems and GeoSense.

Most of the existing systems follow conventional methods based data collection (weather station, etc.), and one has to collect physically the crop/weather/environmental parameters or through data loggers, whereas in GeoSense the data has been dynamically collected at every one-minute interval and the collected data has been transmitted to the desired remote server (GeoSense server), which will store the data in the structured and usable (unit) format.

Table 1: Specific development/functionality of GeoSense and existing related systems.

S. No	GeoSense	E-Sagu	aAQUA	Common-Sense	Agrocom	Akshaya
(1)	Real-time dynamic system	Offline system	Offline system	Offline system	Semi-near real-time	Offline system
(2)	LBS	Not available	Not available	Available	Not available	Not available
(3)	WDS with broad band/3G network	Manual data collection/GPRS	Manual data collection/GPRS	ZigBee-based and GPRS	ZigBee-based and GPRS	Manual data collection/GPRS
(4)	3 Different height (1, 2 and 3 meters) weather data collection	Single-height data collection	Single-height data collection	Single-height data collection	Single-height data collection	Single-height data collection
(5)	Real-time soil moisture data collection	Manual data collection	Manual data collection	Manual data collection	AWS-based Soil moisture data collection	Manual data collection
(6)	Dynamic crop water requirement simulation	Manual advisory system	Manual advisory system	Manual advisory system	Manual advisory system	Manual advisory system
(7)	Dynamic real-time crop yield simulation	Manual advisory system	Manual advisory system	Manual advisory system	Manual advisory system	Manual advisory system
(8)	GeoSense cloud service	No cloud facility	No cloud facility	No cloud facility	No cloud facility	No cloud facility
(9)	Real-time decision support system	Semi-near real-time	Semi-near real-time	Semi-near real-time	Semi-near real-time	Semi-near real-time

This database is simultaneously available in the GeoSense database management system with cloud service. In addition, FieldServer in GeoSense system equipped with web camera, which will be helpful in monitoring the real-time/live pest/disease incidences/crop-quality/environmental conditions, whereas in the existing system one has to physically take the picture, send to the remote expert by various communication modes and analyze the situation. The hand-held devices such as Amprobe and weather tracker have been used to obtain the CO_2 and wind speed/velocity and humidity parameters, respectively, in the existing systems, where as in GeoSense system, these parameters are collected through already embedded sensors.

2. GeoSense

GeoSense is an attempt towards developing a real-time DSS to assist the rural stakeholders for improving the rural livelihood, environmental sustenance/security, and agriculture productivity. It is an integrated model with Geo-ICT and WSN for location-based sensory information and modeling services for precision agriculture with web-based GIS and short- and long-range communication/network systems.

2.1. Location-Based Services (LBSs) in GeoSense. Location specific information provide real-time dynamic sensory information on the basis of geospatial location/position (Figure 1) of the sensor to support a large user community and to provide more intelligent (using data for user-defined model/application) services. In the present study, LBSs are built with open-source Web-GIS system, called ALOV [18], to explore high-resolution spatiotemporal distributed sensory data. ALOV uses shape files (.shp) as its default vector file format. This attempt has brought out a new light on LBS in WSN research.

2.2. Wireless Sensor Network. WSN is an emerging technology, which has revolutionized the data collection in agricultural research in obtaining real-time data from the field, which will help to improve the decision making process to a large extent and help user community to draw contingent measures in [19]. GeoSense consists of three different WSN systems such as Agrisens (AS), FieldServer (FS), FieldTwitter (Open FieldServer) (FT) [13] as well as FS-based Towers (FLTs) [20] for precision agriculture in SAT region.

2.2.1. Design of Agrisens. Agrisens (AS) is a ZigBee-based self-organizing short range wireless sensor network communication system. It comprises several sensors to sense the environmental/weather/agricultural parameters. Different sensors have been used in AS (Figure 2) are temperature, soil moisture, soil temperature, leaf wetness, relative humidity, and ambient temperature. AS is a predefined closed-loop system, which senses the data automatically at user-defined intervals. The interval (data collection timing) depends on the sampling requirement.

AS comprises a three main components: (i) MICAz mote (sensor pods connected with an array of sensors), (ii) signal processing/transmitting (two-tier hierarchical cluster topology) and (iii) software development (algorithm process for raw sensory data conversion and user friendly GUI to view the sensory data in various formats such as Excel, CSV, and XML tables and graphs interactively.

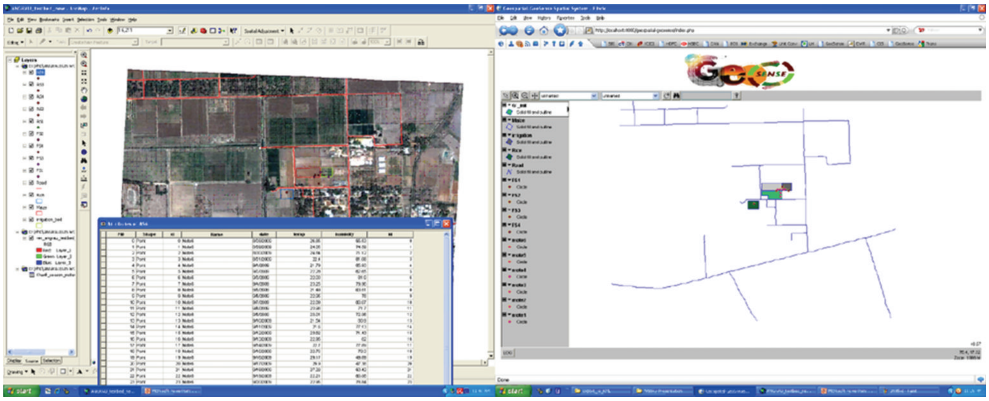

Figure 1: Location-Based sensory information through open-source GIS.

