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Review on Application of Wireless Sensor Networks in Industrial Environment

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Abstract

Wireless Sensor Networks (WSNs) are found as perhaps the most convenient and effective mechanismfor gathering information on the industrial shop floor. Industrial WSN (IWSN) is gaining grounds in many expanding industries as the innovation at the lower layers for gathering raw information from the shop floor. The sensor nodes, aside from gathering information, can likewise be utilized to acknowledge strange conditions happening in the process that is being checked by them. This paper investigates latest developments in the industries in utilizing WSN. It insights regarding how the innovation is creating different segments of WSN in these recent couple of years. The paper likewise portrays the current situation of integration of WSN with industrial measures and later mentions some success stories of overcoming adversity in IWSN. The paper concludes with a short depiction of current focus areas of interest in this field.

Keywords—Wireless Sensor Network, IWSN, Industrial Process Integration, MEMS, Business Process Integration.

I. INTRODUCTION

1.1. Wireless Sensor Networks

Wireless sensor network (WSN) is used to sense the environment like we can get the temperature and humidity by using DHT11 sensor and other parameters like pressure, density, level, movement etc. Sensors are capable of transmitting data to the server or sink with the help of Gateway [1], [2]. WSN consists of deployment of various sensors in large number. As this network is wireless it can be applied to flexible kind of environment but we should take care of count of sensors deployed in particular area as large number can increase the interference and can affect the working of the network collisions to increase as well [3].

Wireless Sensor Networks (WSNs) are networks formed by small, stand-alone, battery-powered processing gadgets outfitted with sensors and actuators. WSNs can be effectively

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conveyed and can be self-arranged to accomplish application objectives. WSN is widely regarded as one of many vital innovations to help universal processing in the future. The nodes of WSN are for the most part self-coordinated and structure in an ad-hoc system to monitor the activities in the target environment and send data to a base station (Figure 1).

Exploration has gained critical ground in settling WSN-explicit difficulties, for example, energy productive correspondence, reliability, fault-tolerant networking, etc. When deployed in large quantities in the field of interest, these sensor nodes act like one homogenous system which can be used to keep scanning parameters of the specific target system. Furthermore, it can report occasions or data utilizing radio correspondence to an exceptional node called sink node which assumes responsibility for handling and sending the data further up the hierarchy in the network and finally also through to the Internet.

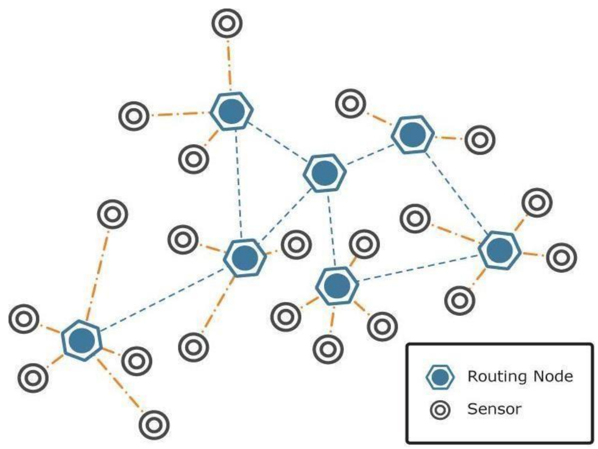

Fig. 1. Wireless Sensor Network

1.2. Application Areas

WSN came into existence during the 1990s and a few applications are being considered and created utilizing WSN frameworks to permit the acknowledgment of omnipresent processing. Noticeable areas in which WSN are being used are-

- **Area Monitoring** – Military Applications to detect enemy intrusion, Land-mine detection,
- **Environmental Monitoring-**Air quality monitoring, detection of a forest fire; landslide, natural disaster, etc
- **Industrial Monitoring**– Machine health, Data acquisition, Alarm
- **Agriculture**– Precision agriculture, irrigation management, greenhouse management.
- **Home Automation**– Intrusion detection, power metering, intelligent equipment, smart-phone interface, etc. Home robotization frameworks empowered home apparatus are used to collaborate shrewdly with its home. For instance, lights are turned on automatically when the proprietor opens a particular entryway.
- **Health Care Monitoring**– for assisted-living residents, remote diagnostics for doctors,

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etc.

