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Industrial Automation using Wireless Sensor Networks

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Abstract

Background/Objectives: The advent of Wireless Sensor Networks (WSNs) have revolutionized the field of automation in many ways. This paper presents the implementation of one such WSN useful for industrial applications. **Methods/Statistical Analysis:** The establishment of the WSN cluster using low cost MSP430 processor and RF transceivers is explained. This network could be easily modified to suit the needs of a particular process in an industry. **Findings:** A basic hardware system comprising of a cluster having five nodes is tested with real time control signals. Such a network was found to be reliable, low cost and low power consuming. This cluster can be duplicated and such clusters can be integrated with the use of gateways to form a large network to monitor and control the various processes in an industry simultaneously. In the consumer end, these networks will be more user friendly and available at low cost. **Applications/Improvements:** The WSN clusters can be used for automation of various industries with the possibility of easy modification or expansion in the future.

Keywords: Actuation, Industrial Automation, Sensing, Wireless, Wireless Cluster, WSN

1. Introduction

Feedback control has enabled manually operated machines to be replaced by automated equipment. This increased productivity and quality of the products. Automation applications span plant automation, discrete and batch process control, embedded machine control and manufacturing production line automation. Further the advent of wireless communication increased the productivity and efficiency of automation in industries owing to the easy installation, maintenance and flexibility of Wireless Sensor Networks (WSNs).

WSNs are being used in various domains to meet the needs of many applications. WSNs consists of a number of small, inexpensive and low-power consuming devices called nodes that work together by communicating with each other through a sophisticated network. These nodes are deployed to gather sensory information and may also be used to control certain actuations that in turn control the environment (or system). Flexible installation and maintenance of nodes in locations difficult to access, wide range of deployment along with low costs make WSNs the most sought after technology in various field varying from agriculture[1] to automation in industries[2].

A process in an industry can be controlled effectively using a WSN. The network would consist of many smaller clusters which would then be inter-connected using gateways. This paper aims in developing a cluster which could further be duplicated into desired number of clusters and connected together. Such a cluster would consist of a few nodes used for sensing data and a few nodes that would be used to control various actuations. These nodes in the cluster communicate among themselves and with the user via a central node which acts as a user interface. A WSN that can be used for industrial automation is shown in Figure 1.

The communication in the network is based on star topology and uses Simpliciti protocol. The network can be easily redesigned to fulfill the requirements of the particular industry making it adaptable to the different classes of industries[3].

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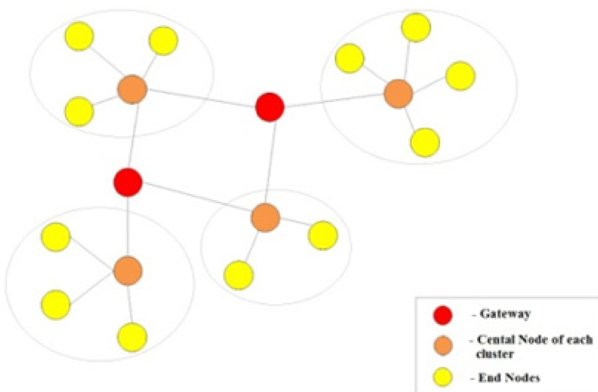

Figure 1. Pictorial representation of a WSN network for industrial automation.

Continuous communication between widely spread locations in industries, flexible installation and maintenance has made wireless communication a boon to industries. Integration of computation with physical processes resulted in Cyber Physical Systems (CPS). CPS can provide effective control over complex industrial processes through a heterogeneous system of sensors, processors and actuators[4]. Clint Heyer has discussed on how the use of remotely controlled industrial robots could enable work to be carried out in regions that are difficult or dangerous for human beings in the oil and gas industry[2]. The discussion surrounds human-robot interaction and the challenges faced there in.