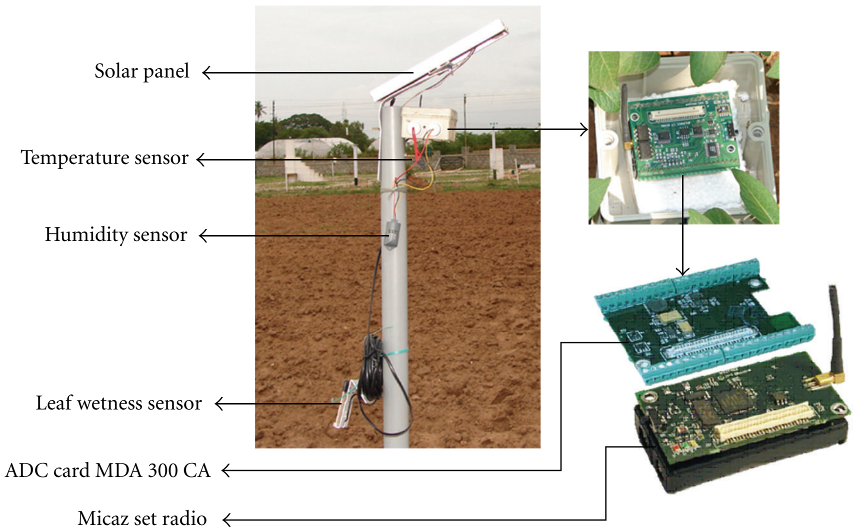

Figure 2: Agrisens and its components in the test bed.

(i) MICAz Mote. AS use crossbow's new ZigBee-ready, 802.154 radio-compliant MICAz mote operating on 2.4 GHz (IEEE 802.15.4 compliant) and associated sensor board, MDA300-CA as sensor pods [21]. Apart from the onboard sensors (relative humidity, and ambient temperature), Agrisens can also embed with external sensors such as ECH_2O [22] soil moisture (probe) and leaf wetness (Davis) [23] sensors.

(ii) Signal Processing/Transmitting. In AS, the communication module of the node consumes more power than any other part. Zigbee-based communication (receiving and transmitting) program takes charge of receiving orders/data from sink node (data transmitting node) as well as sending its own data to other/sink nodes and then to consume mode (gateway). The design flow of the program is shown in Figure 3.

Agrisens deployment consists of multiple nodes (client nodes) in the experimental bed. If the client node broadcasts a packet then it becomes a clusterhead. All nodes that receives packet stop their timers and become a member (one of the client nodes) of the clusterhead depending on the strength of the received signal. The member sends a "member announce" packet to its clusterhead. The clusterhead collects data using time division multiple access (TDMA). During data transmission phase, every node is assigned a level based on its proximity to the base station, which is assigned level 0. After collecting data from all its members, a clusterhead searches for the nearest lowest-level clusterhead. The clusterhead broadcasts a beacon containing its ID and level (IEEE 802.15.4), and all clusterheads in the lower level that receive this beacon acknowledge specifying their own ID and level. The clusterhead transmits its data to the base station, it follows this process till the base station (stargate/gateway) receives all the data. This approach becomes particularly attractive in heterogeneous settings when the clusterhead nodes are more powerful in terms of computation/communication. The advantage of the hierarchical cluster-based approach is that it naturally decomposes a large network into separate zones within which data

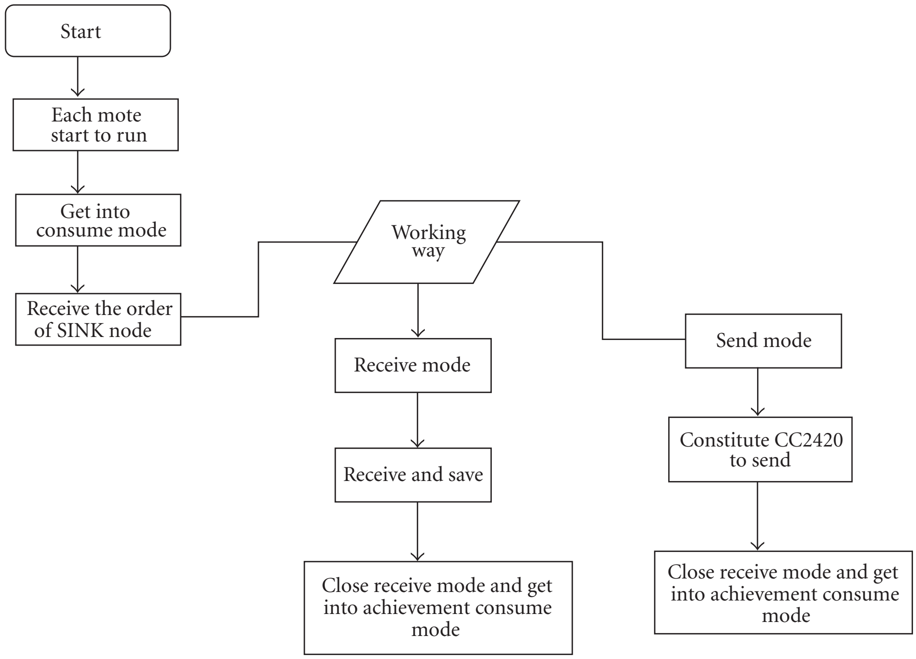

Figure 3: Agrisens wireless packets (sending and receiving) flow chart.

processing and aggregation can be performed individually with single-hop communication. Stargate [24] is a powerful single-board computer with enhanced communications and sensor signal processing capabilities. It has been configured with PostgreSQL [25] database server to log the data from AS clusterheads. It provides the data access capability to the server using WiFi with in-built xlisten client software [26]. Stargate send the sensory data from the PostgreSQL database to the Agrisens centralized server database via GPRS.