1.3. WSN in Industrial Environment (IWSN)

Generally, modern computerization frameworks are acknowledged through wired correspondences.With an expanding period of numerous modern frameworks and the consistently changing mechanical assembling area, minimal effort and astute mechanical mobilization frameworks are sought after to improve the proficiency and efficiency of such frameworks [7]. With the new advances in remote sensor organizations, the acknowledgment of ease installed modern mechanization frameworks has become possible. Remote sensor network have many advantages in industrial process plant like [8] –

- Automatic collection of data from the hazardous or non-accessible area,
- Reduction of cost of data acquisition,
- Adaptability in introducing/updating organization,
- Low arrangement and support costs,
- Decentralization of mechanization capacities,
- Drastic improvement of fault localization and isolation and hence improvement in maintenance efficiency.

The collaborative nature of IWSNs makes it possible to create an exceptionally dependable and self-recuperating modern framework with inherent intelligent-processing capability. Such a system quickly reacts to continuous occasions with proper activities.

A node in an IWSN essentially consists of 4 functions – *sensing, actuating, processing,* and *communicating* [12].Out of these, the actuating function may or may not exist in all nodes but the other three are essential features. Apart from these, there also exist power management functions such as battery pack and energy scavenging system (Fig. 2). In this paper, we aim to explore the most recent developments happening in the field of Industrial WSN with a brief look at future trends in this ever expanding and promising field.

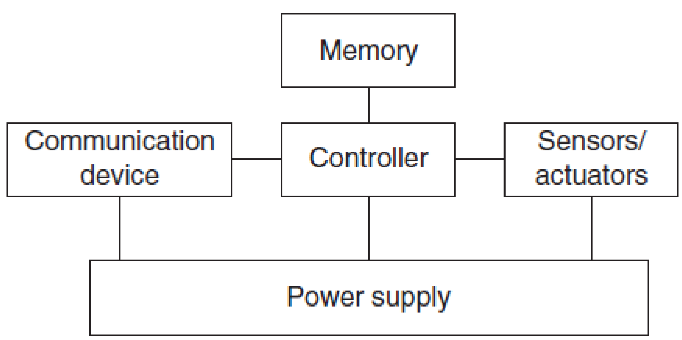

Fig. 2. Components of a WSN Node

II. TECHNOLOGYTRENDS

2.1. Processor and Memory

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Microprocessor or microcontroller is used as a processor for WSN node. But low-power FPGAs are now being increasingly used. The key deciding factor for the choice of a processor is power consumption and power management functionality. The memory capacity and speed also serve as important driving factors. Memory capacity is not an issue if data is to be sent to the sink node frequently.

The most common microcontrollers that were used for WSN nodes were ATMEL ATMega128L, the Microchip PIC16F877, the TI MSP430C1351, the Analog Devices ADuC845 which contains an 8051core, and the Microchip PIC18F4525. With the cost of high-end processors becoming no more a prohibiting factor, ARM processors also became the processor of choice for WSN nodes. “The ATMega128L uses a Harvard architecture with one dedicated stack pointer and three dedicated 16-bit indirect memory access registers. It has a variety of power-down modes. The CPU clock can be stopped, leaving the peripheral clocks running. The CPU oscillator can be kept running – allowing it to restart in under one microsecond [11]. The PIC18 has two power-saving modes – One runs the peripherals but not the core, the other powers down both. The PIC18 also uses Harvard architecture. It contains a dedicated, 32-level function call stack”.

The MSP430 has a single (Von Neumann) address space, with data RAM and program ROM all accessed by a single 16-bit pointer. It has six different power modes – apart from normal operation of fully active, it can also be switched over to a model in which only the core is clocked or only the digital oscillator can be kept running to generate the clock but disable the loop control.

“Berkeley motes, UCLA's Medusa MK-2, and ETHZ's BTnodes use low-cost Atmel AVR 8-bit RISC microcontrollers which consume about 1500 PJ/instruction [4]. A large number of IWSN use these nodes. More sophisticated platforms, such as the Intel iMote and Rockwell WINS nodes, use Intel StrongArm /X Scale 32-bit processors [4]”. ARM processors boast of RISC architecture, low energy operation, flexible power management functions, and a rich set of I/O instruction set.

The FPGA was lagging as a contender for processors in the WSN node due to its high power consumption. However, modern FPGA chips such as Spartan 3L, Actel logo, etc. consume low power. So now we find, FPGA being commonly used on WSN nodes. FPGA based sensor nodes using Spartan device XA3S700A have been realized. The FPGA may either be used as a dedicated signal processor to support the main processor or it may be the main processor itself. WSN nodes using Xilinx FPGA Spartan chips are now being used for their flexibility, low cost, and low power.

