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Optimization of Water Use for Agriculture Using a Wireless Sensor Network and GPRS Module

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Abstract: An automated irrigation system was developed to optimize water use for agricultural crops. The system has a distributed wireless network of soil-moisture and temperature sensors placed in the root zone of the plants. In addition, a gateway unit handles sensor information, triggers actuators, and transmits data to a web application. An algorithm was developed with threshold values of temperature and soil moisture that was programmed into a microcontroller-based gateway to control water quantity. The system was powered by photovoltaic panels and had a duplex communication link based on a cellular-Internet interface that allowed for data inspection and irrigation scheduling to be programmed through a web page. The automated system was tested in a sage crop field for 136 days and water savings of up to 90% compared with traditional irrigation practices of the agricultural zone were achieved. Three replicas of the automated system have been used successfully in other places for 18 months. Because of its energy autonomy and low cost, the system has the potential to be useful in water limited geographically isolated areas.

Keywords: Automation, cellular networks, Internet, irrigation, measurement, water resources, wireless sensor networks (WSNs).

I. INTRODUCTION

Agriculture uses 85% of available freshwater resources worldwide, and this percentage will continue to be dominant in water consumption because of population growth and increased food demand. There is an urgent need to create strategies based on science and technology for sustainable use of water, including technical, agronomic, managerial, and institutional improvements. A system developed for malting barley cultivations in large areas of land allowed for the optimizing of irrigation through decision support software and its integration with an infield wireless sensor network (WSN) driving an irrigation machine converted to make sprinkler nozzles controllable. The network consisted of five sensing stations and a weather station. Each of the sensing stations contained a data logger with two soil water reflectometers, a soil temperature sensor, and Bluetooth communication. Using the network information and the irrigation machine positions through a differential GPRS, the software controlled the sprinkler with application of the appropriate amount of water. In this project, the development of the deployment of an automated irrigation system based on microcontrollers and wireless communication at experimental scale within rural areas is presented. The aim of the implementation was to demonstrate that the automatic irrigation can be used to reduce water use.

II. AUTOMATED IRRIGATION SYSTEM

The automated irrigation system hereby reported, consisted of two components (Fig. 1), wireless sensor units (WSUs) and a wireless information unit (WIU), linked by radio transceivers that allowed the transfer of soil moisture and temperature data, implementing a WSN that uses ZigBee technology. The WIU has also a GPRS module to transmit the data to a web server via the public mobile network. The information can be remotely monitored online through a graphical application through Internet access devices.

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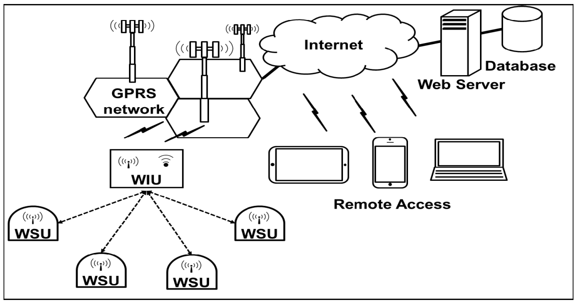

Fig. 1. Configuration of the automated irrigation system. WSUs and a WIU, based on microcontroller, ZigBee, and GPRS technologies.

A. *Wireless Sensor Unit*

A WSU is comprised of a RF transceiver, sensors, a microcontroller, and power sources. Several WSUs can be deployed in-field to configure a distributed sensor network for the automated irrigation system. Each unit is based on the microcontroller PIC24FJ64GB004 (Microchip Technologies, Chandler, AZ) that controls the radio modem XBee Pro S2 (Digi International, Eden Prairie, MN) and processes information from the soil-moisture sensor VH400 (Vegetronix, Sandy, UT), and the temperature sensor DS1822 (Maxim Integrated, San Jose, CA). These components are powered by rechargeable AA 2000-mAh Ni-MH CycleEnergy batteries (SONY, Australia). The charge is maintained by a photovoltaic panel MPT4.8-75 (PowerFilm Solar, Ames, IN) to achieve full energy autonomy. The microcontroller, radio modem, rechargeable batteries, and electronic components were encapsulated in a waterproof Polyvinyl chloride (PVC) container. These components were selected to minimize the power consumption for the proposed application.