(iii) Software Development. Agrisens has a dedicated server for storing, processing, and publishing the data in the web environment by using X (any of four different operating systems), Apache, MySQL, PHP and Perl (XAMMP) tool [27]. Agrisens web interface has been developed with HTML and PHP languages and PostgreSQL acts in the backend, which stores the collected sensory data in a structured format. The interface helps the user to view/download the data in Excel (CSV) as well as graphical (line/bar/pie) formats [14].

2.2.2. Design of FieldServer (FS). FS is evolved out of many dynamic experiments on agriculture/environmental aspects in 90's and currently, 3rd generation FSs are available, which is a WiFi (long-range communication) based self-organizing distributed sensing device (Figure 4) with 24 bit and 24 channels. Field sensor embedded board could accommodate the sensors to sense weather, agricultural and environmental parameters such as air-temperature, humidity, relative humidity, solar radiation, leaf wetness, soil moisture, and CO_2 concentration. These sensory data will be transmited to the centralized server and stored into the database for information service as well as modeling service for decision making at microclimatic level for various applications such as precision agriculture. In addition, FS has the facility to observe/monitor the agricultural/environmental operations/processes through web camera. By using GPS timer, FS senses various weather and environmental parameters in real-time conditions at user-defined time intervals.

FieldServer Components. FS includes five main components: (i) FieldServer engine (FSE), (ii) sensors, (iii) network camera (iv) signal processing/transmitting (Star-connect single-hop topology), (v) web server and (vi) software development.

(i) FSE. The core part of FS is FSE; it is developed to have a vision in Field-Programmable Analog Array (FPAA) mode. The FSE (Figure 5) carries analog calculator, 24 channels (to accommodate 24 sensors) and 24-bit analog/digital (A/D) convert (to obtain mounted sensory data without any packet/data loss).

(ii) Sensors. Currently, in GeoSense project the sensors are used for air temperature, system temperature, soil temperature, humidity, soil moisture (at 3 different depths), CO_2 concentration, solar radiation, and leaf wetness. These real-time sensory parameters are important in precision farming aspects such as crop water requirement and crop yield modeling and nitrogen management.

(iii) Network Camera. FS has the capacity to take pictures/conditions of the crops from 0.3 to 8.0 Megapixel. It can also

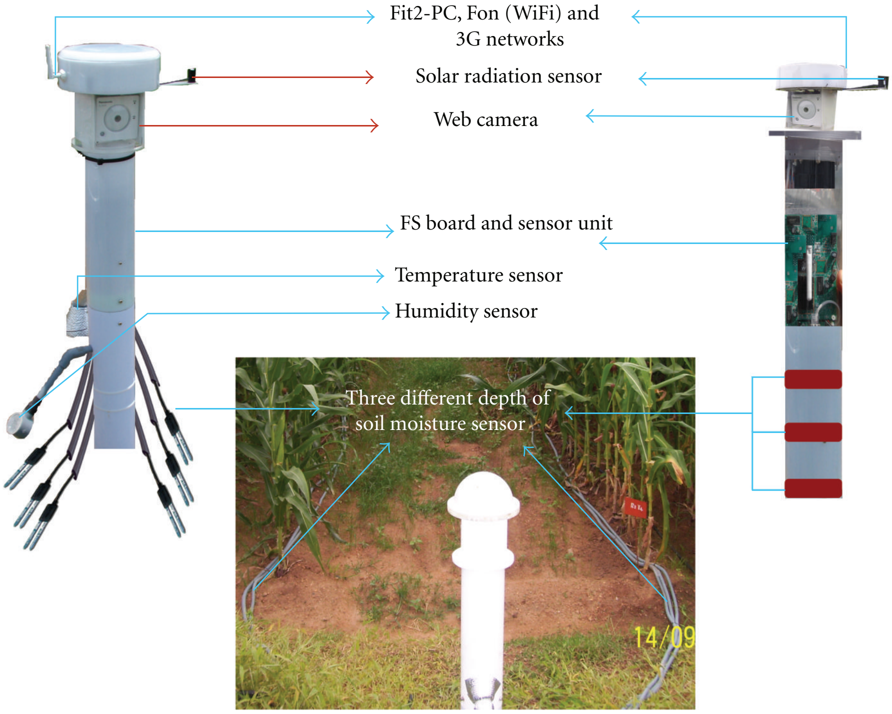

Figure 4: FieldServer and its components.

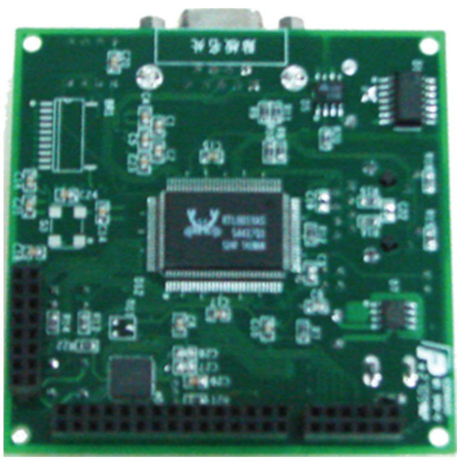

Figure 5: FieldServer engine.

take images ranging from omnidirection to 360°. Currently Panasonic KX-HCM230 and KX-HCM270 model cameras are embedded in the FS. Since these hardware models were works in −5°F to 122°F they are splash resistance for different weather conditions. In addition, facility is also available web-based viewing with remote pan and 180° tilt functions to adjust camera angles from remote/network/Internet environment. Live Image can be viewed up to 30 frames per second and motion video in VGA mode at 7.5 fps. The remote image collection can help in traceability, visualize agriculture/farm observations in agricultural product quality certification.