WSNs are built with small size, low cost wireless communication enabled sensors that are deployed to build various monitoring and control networks that are used in diverse fields like industrial automation, process control, agriculture, hospital monitoring systems and so on. Some examples are an automated irrigation system that optimises the use of water for agriculture through a wireless network and also transmitted data through the internet developed by Joaquin Gutierrez and team[1]. Another implementation of WSN is the development of a network that helps in monitoring patients (with chronic diseases) who need to be observed continually but who stay at home was developed by R. Dilmaghaniand group. The network used SimpliciTI protocol and the data was uploaded to the internet for real time analysis in hospitals[5].

In[6] discussed the design of Wireless Sensor Networks (WSNs). They have explained the various measures to be taken to bridge the gap between control algorithm designs and network designs. WSNs have evolved to a great extent through the years[7] and different standards have been developed[8]. WiFi, Bluetooth[9], Zigbee, WLAN are some of the commonly used protocols in industries[10]. Each protocol has its own pros and cons. For example WLAN has a high data rate but low battery life as when compared to Bluetooth or Zigbee[11]. To select a protocol for a particular network many factors such as data size, speed, number of nodes, range and so on have to be considered. Location routining protocols make communication between the nodes effective. In[12] proposed such location routing protocol using smart antennas to estimate nodes positions into the network and to deliver information basing routing decisions on neighbor's status connection and relative position.

In WSNs, energy efficiency and communication reliability are key factors to be looked into[13]. [14]Have showed how zero-power WSNs can be developed using RFID. Real-world implementation of RFID-based strain, temperature, water quality and noxious gas sensors were presented in this work.

[15]Had developed WSN gateway based on Zigbee and GPRS. The data conversion task between ZigBee network and GPRS network have been elaborated and had also proposed a solution of data loss, which is caused by the different transmitting rates of ZigBee module and GPRS module.

[16]Discussed a smart sensor platform which is used for instrumentation and predictive maintenance systems. Experiments were conducted to study the relevant performance metrics such as link delays, bandwidth with varying distance, traffic and packet bursts. These metrics of Bluetooth and WiFi were compared and Bluetooth was considered as the better option for industrial applications. [17]Proposed a new complex system in which the network itself acts as the controller. They called it Wireless Control Network.

Implementation of WSN in industries has helped in the effective automation of different processes. Requirements in the industrial systems differ from the general WSN requirements. In[18] discussed various state-of-art WSN standards to satisfy these requirements of those industries.[19]Discussed the advantages and challenges faced in the implementation of WSN for industrial process monitoring and control. [20]Diverse protocols that can be used for process automation in industries and the activities of international standardisation have been introduced by.

Requirements for WSNs deployed at industrial applications include real time characteristics meeting application and communication parameters. Few state-of-art solutions for wireless communication in industrial automation are available[3]. Presented a locally collaborative control algorithm, based on a distributed estimation to cope with sensory measurement noise and packet loss in wireless communications, which fully exploits the collaborations between actuators and sensors for industrial automation[21].

2. Proposed Methodology

This paper proposes a method to establish a cluster that consists of five nodes. The cluster is connected in star topology. All the end nodes - Node 1 to Node 5 are connected to the central node through RF transceivers. The central node controls all the other nodes. The basic block diagram of the cluster is shown in the Figure 2.

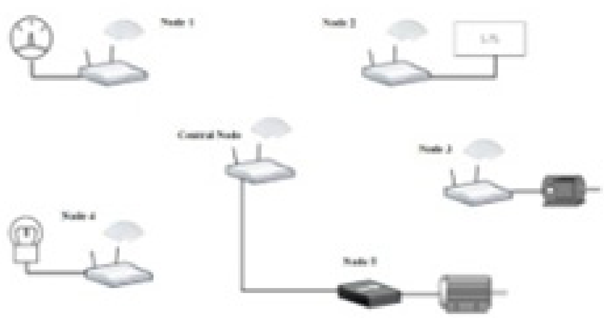

Figure 2. Block diagram of the cluster having 5 end nodes and a central node.