1) Single-Chip PIC24FJ64GB004: A 16-bit microcontroller with 44-pins and nanoWatt XLP technology that operates in a range 2.0 to 3.6 V at 8 MHz with internal oscillator. It has up to 25 digital input/output ports, 13-, 10-bit analogto-digital converters (ADC), two serial peripheral interface modules, two I2C, two UART, 5 16-bit timers, 64 KB of program memory, 8 KB of SRAM, and hardware real-time clock/calendar (RTCC). The microcontroller is well suited for this remote application, because of its low-power operating current, which is 175 μA at 2.5 V at 8 MHz and 0.5 μA for standby current in sleep mode including the RTCC. The microcontroller was programmed in C compiler 4.12 (Custom Computer Services, Waukesha, WI) with the appropriate algorithm for monitoring the soil-moisture probe through an analog-to-digital port and the soil-temperature probe through another digital port, implemented in 1-Wire communication protocol. A battery voltage monitor is included through a high-impedance voltage divider coupled to an analog-to-digital port. The data are packed with the corresponding identifier, date, and time to be transmitted via XBee radio modem using a RS-232 protocol through two digital ports configured as transmitter (TX) and receiver (RX), respectively. After sending data, the microcontroller is set in sleep mode for certain period according to the sensor sampling rate desired, whereas the internal RTCC is running. This operation mode allows energy savings. When the WSU is launched for first time, the algorithm also inquires the WIU, the date and time to program the RTCC, and periodically updates it for synchronization.

2) Soil Sensor Array: The sensor array consists of two soil sensors, including moisture and temperature that are inserted in the root zone of the plants. The VH400 probe was selected to estimate the soil moisture because of low power consumption (<7 mA) and low cost. The probe measures the dielectric constant of the soil using transmission line techniques at 80 MHz, which is insensitive to water salinity, and provides an output range between 0 and 3.0 V, which is proportional to the volumetric water content (VWC) according to a calibration curve provided by the manufacturer. The sensor was powered at 3.3 V and monitored by the microcontroller through an ADC port.

Soil temperature measurements were made through the digital thermometer DS1822. The sensor converts temperature to a 12-bit digital word and is stored in 2-B temperature registers, corresponding to increments of 0.0625 °C. The temperature is required through a reading command and transmitted using 1-Wire bus protocol implemented in the microcontroller through one digital port. The thermometer has 2.0 °Caccuracy over −10 °C to +85 °C temperature range and a unique 64-bit serial number. The sensor is a 3-pin single-chip and TO92 package that was embedded in a metal capsule and sealed in a waterproof PVC cylindrical container. To calibrate the soil moisture, several samples were prepared with 1 kg of dry soil from the crop area. Its composition was loamy sand with 80% sand separate, 4.5% clay separate, and 15.6% silt separate. The soil water holding capacity was of 20.7% VWC corresponding to measured output voltages of 1.45 V. The temperature sensors were calibrated through a reference mercury thermometer CT40, with 0.1 °C divisions and a range from −1 °C to 51 °C. The thermometer and the temperature sensors were placed in an insulated flask filled with mineral oil at 10 °C and 40 °C.

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3*) Photovoltaic Cell:* To maintain the charge of the WSU batteries, a solar panel MPT4.8-75 was employed. Each solar panel delivers 50 mA at 4.8 V, which is sufficient energy to maintain the voltage of the three rechargeable batteries. A MSS1P2U Schottky diode (Vishay, Shelton, CT) is used to prevent the solar module and to drain the battery when is in the dark. The solar panel is encapsulated in a 3-mm clear polyester film with dimensions of 94 mm × 75 mm. This flexible panel was mounted on a PVC prismatic base (100 mm × 80 mm × 3.17 mm) that is fastened in the upper part of a PVC pole allowing for the correct alignment of the photovoltaic panel to the sun. The stick is 50 cm of length and 12.5 mm of diameter; the lower end of the pole had a tip end to be buried.