(iv) Signal Processing/Transmitting. FS can be deployed on the basis of simple WSN topology such as single-hop star network system. Embedded FMS communicates directly to the gateway, a central/server FS. Wherever feasible, this approach can significantly simplify design as the networking concerns are reduced to a minimum. In larger areas, nodes that are distant from the gateway will have poor-quality wireless links/pocket losses. Such cases hauler WiFi router/dongle (with beam antenna) help to gain the maximum pockets (Figure 6).

FS can utilize the WiFi devices/boards like Asus RT-N13U [28], Wireless (IEEE 802.11b/g/n) and Fon [29] (802.11b/g/n) routers to transmit large data in short time and with high speed. FSs also utilize the WDS for WiFi as ad hoc connection [30]. Usually, WDS is used between access points to allow transparent bridging of two Ethernets/systems over a wireless link. To transparently bridge two wired networks over WLAN, this way one will have 2 sets of MAC addresses. WDS functionality in router (Fon, in the present studies), will be made available through dd-wrt firmware (third party developed firmware released under the terms of the GPL for many IEEE 802.11a/b/g/h/n wireless routers based on a Broadcom or Atheros chip reference design) [31] (Figure 7).

All collected sensory data, including images, transfer (through WiFi ad hoc facility) to the base station/Mini-computer/Fit2-PC. The Fit2-PC [26] (agent) system has been utilized to store the data as well to push the data into the internet clouds. Agent system [32] also serves as a small Web server for standalone sensory web enablement. In addition, agent system supports MetBroker [33] for location based open sensor web enablement. The advantage of agent system is its capacity to shows and operates by any browser running on the webserver without any operating system. GUI interface has been developed for viewing/downloading the sensory data in the web environment with the help of HTML and Java codes [34]. In addition, it also consists of modeling interface (crop water requirement and rice crop yield simulation). This developed system also provides an open web server facility for SWE with OSC standard [35] and compatible with cloud computing functions.

(v) Web Server. WAMP [36] tool has been used for web server application. Since it is a Windows web development environment, it allows to create web applications with Apache, PHP and the MySQL database. It also comes with phpMyAdmin [37] to easily manage the databases. This WAMPServer has been used to maintain the FieldServer sensory database as well as export the sensory database or its structure in standard (open-source consortium) OSC format. Self-algorithm has been written in PHP language for raw sensory data convert to usable parameter/unit in dynamic real-time mode. This package has been used to maintain the FieldServer database management.

(vi) Software Development. FS sensory data are stored as distributed XML databases by FS agent system that control FS automatically. The agent program was developed with Java and XML languages [38] for viewing/processing the sensory data into a useable format. These raw and processed sensory data are stored into the virtual (temporary) and server database (permanently).

2.2.3. Design of FS-Based Flux Towers. Two FLTs were deployed (in maize field) (Figure 8) to study the weather profiles and partitioning of energy into different fluxes (latent heat flux, sensible heat flux, ground heat flux) [33]. Each flux tower consists of three sensor modules with temperature, relative humidity and CO_2 concentration sensors at different heights (1 m, 2 m and 3 m). Real-time knowledge of weather profiles and energy fluxes allows farming community to calculate water requirement (ET), irrigation scheduling, pest and disease management, and so forth. Flux tower sensors are embedded with FSE board and parallel connected with FS with RJ45 connectors, with which associated FS collects and transmits sensory data to the designated server.

2.2.4. Design of FieldTwitter. FieldTwitter (FT) [39] comprises (i) Arduino [40] (ii) signal (transmitting to the internet clouds) through Fon (iii) Algorithm process for FieldTwitter data to the twitter environment.

(i) Arduino. Arduino is an open hardware electronics prototyping platform based on flexible, easy-to-use hardware and software. Arduino attach with external handmade

Figure 6: Wireless router in the test bed.

soil moisture sensor (probe) at 15 cm depth. This is the first attempt in the world for developing a cost-effective open-hardware-based real-time dynamic distributed sensory system, which communicate directly to the Internet cloud (Twitter environment) instead of communicating to the dedicated server. This approach is useful particularly in developing countries where WSN is still a novice and costly technology (Figure 9).

(ii) Signal Transmitting. In FT, the communication mode consumes more power than any other parts, as it has been customized into WiFi-based communication system by using Fon that helps in receiving the internet pockets from the FieldServer (3G). Subsequently, it tweets/transmit the attached sensory data to the gateway/internet/twitter (Hydbot01) environment. Anyone can follow the FieldTwitter sensory data in Twitter social network in the name of "Hydbot01."

(iii) Software Development. FT sensory data are stored in twitter (Twillog) database system in the form of webpage, with XML syntax, which could be useful to maintain FT database. In FT web interface, the sensory data is available in raw format (analog to digital conversion (ADC)). A php-based algorithm has been developed for converting raw data into usable format and stores the data in GeoSense database.