2.1 Central Node

The central node, also called the access point, serves as the hub that connects all the other nodes to one another in the cluster. It is used for network management duties and can also instantiate sensor and actuators in the network. Each end node is connected only to the central node in half duplex transmission mode. The central node is by default in receive state, ready to receive requests from other end nodes and also to receive any alert messages (interrupts) so that the appropriate action can be taken.

When the central node is in need of sensory data or if a command for an actuation (for example turning ON/OFF of a motor) has to be given, the central node moves into transmission state and transmits a packet that has both the address of the destination node and the command to be transmitted to that node. If a message has to be sent to all the end nodes in the cluster, the central node marks it as a broadcast message and it will be delivered to all the end nodes in the cluster. The command maybe instructing the node to send sensory data back to the central node or for an actuation to take place. Once the message is transmitted, the central node changes back to the receive state.

2.2 Sensory Nodes

Node 1 and Node 2 in this cluster are sensory nodes. These sensors can be either digital or analog sensors. They monitor the physical parameters continuously and stores the required values. These nodes are also in the receive state by default. Whenever the central node is in need of sensory data, it sends a command addressing the corresponding sensor node to send its data. Once this command is received by the sensor node, it changes to transmit state, acknowledges the command and sends the required data to the central node. Then it gets back to receive state.

2.3 Actuation nodes

Node 3, Node 4 and Node 5 are actuation nodes in this cluster. Node 5 is connected to the central node using a wired protocol. The purpose of using wired protocol is just as an example to show that different protocols can be incorporated into the clusters to suit the need of an application. If required, the communication between Node 5 and the central node can also be made wireless similar to other end nodes. Hence these clusters are flexible and can be customised to fulfil the needs of an application.

Node 3 is used to control an actuator, say a motor that drives a conveyor belt. Depending on the command from the central node, the motor can be made to run at desired speed, direction and so on. Node 4 is also a similar actuator node that can be used for controlling another actuator for example lighting loads in an industry. All these nodes are in receive state and awaits the command from the central node in order to interrupt any activity that are taking place at the respective nodes. It can be programmed to send back the status of the actuation once the command from the central node is executed.

2.4 Communication between the Nodes

The nodes are connected in star topology with the central node at the centre of the star. All the end nodes in the cluster are connected only to the central node. Any communication between the nodes have to take place only through the central node. Hence the user can access and control the cluster through the central node.

The communication between two nodes in the cluster takes place as follows. Initially the node that is to transmit the message momentarily changes to transmission state and sends the message and once the transmission is over, the node gets back to receiving state. When any node transmits a message, it includes three entities namely, the destination address, the message for the destination node and the source address. Each node has a unique address. All the nodes are by default in receive mode. If a message is sent out, all nodes receive it, compare the destination address to its unique address. If the address does not match, the command is ignored. If the address matches the address of the node, the node decodes the command and carries out the necessary action. The same process is followed if the message has to be sent from the central node to an end node or if the message has to be sent from an end node to a central node. However there is one exception. If the destination address is 0X00, the message is considered a broadcast message i.e. a message to all nodes. This can be sent only by the central node. In this case all the nodes that receive the message, decode the message and carry out necessary actions.

In the above methodology only a single cluster in the network has been explained. Identical clusters that have nodes (variable number of sensory and actuator nodes) to suit the respective applications can be established and the complete network to automate an industrial process is achieved by connecting them together using gateways.

3. Implementation

The fundamental idea of the proposed type of WSN is that it can be easily customised to suit the needs of any industry. This section describes how the above mentioned cluster was implemented.

Each node in the cluster is implemented with the help of the Texas Instruments MSP-EXP430G2 LaunchPad which is used as an interface between the sensor and the RF communication module. The nodes have a MSP430 processor, 16 bit. The communication module is based on the CC110L device, the on-board A110LR09A radio module with integrated antenna operates in the European 868-870MHz and US 902-928MHz ISM bands. This radio module acts as the transceiver in each node including the central node.868-870MHz ISM band was used to establish the network. The LaunchPadwith the RF module is shown in Figure 3. Node 5 uses an ATMEGA processor, 8 bit, which is connected to the central node through a wired protocol.