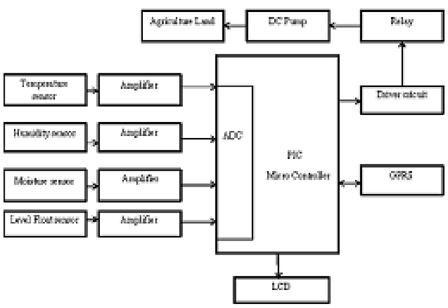

Fig. 2 ***Block diagram for GPRS Module***

B. Wireless Information Unit

The soil moisture and temperature data from each WSU are received, identified, recorded, and analyzed in the WIU. The WIU consists of a master microcontroller PIC24FJ64GB004, an XBee radio modem, a GPRS module MTSMC-G2-SP (MultiTech Systems, Mounds View, MN), an RS-232 interface MAX3235E (Maxim Integrated, San Jose, CA), two electronic relays, two 12 V dc 1100 GPH Livewell pumps (Rule-Industries, Gloucester, MA) for driving the water of the tanks, and a deep cycle 12 V at 100-Ah rechargeable battery L-24M/DC-140 (LTH, Mexico), which is recharged by a solar panel KC130TM of 12 V at 130 W (Kyocera, Scottsdale, AZ) through a PWM charge controller SCI-120 (Syscom, Mexico). All the WIU electronic components were encapsulated in a waterproof PVC box The WIU can be located up to 1500-m line-of-sight from the WSUs placed in the field.

1) Master Microcontroller: The functionality of the WIU is based on the microcontroller, which is programmed to performdiverse tasks, as is shown in Fig. 7. The first task of the program is to download from a web server the date and time through the GPRS module. The WIU is ready to transmit via XBee the date and time for each WSU once powered. Then, the microcontroller receives the information package transmitted by each WSU that conform the WSN. These data are processed by the algorithm that first identifies the least significant byte of a unique 64-bit address encapsulated in the package received. Second, the soil moisture and temperature data are compared with programmed values of minimum soil moisture and maximum soil temperature to activate the irrigation pumps for a desired period. Third, the algorithm also records a log file with the data in a solid state memory 24FC1025 (Microchip Technologies, Chandler, AZ) with a capacity of 128 kB. Each log is 12-B long, including soil moisture and temperature, the battery voltage, the WSU ID, the date, and time generated by the internal RTCC. If irrigation is provided, the program also stores a register with the duration of irrigation, the date, and time. Finally, these data and a greenhouse ID are also transmitted at each predefined time to a web server through HTTP via the GPRS module to be deployed on the Internet web application in real time. When the server receives a request for the web page, it inserts each data to the corresponding field in the database. This link is bidirectional and permits to change the threshold values through the website interface; scheduled watering or remote watering can be performed. The WIU has also a push button to perform manual irrigation for a programmed period and a LED to indicate when the information package is received. All the WIU processes can be monitored through the RS-232 port. The WIU includes a function that synchronizes the WSUs at noon for monitoring the status of each WSU. In the case that all WSUs are lost, the system goes automatically to a default irrigation schedule mode. Besides this action, an email is sent to alert the system administrator.

2) GPRS Module: The MTSMC-G2-SP is a cellular modem embedded in a 64-pins universal socket that offers standards based quad-band GSM/GPRS Class 10 performance. This GPRS modem includes an embedded transmission control protocol/Internet protocol stack to bring Internet connectivity, a UFL antenna connector and subscriber identity module (SIM) socket. The module is capable of transfer speeds up to 115.2 K b/s and can be interfaced directly to a UART or microcontroller using AT commands. It also includes an onboard LED to display network status. The GPRS was powered to 5 V regulated by UA7805 (Texas Instruments, Dallas, TX) and operated at 9600 Bd through a serial port of the master microcontroller and connected to a PCB antenna. The power consumption is 0.56 W at 5 V. In each connection, the microcontroller sends AT commands to

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the GPRS module; it inquires the received signal strength indication, which must be greater than −89 dBm to guarantee a good connection. In addition, it establishes the communication with the URL of the web server to upload and download data. If the received signal strength is poor, then all data are stored into the solid-state memory of the WIU and the system try to establish the connection each hour.

3) Watering Module: The irrigation is performed by controlling the two pumps through 40-A electromagnetic relays connected with the microcontroller via two optical isolators CPC1004N (Clare, Beverly. MA). The pumps have a power consumption of 48 W each and were fed by a 5000-l water tank.

Four different irrigation actions (IA) are implemented in the WIU algorithm:

1) fixed duration for manual irrigation with the push button;

2) scheduled date and time irrigations through the web page for any desired time;

3) automated irrigation with a fixed duration, if at least one soil moisture sensor value of the WSN drops below the programmed threshold level;

4) automated irrigation with a fixed duration, if at least one soil temperature sensor value of the WSN exceeds the programmed threshold level.