2.3. Energy Efficiency in GeoSense. Many problems are associated with rural electrification and do not have simple solutions to solve the issue. Alternative energy sources have been attempted to overcome the power issues and GeoSense utilizes the solar panel (photovoltaic module), which is composed of individual photo voltaic (PV) cells with crystalline-silicon module. The silicon p-n junctions trap the energy in the form of heat which is transferred and transported into a heat storage vault to produce the

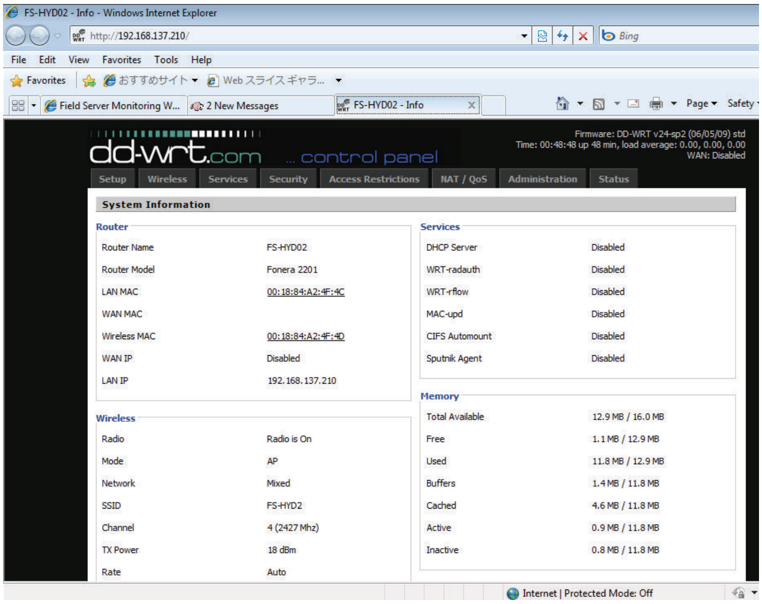

Figure 7: Wireless distribution system using dd-wrt open router firmware.

Figure 8: FieldServer-based flux towers.

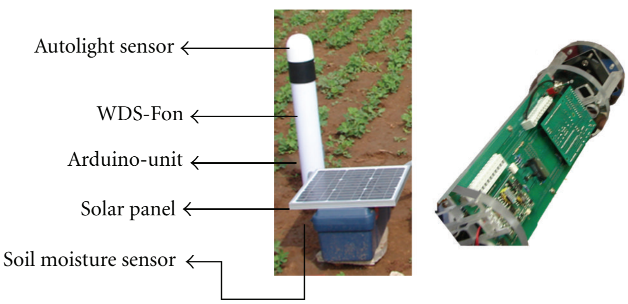

Figure 9: FieldTwitter with Arduino.

electricity. The details of GeoSense energy efficiency and power consume details are given in Table 2.

3. GeoSense Deployment and Utility

3.1. Test Bed. Long-term field experiments are being carried out since 1980 at ARI, ANGRAU, Rajendranagar, Hyderabad, Andhra Pradesh, India to study weather-based precision agriculture aspects (precision irrigation, crop yield modeling, and pest management) as well to design mitigation and adaptation strategies associated with climate risks for majorly grown rice, maize, and groundnut crops in semi arid tropics. The test bed is situated at 17°19′ 00′′ Latitude, and 78°23′00′′ Longitude and at an altitude of 543.3 meter mean sea level (MSL). The test bed falls under Southern Telangana agroclimatic region with average annual rainfall of 783 mm and mean temperatures ranging from 14°C to 40.0°C [41]. The physiochemical analysis of study area soil indicate that clay loam nature with high organic carbon content, medium in available nitrogen, phosphorus and low in available potassium.

Weather parameter, obtained from a meteorological station situated in close proximity, has been used in the above experiments. The GeoSense has been deployed in the test bed to augment the precision agriculture/climatic change researches with proximal WSN systems and to develop a real-time decision support system along with location based sensory information service.

3.2. Experiment. Standard agriculture experiments were adopted with (a) with three replications (R1, R2 and R3) and four dates of sowing (D1, D2, D3 and D4) for groundnut, maize, and rice for advising the farming community to adopt the better sowing date and mitigate crop yield and the pest/disease attacks owing to climate risks in this region, (b) five different levels (kg/ha) of nitrogen (0, 100, 200, 300, 400) to understand the optimum level of nitrogen of the experimental crops (maize, groundnut and rice), (c) different irrigation patterns (rainfed, ridge and furrow, drip irrigation as per crop water requirement, and life-saving irrigation) for validating crop water requirement and crop-yield modeling in groundnut and maize crops, and (d) rice experiment with 0, 100, 150, 200, 250, 300 (kg/ha) nitrogen levels under (three replication and four dates of sowing as in case of groundnut and maize) and irrigated conditions of rice

Table 2: Energy consumption and efficiency of GeoSense.

S. number	Name of the System	Number of Solar Panels	Battery capacity	Test crop
(1)	Agrisens	10 (5 V 3 Watts)	2.5 V 2500 mAh	Groundnut and maize
(2)	FieldServer	05 (12 V 24 Watts)	12 V 400 mAh	Rice, maize and groundnut
(3)	Flux tower	04 (12 V 24 Watts)	12 V 180 mAh	Maize
(4)	FieldTwitter	02 (12 V 24 Watts)	12 V 90 mAh	Groundnut

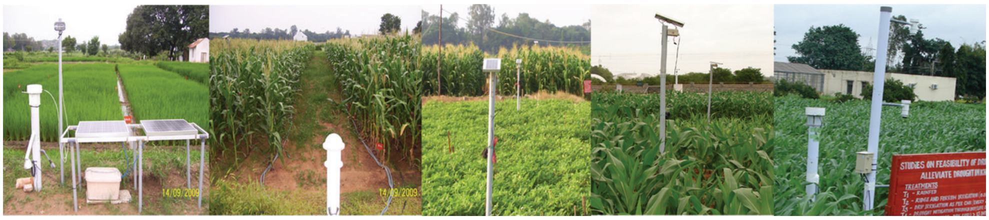

Figure 10: Experimental crops with GeoSense systems.

crop to validate and advice the farming community on yield aberrations under different dates of sowing with different level of nitrogen. Figure 10 illustrates the experimental crops under GeoSense system.