The wireless protocol used to establish the connection is SimpliciTI, a low power RF protocol from Texas Instruments. It is a flexible protocol that supports peer to peer or star topologies and can be used for low power applications as it supports sleeping devices. Table 1 gives the details of all the end nodes in the cluster.

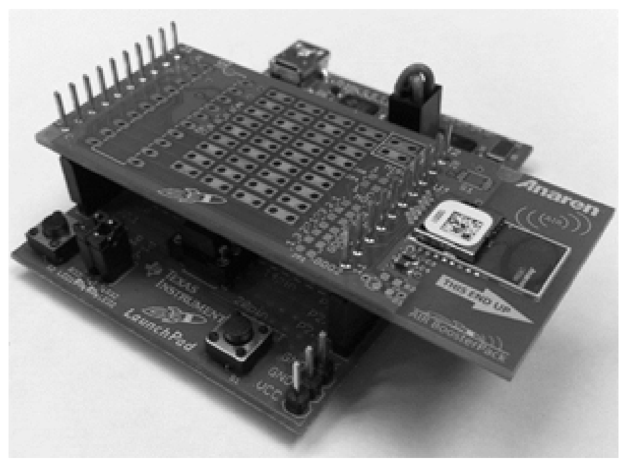

Figure 3. MSP-EXP430G2 LaunchPad with RF module.

3.1 Node 1

This is a sensor node. It is used to monitor the temperature of an entity in a process. The sensor used is LM35, a precision 3 pin integrated-circuit temperature sensor. In

Table 1. Features of all the end nodes in the cluster

Node	Mode of Communication	Communication Protocol	Transmission Mode	Sensor / Actuator controlled by the Node
Node 1	Wireless	SimpliciTI	Half Duplex	LM35 – Temperature sensor
Node 2	Wireless	SimpliciTI	Half Duplex	ADXL335 – Accelerometer
Node 3	Wireless	SimpliciTI	Half Duplex	Stepper Motor
Node 4	Wireless	SimpliciTI	Half Duplex	Light Loads
Node 5	Wired	SPI	Full Duplex	DC Motor

LM35, the temperature is directly proportional to the voltage across the resistor connected to the output pin. The temperature is calculated by measuring the voltage with the help of the MSP430 processor. Hence the node continuously monitors the temperature. Whenever the node is interrupted by a message from the central node, it sends the temperature at that instant is sent to the central node by momentarily changing itself to the transmission state, changes back to the receive state and continues to monitor the temperature.

3.2 Node 2

This is also a sensor node. The sensor used in this node is an accelerometer, ADXL335. Functional block of ADXL335 is shown in Figure 4. The accelerometer has 3 outputs, one for each axis. This node monitors the three dimensional position of an object. We assume the object to be moving only along a single axis. The accelerometer is calibrated to three ranges. If the value of the accelerometer output is within threshold values it is in neutral position. If it exceeds the threshold it is calibrated as inclined position and if the value is below the threshold it is calibrated as declined position. Hence this node continuously monitors the "position" of the system. Similar to Node 1, if it receives a message from the central node, it sends the current position of the system.

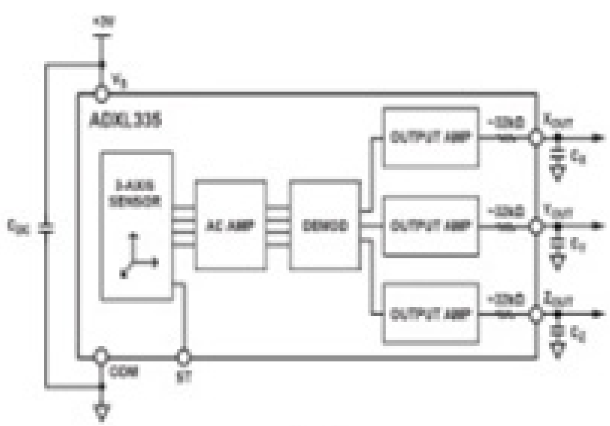

Figure 4. Functional block diagram of ADXL335.