III. Irrigation System Operation

The system was tested in a 2400-m2 greenhouse, located near San Jose del Cabo, Baja California Sur (BCS), Mexico (23° 10.841' N, 109° 43.630' W) for organic sage (Salvia officinalis) production. The greenhouse had 56 production beds covered with plastic. Each bed was 14-m long and had two black polyethylene tubes with drip hole spacing of 0.2 m.

Fig.:3 Greenhouse for organic sage production with WSUs located arbitrarily in different cultivation beds. (a) WSU-55 on bed 2. (b) WSU-56 on bed 12. (c) WSU-57 on bed 23. WSU-54 was on bed 1.

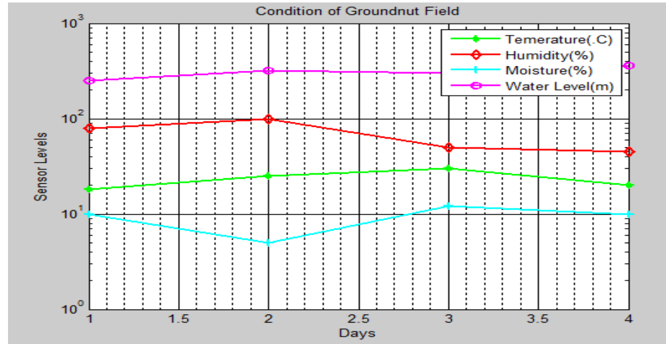

Fig 4. Web application of the automated irrigation system to remotely supervise the soil moisture and temperature of each WSU and change the threshold values and the scheduled irrigation.

The automated irrigation system was used to irrigate only 600 m2, which corresponded to 14 beds; whereas, the remaining 42 beds were irrigated by human supervision to compare water consumption with the traditional irrigation practices in this production place. Four WSUs labeled by the last significant byte of the unique 64-bit address (WSU-54, 55, 56, and 57) were located in the greenhouse at arbitrary points (Fig. 2). TheWSU-57 unit was used to measure the soil moisture and temperature in the area (bed 23) where the traditional irrigation practices were employed. The other three units (WSU-54, 55, and 56) were located in beds 1, 2, and 12 to operate the automated irrigation system with their corresponding soil moisture and temperature sensors situated at a depth of 10 cm Fig.3. Gathered data of the WSUs, in the web application of the automated irrigation system: soil temperatures, soil moisture, and water supplied (vertical bars indicate automated and scheduled irrigation). in the root zone of the plants. These three units allowed data redundancy to ensure irrigation control. The algorithm considered the values from the WSU-54, 55, and 56, if one reached the threshold values the automated irrigation was performed.

The pumping rate provided 10 ml/min/drip hole, which was measured in the automated irrigation zone in six different drip holes. In accordance with the organic producer's experience, a minimum value of 5% VWC for the soil was established as the moisture threshold level and 30 °C as the temperature threshold level for the automated irrigation modes (IA-3 and IA-4, respectively). Initially, the scheduled irrigation (IA-2) of 35 min/week was used during the first six weeks. After that, the scheduled irrigation was set at 35 min three times per week. Sage cultivation finalized after 136 days. During the cultivation, several automated irrigation periods were carried out by the system because of the soil-moisture (IA-3) or temperature (IA-4) levels,

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regardless of the scheduled irrigation (IA-2). All data were uploaded each hour to the web server for remote supervision. For instance, data of five days are shown (Fig.2). The first graph shows soil temperatures. The vertical bars indicate automated irrigation periods triggered by temperature when soil temperature was above the threshold value (30 °C). The second graph shows soil moistures that were above the threshold value (5.0% VWC), and thus the automated irrigation was not triggered by soil moisture. Finally, the last graph shows the total water used by the sage with the corresponding scheduled irrigation vertical bars for the IA-2. The dots denote the automated and scheduled irrigation. Automated irrigation triggered by soil moisture for four days are shown in Fig. 11; when the soil moisture value fell below the threshold level of 5.0% VWC, the irrigation system was activated for 35 min according to IA-3, whereas the soil temperature remained below the threshold level. Similarly, automated irrigation triggered by soil temperature; when the temperature was above 30 °C, the irrigation system was activated for 5 min according to IA-4, whereas the soil moisture remained above the threshold level.