3.3. GeoSense Integrated Communication System. The integrated distributed wireless sensor network system, consisting of ASs, FSs, FLTs, and FT, was deployed in the test bed. This small-to-medium scale GeoSense network, for monitoring weather, agriculture and environment parameters, includes 11 distributed sensing devices (6 AS, 2 FS, 2 FLT and 1 FT), 1 Stargate. GPRS/Broadband/3G networks were used for accessing/sharing the data/system at a field/micro level. The sensory data from the test bed is transferred to the GeoSense server through a dedicated asymmetric digital subscriber line (ADSL). This is also the first approach to combine wireless broadband/3G and WSN technologies in India. Figure 11 illustrates the overall architecture of GeoSense. The deployed GeoSense system provides a continuous and dynamic communication between sensing devices (AS/FS) without pocket lost (communication signal) and centralized GeoSense server. The server processes the raw sensory data into the real/usable format in a dynamic manner. This real-time dynamic distributed sensory data (raw as well as real/usable) from (FS, FLT, AS, and FT) can be accessed through GeoSense web portal [38] by any authorized/registered member (rural extension/farming community/decision makers).

Figure 12 depicts the screen shots of AS, FS/FLT, and FT web interfaces to access/view/download the dynamic sensory data in the internet cloud.

GeoSense has been used for various applications under Indo-Japan initiatives: (a) dynamic weather/agriculture/environmental information system [42], (b) crop yield modeling [43], (c) real-time decision support system [44] energy balance studies [33], (d) primarily climate change analysis [39], (e) integrated pest management for pest counting [45], and (f) pest and disease forecasting [43].

3.3.1. FieldServer-Virtual Private Network (FS-VPN). A virtual private network (VPN) is an effective form of data security that moves from a wireless network client to a host system. It uses a "data tunnel" to connect two points on a network through an encrypted channel. The endpoints can be a single network client or a network server or a pair of client computers or other network devices. Data that passes through a public network, such as the Internet, is completely isolated from other network traffic. It uses login and password authentication to restrict access to authorized users. It encrypts the data to make it unintelligible to intruders who intercept and can manipulate the data; it uses data authentication to maintain the integrity of each data packet and to ensure that all data originates with legitimate network clients. GeoSense utilized PacketiX.NET VPN (academic version) [46] in the FS VPN system to connect server/client networks at different locations into one integrated network, so that all resources can be easily accessed ubiquitously. Fi-VPN could be accessed through server/client by using ultra virtual network computing (UltraVNC) server/client executable system. UltraVNC server helps to Share/access the FS (server) system through dynamic domain name system (DNS) mode. It also controls dynamic internet protocol (IP) into static IP.

3.3.2. GeoSense Private Cloud Services. Cloud computing is a dynamically scalable and often a virtualized resource as a service over the internet cloud. The users do not need necessarily to have knowledge of, expertise in, or control over the technology the clouds that support others. In [47], the Internet is often represented as a cloud and the term "cloud computing" arises from that analogy. Cloud computing has the dynamic provision of IT capabilities (hardware, software, various services) from third party over a network. GeoSense distributed sensor network system has formed a new cloud, called GeoSense cloud (Figure 13). This GeoSense cloud server is running in Mini-PC (Fit2PC) associated with Opera-Unite [48] for file sharing, web server, file upload,

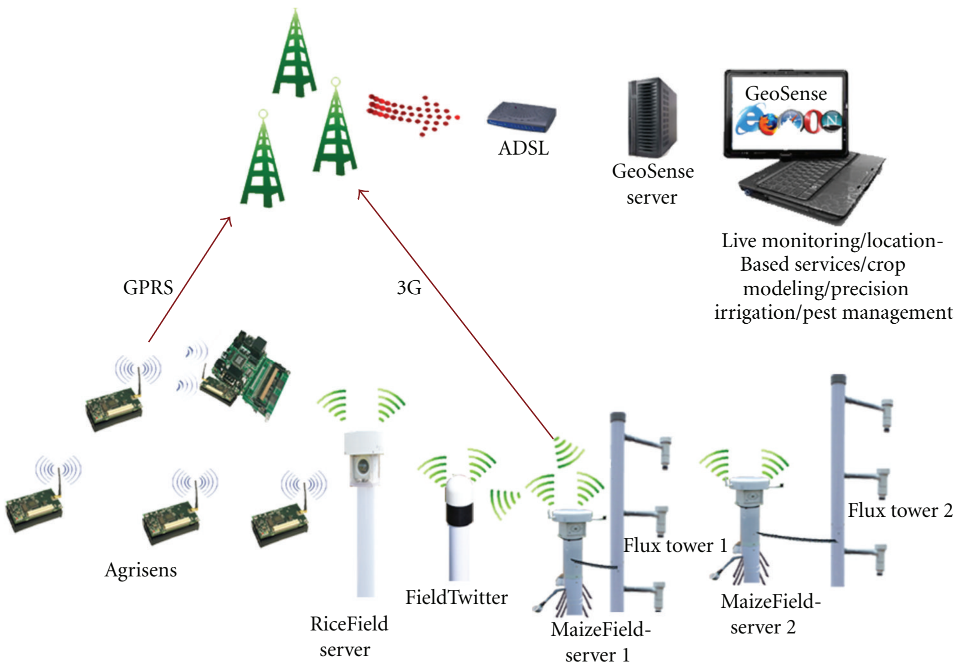

Figure 11: Integrated GeoSense Architecture.