2.2. Sensors

Sensor technology is now dominated by MEMS (Micro- Electro-Mechanical-System). MEMS is an element manufactured using micro-fabrication technology to include scaled-down mechanical and electro-mechanical components. The actual elements of MEMS gadgets can shift from one micron to a few millimeters (Figure 3).

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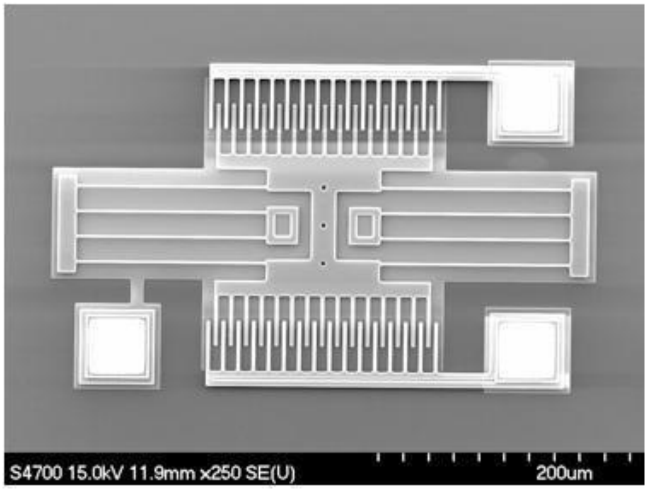

Fig. 3. MEMS Device

Sensors used in an industrial environment are mainly categorized into 5 categories – process parameter sensing (temperature sensor, pressure sensor, flow sensor), Safety related (leakage detector, smoke detector), Environmental (luminosity sensor, humidity sensor, specific gas sensor - O2, CO, N, etc), proximity or movement-related (motion sensor, vibration sensor, acceleration sensor) and In-machine sensor (stress sensor, pH sensor, etc).

The Miniature machined sensors have exhibited exhibitions surpassing those of their full-scale partners. The presentation of MEMS gadgets is outstanding, and their strategy for creation has similar points of interest of the clump manufacture methods utilized in the coordinated circuit industry like low per-gadget creation expenses and high dependability. Therefore, it is conceivable to accomplish brilliant gadget execution at a moderate ease level. Because of this, silicon-based discrete miniature sensors are increasingly being used as an inherent part of a WSN node in an industrial setup.

On the actuator front also MEMS devices are scaling new heights. The MEMS innovative work network has shown various miniature actuators including miniature valves for control of gas and fluid streams; optical switches and mirrors to divert or regulate light pillars; freely controlled miniature mirror clusters for shows, miniature resonators for various applications, miniature siphons to create positive liquid pressing factors, miniature folds to tweak air streams on airfoils, etc.

2.3. Energy Scavenging Techniques

A WSN node is supposed to work for a long time without any need for change for battery, but as the organization's increment in number and gadgets decline in size, the substitution of exhausted batteries won't be useful. Utilizing a battery enormous enough to endure the whole lifetime of the remote sensor gadget will rule the general expense and size.

Even though the performance of battery technology is improving and the power requirement of electronics is reducing, these are unable to keep pace with the ever-increasing demands of many WSN applications. There is a need to find innovative ways to either distribute power to the nodes or to empower a node to produce or “scavenge” its capacity. The idea is to extract useful

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electrical energy from existing environmental sources. Force searching sources are generally portrayed by their capacity thickness as opposed to energy thickness on account of energy repositories. Energy stockpiling gadgets have a particular energy thickness, and the normal force which they can give relies upon the lifetime over which they work. However, then again, the energy gave by a force searching source is dependent on the duration for which the source is operating continuously.

There are mainly five sources from where energy scavenging is done in an industrial environment –

- **Solar Energy** -Sunlight based cells are largely being used to charge a rechargeable battery. They can be straightforwardly associated through a basic arrangement diode to keep the battery from releasing through the sun based cell. Meager film undefined silicon or cadmium telluride cells give about 10% effectiveness.
- **Thermal Gradient** –Normally happening temperature variations can give methods by which energy can be searched from the climate. Numerous analysts are utilizing thermoelectric generators that misuse the Seebeck impact to produce power.
- **Wind / Air Flow** –This method is not suitable for WSN since this mode of energy conversion gives reasonable efficiency only when operated at a large scale.
- **Pressure Variation** – Variations in pressure factors can be utilized to create power. Environmental pressure factor changes for the duration of the day. The adjustment in energy for a fixed volume of ideal gas because of an adjustment in the pressure factor is given by $\Delta E = \Delta PV$. An atmospheric temperature change of 10^o C occurring in a day gives approx. 17 $\mu W/cm^3$ for He gas. This technique is still to be exploited for WSN nodes.
- **Vibrations** – Vibration-to-power transformation offers the potential for remote sensor nodes to act naturally supporting in numerous conditions. Low-level vibrations happen in numerous conditions including huge business structures, cars, airplanes, boats, trains, and mechanical conditions. A blend of hypothesis and analysis shows that around 300 μW/cm3 could be created from vibrations that may be found in such conditions.