Water consumption with the organic producers' traditional irrigation procedure consisted of watering with a 2" electrical pump during 5 h three times per week for the whole cultivation period. Under this scheme the volume flow rate measured on site was 10 ml/min/per drip hole, giving a total of 174 l/drip hole, whilst the automated irrigation system used 14 l/drip hole. In the entire greenhouse, the sage plants presented similar fresh biomass regardless of the irrigation procedure during the whole production period. The average biomass per cut was 110 pounds for the traditional irrigation system corresponding to 42 production beds and 30 pounds for the automated irrigation system corresponding to 14 beds. The automated system was tested in the greenhouse for 136 days

Fig.5. Automated irrigation systems for the experimental production of: sage (top left), thyme (top right), origanum (bottom left), and basil (bottom right) in San Jose del Cabo, Los Arados, El Pescadero, and El Comitan, respectively.

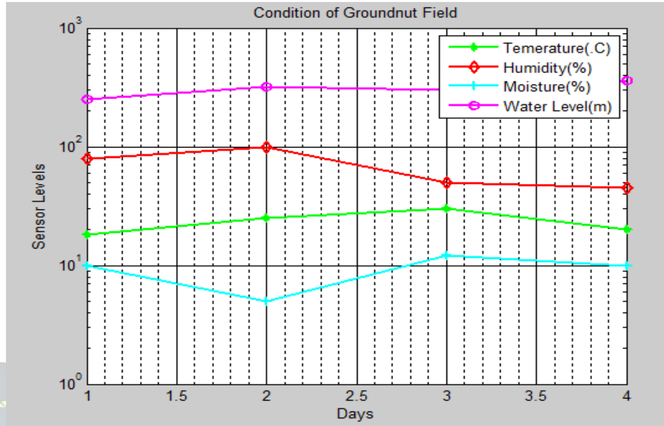

Fig.6. Daily mean soil temperature (a: traditional; b: automated), daily mean soil moisture (c: traditional; d: automated), and accumulated water irrigation volumes (dotted line: traditional; solid line: automated) over the entire sage cropping season.

(Fig. 5). Daily mean soil moisture and temperature are shown, as well as the accumulated water used for both systems. Both mean temperatures presented similar behaviour for the production period, except for the last 30 days, where the soil temperature for the traditional irrigation practice (curve a) was lower than the automated irrigation (curve b). The daily mean VWC for the traditional irrigation practice (curve c) was almost constant >16%, whereas that for the automated irrigation (curve d) was below 10%. In addition, the accumulated water used are shown corresponding to 14 beds for each irrigation system. The total water requirement was 341 m3 for the traditional one and 29 m3 for the automated one. Then, the automated irrigation used ~90% less water with respect to the traditional irrigation practice. Another three automated irrigation systems (Fig. 14) have been tested along 18 months in other places in BCS, Mexico: El Pescadero (23° 21.866' N, 110° 10.099' W), El Comitan- CIBNOR (24° 7.933' N, 110° 25.416' W), and Los Arados (24° 47.1' N, 111° 11.133' W). In these three places, programmed irrigations (IA-2) were compared with triggered irrigations (IA-3 and IA-4), water savings □60% were obtained. For cases such as Los Arados, it was found that the signal receiving strength was too low and the Internet connection could not be established, hence in this case all data were stored into the solid state memory of the WIU. Power consumption of a WSU was measured through current oscilloscope (UNI-T UT81B) in the monitoring and sleep operational modes (Fig. 15). Each hour, the soil-moisture and temperature data were transmitted to the WIU. Before transmitting the data, the XBee of the WSU was powered on

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through the voltage regulator that was enabled for a period of 20 s by the microcontroller, which was a long enough time for the radio modem to wake up and transmit the data. Then, the total average power consumption was kept at 0.455 mAh. The charge-discharge cycle of the batteries is shown for 20 days in the winter with the solar panel connected and disconnected using the data registered by the battery voltage monitor. The solar radiation for those days is shown in Fig. 17. Thus, the photovoltaic panel and the batteries provide sufficient energy to maintain the WSU running for the whole crop season at almost any latitude, due the low energy consumption.

The WIU average current consumption because of the electronic components was of 80 mAh in operational mode. However, the total average power consumption was 4 Ah per day considering the two irrigation pumps.