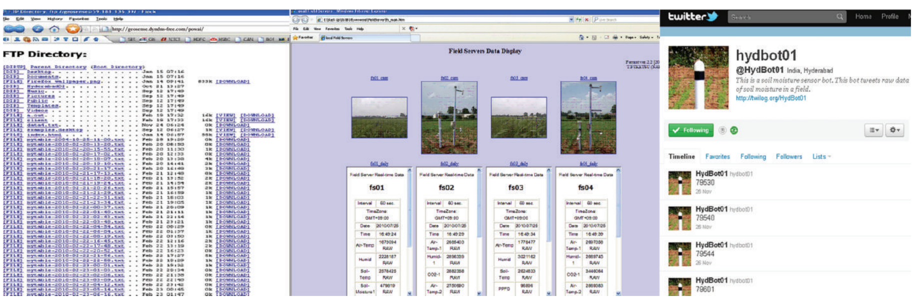

Figure 12: GeoSense near/real-time sensory data.

web proxy, and so forth functionalities. The GeoSense cloud services include

(i) infrastructure cloud: The inter connected (FS and FLT) and inter-related (FS and FT) distributed sensing system, which an connected with WDS functionality, are part of this cloud service;

(ii) service cloud: Provision of distributed sensory data (both in raw and usable format) to the multiusers with OSC standards from the service cloud;

(iii) application cloud: GeoSense application cloud facilitates crop water requirement and crop yield modeling services.

The main advantage of the GeoSense cloud service is to provide dynamic real-time accessibility of data and modeling services to the user community for ubiquitous decision making in a real-time manner. Other advantages include the cost-effectiveness and easy maintenance.

3.4. GeoSense Database Management System. Database management application is common in nearly all walks of life. However, maintaining cost effective dynamic real-time farm level database management system is a complex and challenging task. In this paper, main emphasis is given to the open-source cost effective database management system "phpMyAdmin" used to maintain the distributed sensory database from robust FS and its related systems (FLTs and FTs) in a real-time manner.

3.4.1. GeoSense Database Development. Recently, XML has become an emerging standard for information exchange on the World Wide Web and has gained great attention among the database communities. XML is a unicode language that creates structured data from interchange format/unstructured data. In the present study, sensory XML data are processed using PHP language to store in the sensory database into the GeoSense relational database

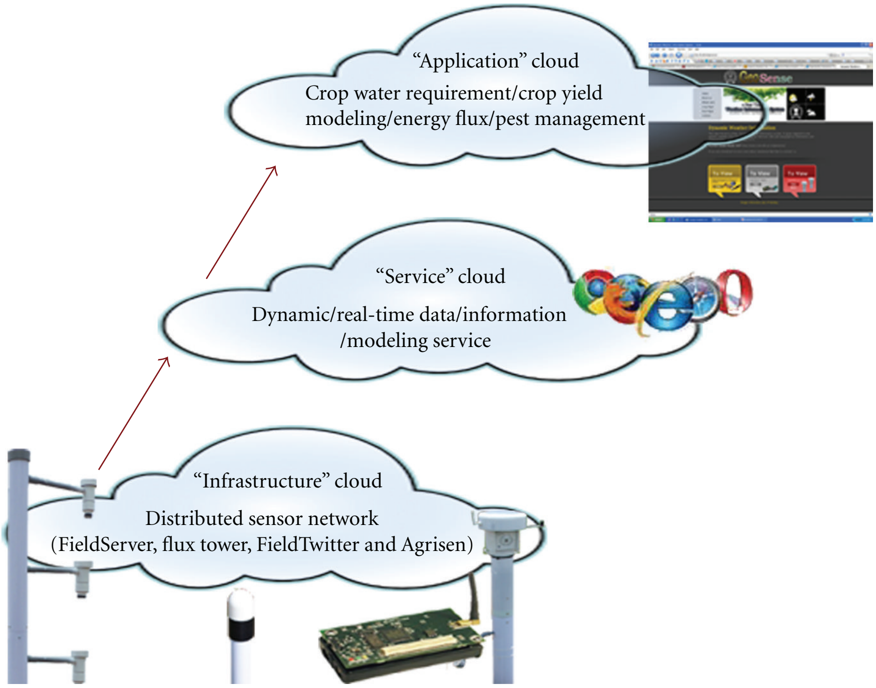

Figure 13: Cloud Services in GeoSense.

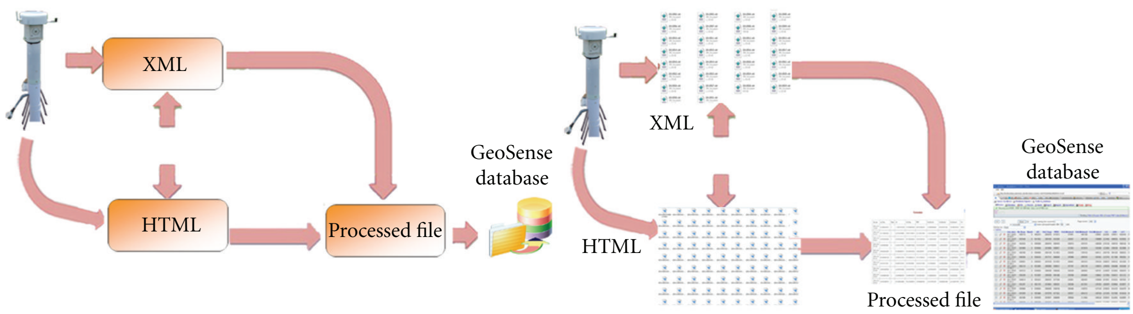

Figure 14: GeoSense Database Development.

management system (RDBMS). The schematic GeoSense RDBMS is illustrated in Figure 14.

3.4.2. Comparison of Sensor-Based Experimental with Weather Station-Based (Existing System) Observed Values. Traditionally, long-term experiment with various crop carried out in the test bed at Acharya N G Ranga Agriculture University (ANGRAU) research station with a nearby weather station (situated approximately 50 meters away) to simulate the predicted yields with CERES-Rice [49] and SIMRIW [50] simulation models. A comparative study on rice yields (with 2010 after monsoon/Kharif data) was carried out to understand the sensitivity of weather-based traditional system and sensory-based dynamic GeoSense system with the simulation and observed yield values (Table 3). This exercise exhibits the contribution and value of the GeoSense system. It is observed that the results from both the systems (traditional and GeoSense) are well comparative with the actual yields. CERES-Rice model comparatively is well close to the actual values as it takes care of most of the yield processing parameters. However, the minimum data SIMRIW model, being a Java-based web model, the results can be obtained dynamically in real time that will not only help the user community to take necessary contingent measures but also help the crop insurance agencies and markets for better and advance decision making.