2.4. Communication

The IEEE 802.15.4 standard is the basis for most WSN arrangements that exist in the market today. Additionally, the 802.11 standard is the establishment for WLAN applications. The two norms show low force blasting of energy and work in the Industrial Scientific and Medical (ISM) band of 2.4 GHz band. This band is significant because of numerous reasons. To start with, this band doesn't need the utilization of a legislative permit for its use in many parts of the world, giving worldwide accessibility. Second, it is has a transfer speed of 83.5 MHz, wide enough for most WLAN and WSN applications. At last, it includes the best spread qualities accessible for worldwide unlicensed groups. Due to the common frequency band, the coexistence of multiple nodes needs to use diversity techniques for proper operation. Time diversity, Frequency Diversity, and Path diversity are commonly used techniques [9].

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2.5. Mobility

The examination has indicated that sensors which are closer to the information sink, exhaust their battery power quicker than those far separated because of their weighty overhead of transferring messages. On the contrast, sensors far separated from a sink and close by sensors are shared by additional Sensor-to-sink ways, which have heavier message hand-off burden, and accordingly devour more energy. If all the sensors around a sink run out of energy, the sink will be detached from the organization; if all sinks are disconnected, at a point, whole organization comes to a standstill.

Recently, sink versatility has been abused to diminish and adjust energy consumption among sensors. Sink portability can successfully improve network lifetime without bringing previously mentioned negative effects on the organization. From a data-gathering perspective, there are two types of WSN – delay-tolerant WSN and Real-Time WSN. Both types are used in industrial scenarios depending on the application.

In delay-tolerant WSN, the sink visits each node to collect the data [10]. For example, a shop floor employee with a handheld unit acting as a sink goes around the plant and collects process data from various sensors located in the field. This strategy dispenses with the message transfer overhead of sensors and consequently enhances their energy investment funds. In any case, it has huge information assortment inertness for the sluggish sinks. To diminish time delay, sinks may visit a couple of chosen rendezvous focuses, where sensor readings of all information sources are cushioned and potentially summed up, evading long travel distance at an energy cost of multi-jump information correspondence. Progressively, WSN sensor readings should be conveniently gathered by sinks. With viable portable sink-based information dispersal (i.e., source-to-sink directing) strategies, network lifetime can be drawn out by adaptively migrating sink nodes to positions with the biggest energy acquire as the organization advances.

2.6. Protocol Standards

“ZigBee, a mesh-networking standard based on IEEE 802.15.4, is now established as radio technology for industrial control and monitoring, embedded sensing, and building & home automation. Due to its extremely low power consumption and support for several different topologies, it is the most sought after technology for several sensor network applications [7]. Wireless HART is an extension of the HART protocol and is specifically designed for process monitoring and control. It employs IEEE 802.15.4-based radio, redundant data paths, frequency hopping and retry mechanisms”.

“Bluetooth has been considered as one possible alternative for WSN implementation. However, due to its high complexity and inadequate power characteristics for sensors, the interest in Bluetooth-based WSN applications has decreased. With data rates of up to 1 Mb/s (5–10 meters) in the 2.45-GHz band, Bluetooth-Low-Energy specification, which is a part of the Bluetooth specification, is now emerging to address devices with very low battery capacity. [7]”.

“6LoWPAN standard aims for standard IP communication over low power wireless IEEE 802.15.4 networks utilizing IP version 6 (IPv6) [7]. The advantages of 6LoWPAN from the industrial point of view is the ability to communicate directly with other IP devices locally or via

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an IP network (e.g., Internet, Ethernet). It can utilize existing architecture and security, established application-level data model and services (e.g., HTTP, HTML, XML), established network-management tools, transport protocols, and existing support for an IP option in most industrial wireless standards".