3.3 Node 3

This is an actuation node. The actuator used is a 12V, 0.4A 1.8° step angle stepper motor. The motor is connected to the processor through a H-bridge driver, LM393. The motor is by default in idle state. The processor has the current position of the stepper motor in its memory. On the reception of a message from the central node, it carries out one of the two tasks depending upon the command sent by the central node. If the command is to send the current position of the motor, the node sends the current position to the central node as discussed in nodes 1 and 2. If the command is to move the stepper to a new position, the direction and speed in which the stepper motor has to be driven are a part of the command sent from the central node. The processor then generates corresponding signals so as to drive the motor to the new position in the given direction and speed. Now the new position of the motor is stored in the memory of the processor. Figure 5 shows the implementation of Node 3.

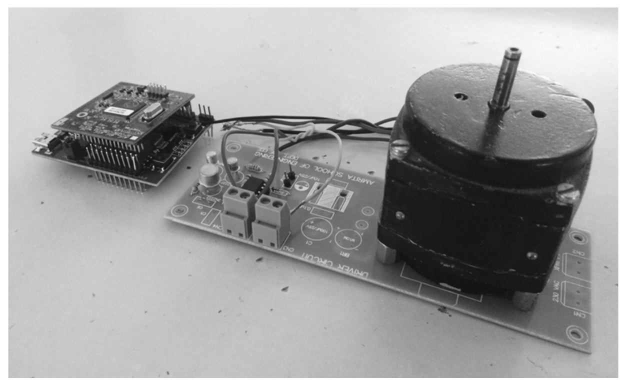

Figure 5. Node 3 connected to stepper motor.

3.4 Node 4

This node can be used to turn On/Off any loads. Here simple light loads are used. The processor has the state of the LED lamps i.e. On/Off in its memory. Similar to Node 3, the node carries out two tasks depending on the command received. It either reports the state of the system or it turns the lights on or off and updates the state in the memory. Implementation of Node 4 is seen in Figure 6.

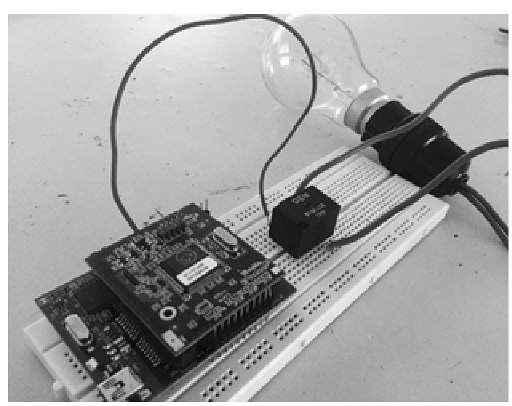

Figure 6. Node 4 connected to a light load.

3.5 Node 5

All the above mentioned nodes are connected to the central node wirelessly thorough SimpliciTI protocol. This node is an exception as it is connected to the central node through wired protocol. The protocol used here is Serial Peripheral Interface (SPI) protocol. This protocol is one of the simplest wired protocols. It supports full duplex transmissionand the speed of transmission is very high as there is no maximum data rate. The transmission (TX) pin of the processor of this node is connected to the reception (RX) pin of the central node. Similarly the RX pin of the node is connected to the TX pin of the central node. The two nodes must have common ground. This node is used to monitor the operation of a 230V, 8.5A, 2 HP DC motor which is continuously running. If the motor comes to a standstill due any reason such as overload or fault an interrupt is generated and an alert message is sent to the central node. Once the problem is rectified, the motor can be switched back on from the central node. The processor is connected to the motor through a power MOSFET which is used to switch the motor On/Off.

All the above mentioned nodes are stand alone devices that are power through a 5V battery. The central node however acts as a user interface to the cluster. The central node is connected serially to a computer via USB cable. The messages from other nodes can be viewed through the serial monitor in the computer. Commands to be transmitted to other nodes are also entered here. As mentioned earlier a message can be broadcasted by giving the destination address as 0X00. If the message has to be transmitted to a particular node, then the address of the destination node has to be specified. Figure 7 shows the implementation of the Central Node and Node 5.