4. Summary

An attempt has been made to integrate Geo-ICT with multi-range WSN-based communication system, the model in which is christened as GeoSense, to provide and assist rural extension community with a real-time dynamic sensory information in OSC standards and modeling service (crop water requirement, simulation model for rice

Table 3: Comparison of existing conventional system (weather station) and GeoSense-based yields (Kharif-Monsoon season, 2010).

N (kg/ha)	Actual/observed	Conventional (weather station) based rice yields (t/ha)		GeoSense-based rice yields (t/ha) in real time	
		CERES-Rice	SIMRIW	CERES-Rice	SIMRIW
100	6.70	5.62	6.35	6.73	6.77
150	6.82	6.15	6.35	6.87	6.94
200	7.20	7.31	7.26	7.25	7.29
250	6.95	7.76	7.02	7.01	7.10
300	7.35	7.94	7.17	7.39	7.42

and weather relation, energy flux studies, pest and disease forecasting, etc.) for precision agriculture. Location based sensory data information service is provided by open-source GIS. The short (mote-based AS) and long-range (WiFi-based FS/FIT/FT) communication systems were deployed in the test bed to collect location-specific weather/agriculture/environmental parameters in a real-time mode. The insights obtained integrating Geo-ICT and WSN indicated that the system performed in collecting and monitoring the data/phenomena precisely and communicating without any data/packets losses. This continuous high spatiotemporal resolution data information is possible through WDS routers, mini-PC, and efficient energy (solar) utility. The authorized user can obtain the DSS services as a cloud service. An interesting communication system to share the distributed sensory information and modeling services is provided in social networking (Twitter) environment through FieldTwitter (with open-source hardware). These twitter-based services are given through private cloud service, called GeoSense cloud service, with open-hardware system integrated with open software (DD-WRT) for long-range communication found to be a cost-effective approach. In this approach, instead of maintaining the dedicated servers, the database could be managed/maintained in the Twitter environment (Twilog). The push-based GeoSense DSS is designed to cater the rural/farming community for their day-to-day decision making in precision agriculture, which could form an intrusion model in the present climate change scenario content.

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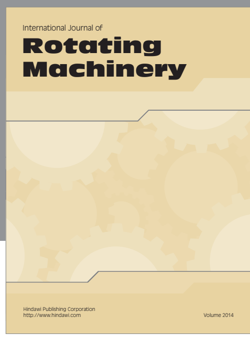
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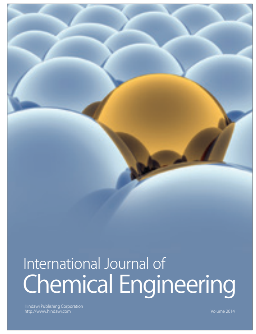
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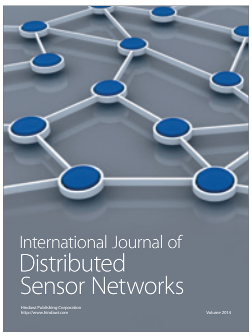
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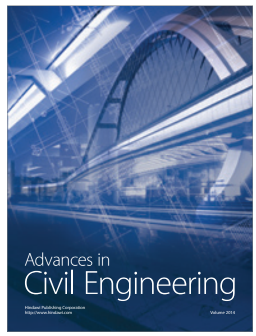
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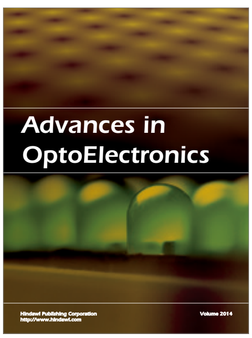
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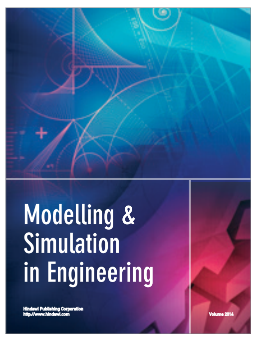
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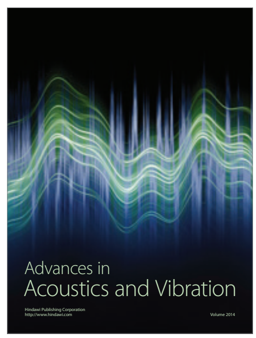
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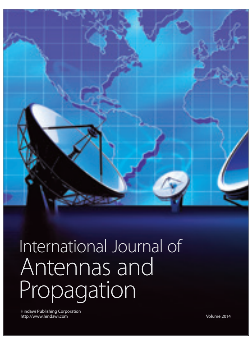
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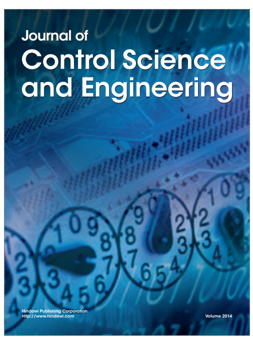
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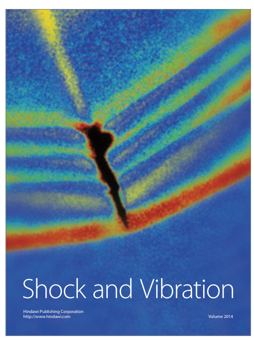
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