ISA100.11a is a wireless networking technology standard developed by the International Society of Automation (ISA). This standard envisages field sensors to be used not only for monitoring, alarm, and control but also that can be vertically integrated from field to business systems. This standard applies to almost all industries like material processing, fluid processing, discrete manufacturing, etc.

2.7. Platforms

TinyOS has now arisen as the working arrangement of the decision in exploration identifying with control of mechanical remote sensor organizations. Its seclusion and C-based sentence structure intend to give a shallow expectation to absorb information to an accomplished developer [11].

III. INTEGRATION OF IWSN WITH BUSINESS PROCESSES

ISA-95 defines 5 levels of control in any industrial plant [8]. Levels 0, 1, and 2 are the levels of process control. Activities at these levels focus on control of equipment infield, to execute production processes. Level 3 is the level of MES (Manufacturing Execution System) activities. This Level consists of activities required for preparing, monitoring, and completing the production process like quality management, detailed scheduling, production tracking, maintenance, etc. The highest level (level 4) is the level of ERP (Enterprise Resource Planning) systems. This level takes care of financial and logistic activities that are not straightforwardly identified with creation. For instance long haul key arranging, Marketing and deals, obtainment, and so on.

3.1. Need

There is a growing need for integrating WSN with the business processes at other higher levels for the following reasons –

- Today all the businesses are looking for Enterprise Application Integration so that the business can be managed efficiently and profitably. For this, the top managers need to have exact data from the shop floor in real-time. This is possible only if the data collector layer which is WSN is integrated with the top layers.
- There are shift in paradigm to begin EAI defense endeavors with the successful top-down business-arranged examination which will empower a durable business incorporation system that is upheld by, rather than directed by, specialized and information coordination methodologies.

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- By integrating the WSN layer with higher-level business processes, we achieve integration of top layer business strategy with low level implementation of those strategies thus saving lot of wastages and re-work.

3.2. Challenges

Even though there have been successful efforts towards integrating IWSN with business processes, there are a few challenges in this -

- There is still absence of significant level, model-driven programming devices for Wireless Sensor and Actuator Network (WSN) applications.
- The coordination with big business administrations requires huge exertion and mastery in installed programming of WSNs.
- Associations are hesitant to introduce enormous scope WSNs, as this actually requires huge, exorbitant, low-level programming of detecting and activation rationale for the WSN.
- Setting up the correspondence channel between a WSN and an endeavor's data framework requires a considerably bigger arrangement of innovations and physically composing of custom code. Area specialists normally do not have the essential low-level programming abilities.

3.3. Implementations in Industry

Regularly, the mix of WSNs into BPs depends on the summon of administrations uncovered by the organization. This outcomes in a displaying approach that utilizes the organization as set of accessible procedure on which a cycle can be built, yet that precludes the programming of the WSN itself. This restricts the likelihood to characterize custom WSN rationale to be done by the organization as a component of the cycle. With all things considerations, the key thought is to utilize a business cycle displaying documentation that permits an area master to program both the BP and the genuine organization rationale, without the need to know and determine all the low level subtleties. Such a cycle model is later used to determine the code that will be executed by the WSN. Thus, the WSN rationale is completely indicated at the cycle level. This definitely improves the simplicity of programming of WSNs by empowering the graphical displaying of WSN applications, leaving low-level subtleties to a model compiler and a run-time framework [6].BPMN (Business Process Modeling Notation) is a significant development towards the efforts of standardizing WSN programming at Business Process Layer. The EU-funded "makeSense" project enables Business process integration with WSN by devising programming abstractions to express the high-level WSN functionality within existing concept of business process model. Such integration allows seamless specification of the WSN behavior and the surrounding business process [5].

Furthermore, Cao et al. [18] researched coverage and lifetime issues by proposing a probabilistic 3-D sensing model and simultaneously deploying directional sensor nodes and relay nodes in a 3-D industrial WSN (IWSN) situation with obstacles (i.e., equipment); however, they did not consider security issues or use a multi-objective optimization evolutionary

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algorithm (MOEA) [19]. Zan et al. [20] transformed the security issue into a sensor node placement problem and exploited optimization methodologies for settlement.

IV. REAL LIFE DEPLOYMENT OF IWSN

Industrial wireless sensing, deployments of more than 20 nodes were rare about a decade back. But today, with increasing network densities, several sites are deployed with 3,000 or more nodes. This is a result of reliability of today's WSN systems, increased awareness and education, maturing wireless mesh solutions, and fast-paced migration towards industry standards, such as WirelessHART and ISA100.11a. IWSN is proving to be disruptive technology. It is making an impact on industrial automation by extending wired sensor networks and creating innovative sensing and control solutions.