IV. Conclusion

The automated irrigation system implemented was found to be feasible and cost effective for optimizing water resources for agricultural production. This irrigation system allows cultivation in places with water scarcity thereby improving sustainability.

The automated irrigation system developed proves that the use of water can be diminished for a given amount of fresh biomass production. The use of solar power in this irrigation system is pertinent and significantly important for organic crops and other agricultural products that are geographically isolated, where the investment in electric power supply would be expensive.

The irrigation system can be adjusted to a variety of specific crop needs and requires minimum maintenance. The modular configuration of the automated irrigation system allows it to be scaled up for larger greenhouses or open fields. In addition, other applications such as temperature monitoring in compost production can be easily implemented. The Internet controlled duplex communication system provides a powerful decision making device concept for adaptation to several cultivation scenarios. Furthermore, the Internet link allows the supervision through mobile telecommunication devices, such as a smartphone.

Besides the monetary savings in water use, the importance of the preservation of this natural resource justify the use of this kind of irrigation systems.

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References

[1]. J. M. Blonquist, Jr., S. B. Jones, and D. A. Robinson, ―Precise irrigation scheduling for turf grass using a subsurface electromagnetic soil moisture sensor, Agricult. Water Manag., vol. 84, nos. 1–2, pp. 153–165, Jul. 2006.

[2]. O. M. Grant, M. J. Davies, H. Longbottom, and C. J. Atkinson, ―Irrigation scheduling and irrigation systems: Optimising irrigation efficiency for container ornamental shrubs, Irrigation Sci., vol. 27, no. 2, pp. 139–153, Jan. 2009.

[3]. D. D. Chaudhary, S. P. Nayse, and L. M. Waghmare, ―Application of wireless sensor networks for green house parameters control in precision agriculture, Int. J. Wireless Mobile Netw., vol. 3, no. 1, pp. 140–149, Feb. 2011.

[4]. N. Wang, N. Zhang, and M. Wang, ―Wireless sensors in agriculture and food industry—Recent development and future perspective, Comput. Electron. Agricult., vol. 50, no. 1, pp. 1–14, Jan. 2006.

[5]. S. A. O'Shaughnessy and S. R. Evett, ―Canopy temperature based system effectively schedules and controls center pivot irrigation of cotton, Agricult. Water Manag., vol. 97, no. 9, pp. 1310–1316, Apr. 2010.

[6]. R. G. Allen, L. S. Pereira, D. Raes, and M. Smith, Crop Evapotranspiration-Guidelines for Computing Crop Water Requirements—FAO Irrigation and Drainage Paper 56. Rome, Italy: FAO, 1998.

[7]. J. M. Corchado, J. Bajo, D. I. Tapia, and A. Abraham, "Using a heterogeneous wireless sensor networks in a telemonitoring system for healthcare," *IEEE Trans. Inf. Technol. Biomed.*, vol. 14, no. 2, pp. 234–240, Mar. 2010.

[8]. G. X. Lee, K. S. Low, and T. Taher, "Unrestrained measurement of arm motion based on a wearable wireless sensor network," *IEEETrans. Instrum. Meas.*, vol. 59, no. 5, pp. 1309–1317, May 2010.

[9]. D.-M. Han and J.-H. Lim, "Smart home energy management system using IEEE 802.15.4 and ZigBee," *IEEE Trans. Consum. Electron.*, vol. 56, no. 3, pp. 1403–1410, Aug. 2010.

[10]. C. Gomez and J. Paradells, "Wireless home automation networks: A survey of architectures and technologies," *IEEE Commun. Mag.*, vol. 48, no. 6, pp. 92–101, Jun. 2010.

[11]. M. Bertocco, G. Gamba, A. Sona, and S. Vitturi, "Experimental characterizationof wireless sensor networks for industrial applications," *IEEE Trans. Instrum. Meas.*, vol. 57, no. 8, pp. 1537–1546, Aug. 2008.

[12]. V. C. Gungor and G. P. Hancke, "Industrial wireless sensor networks: Challenges, design principles, and technical approaches," *IEEE Trans. Ind. Electron.*, vol. 56, no. 10, pp. 4258–4265, Oct. 2009.

[13]. L. Hou and N. W. Bergmann, "Novel industrial wireless sensor networks for machine condition monitoring and fault diagnosis," *IEEE Trans. Instrum. Meas.*, vol. 61, no. 10, pp. 2787–2798, Oct. 2012.