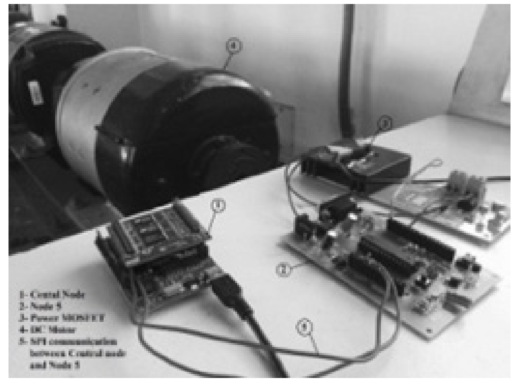

Figure 7. SPI communication between Central node and Node 5.

4. Results and Discussion

A cluster consisting of 5 end nodes, 4 nodes connected through wireless communication and 1 node connected through wired communication was implemented and tested. The central node was programmed to transmit a command every one minute addressing each node individually. The data of the sensors were transmitted back to the central node successfully. The position of the stepper motor was changed by giving sending the desired values from the central node. The lamp was also controlled from the central node. The implementation results are discussed in detail in Table 2 and Table 3.

When the destination address was given as 0X00 and the message sent was "Status", all the nodes sent its corresponding value/status along with the message from which node it was sent. All the above listed cases are the results obtained through wireless transmission.

Table 2. Node parameters during command transmission from central nodes to end nodes

Case	Address of destination node (Sent from central node)	Node Corresponding to destination address	Message sent from Central Node	Status/ Value at the destination node	Action taken at destination node
Case 1	0X01	Node 1	Status	27° C	Send the temperature value to central node.
Case 2	0X02	Node 2	Status	Inclined	Send the position to central node.
Case 3	0X03	Node 3	Status	250°	Send the current position of motor to central node.
Case 4	0X03	Node 3	Position : 300° Direction : Positive Speed : 0.25	250°	Rotate the stepper motor to an extra 50° at a speed of 0.25 revolutions/second.
Case 5	0X04	Node 4	Status	OFF	Send information that lights are off to central node.
Case 6	0X04	Node 4	Turn ON	OFF	Turn on the lamps

Table 3. Node parameters during message transmission from end nodes to central node

Case	Address of destination node (Sent from end nodes)	Node Corresponding to destination address	Current status/ Value at destination	Message sent to central node from end nodes	Message received at to central node
Case 1	0X10	Central node	27° C	From: Node 1 Temperature : 27° C	From: Node 1 Temperature : 27° C
Case 2	0X10	Central node	Inclined	From : Node 2 Position : Inclined	From : Node 2 Position : Inclined
Case 3	0X10	Central node	250°	From : Node 3 Position : 250°	From : Node 3 Position : 250°
Case 4	0X10	Central node	300°	From : Node 3 Position 300°	From : Node 3 Position 300°
Case 5	0X10	Central node	OFF	From : Node 4 Status : OFF	From : Node 4 Status : OFF
Case 6	0X10	Central node	ON	From : Node 4 Status : ON	From : Node 4 Status : ON

The DC motor was subjected to a temporary fault. The motor came to stand still and an error message was sent immediately to the central node. After rectification of the fault the motor was turned on by sending a message "ON" from the central node. The processor generated corresponding gating pulse to the MOSFET thereby turning the motor on. The setup was tested for different case conditions.

5. Conclusion

As proposed a WSN cluster having 5 nodes was implemented with satisfactory results were obtained. The system is easy to implement and maintain. The uniqueness of the WSN is that it is a flexible, reliable and low cost system that can be implemented according to each industry's requirements and can be easily modified in the future. The same cluster can be duplicated and a large network can be created with the use of gateway. The security and Quality of Service (QoS) of the network is currently being worked on. Future work include the establishment of reliable gateways. Further choosing suitable security protocols and reduction of packet losses of the network are areas to be worked on.

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