Some of the major deployments of IWSN in industry today
are –

- SABIC, Saudi Basic Industries Corporation, one of the world's biggest producers of synthetic substances, manures, plastics, and metals, installed WSN capable of monitoring 2000 control loops across the plant to eliminate hydrogen swings and to achieve reduction in nuisance process alarms, thus improving efficiency and productivity [13].

- ACS sugar refinery near Savannah, GA, decided to install IWSN to monitor, in real time, bearing temperature to avoid potential danger of an explosion which had proved to be fatal earlier. The heating of bearings on misaligned sugar conveyor system potentially introduces an ignition point. Emerson Smart Wireless solution is used for every one of the nine transport lines. Every transmitter peruses four bearing temperatures and incorporates into the DeltaV control framework by means of fieldbus to give programmed location, disturbing and moving of temperature, pace of progress and deviation in temperature [14].

- Barrick, the greatest gold maker on the planet with huge land positions on probably the most productive mineral locale, is the proprietor of the Zaldivar Plant in Chile. The cycle used at the mine to separate copper mixes from mineral is lixiviation (or filter cushions). Sulphuric corrosive is a basic and costly segment simultaneously. Barrick needed a savvy approach to improve throughput with better control of the sulphuric corrosive's appropriation by checking pressing factor and pH. They utilized IWSN comprising of 50 remote differential constrain gadgets to address this difficulty. Oneself getting sorted out WSN nodes dependent on Wireless HART standard cover a region of 2km by 650 meters and sends pressing factor and pH factors to the principle control framework [15].

- Fields Exploration and Production Company (PXP), a free oil and gas organization in USA, required exact control of infused steam to improve the impact of warm incitement on creation. There was no force or correspondences in the region of the wells so an IWSN solution with ten wireless pressure transmitters and a sink connected to TCP/IP

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was deployed. The company reported increased profitability due to optimal use of steam [16].

- RWE, Europe's leading electricity and gas company, required an answer that didn't need establishment of new
- Cabling. Installation of five Smart Wireless networks and more than 100 wireless measurement devices have increased visibility into the overall process, thus enabling the plant to run closer to its capacity leading to higher operator efficiency and safety [17].

V. CURRENT FOCUS AREAS OF RESEARCH

IWSN is poised to take the ubiquitous computing paradigm to the industrial shop floor. Even though the applications are still emerging, following are certain specific areas of IWSN where the current research focus seems to be concentrating on

- Integrating IWSNs into Web Service-Based Business Processes – WSNs are imagined to turn into an essential piece of the Future Internet where they stretch out the Internet to the actual world. Consistent mix of IWSN with existing, generally sent SOA (Service Oriented Architecture) innovations, for example, XML, Web Services and the Business Process Execution Language (BPEL) is focus of many researchers.
- Security and Authentication over WSN – There is a growing need for security of the WSN from unauthorized access and intrusion attacks. IWSN is used on an industrial shop floor where its availability is of utmost importance. Any denial of service attack on the network could lead to catastrophic effects on the operation of the plant. Parcel of examination work is going on in this field to explore the various options of how to make the IWSN more secure.
- Data aggregation on IWSN – The main concern of IWSN is using available power efficiently so that the node could last long. The power dissipation of a node depends heavily on volume of data transacted (transmitted and received) by the node. Reduction in this data affects the energy budget of a node drastically. Hence a lot of research is concentrating on data compression, Alarm filtering and en-route data dissemination algorithms on IWSN.
- Model based programming of IWSN – Industrial Area specialists commonly come up short on the fundamental low-level programming abilities to program embedded systems in IWSN. They are used to work on models mapped on a business process. There is research focus on creating special set of tools needed to make it easy for the process modelers to program the IWSNs.

VI. CONCLUSIONS

Industrial applications of WSN are increasing over last few years and there is a growing trend of replacing existing wired sensors with IWSN. There is innovative research happening in some of the frontier areas of IWSN like data dissemination, energy scavenging, communication load reduction and model-based programming. Real-life deployments of IWSN are far and many and show a potential to increase in coming years. We have surveyed in this paper the overall

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technology trend in Industrial WSN. We have also highlighted some of the key research areas which are in great demand today and also described a few real life deployments of IWSN which have yielded economic benefits to its stake holders, There are still many issues to be resolved around IWSN applications like fault tolerance, robustness etc before it can be accepted as preferred technology by the process industry.

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