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UTILIZING ACTIVE RFID ON WIRELESS SENSOR NETWORK PLATFORM FOR PRODUCTION MONITORING

Che Zalina Zulkifli*, Nursyahida Mohd Noor, Ahmad Zamzuri Mohamad Ali, Siti Norainah Semunab

Computing Department, Faculty of Art, Computing and Creative Industry, Universiti Pendidikan Sultan Idris, Tanjung Malim, Perak, Malaysia

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*Corresponding author
chezalina@fskik.upsi.edu.my

Abstract

In today's manufacturing environment, delay in monitoring output performance might cause production mess in the industry. Therefore, an efficient communication and real time feedback to maximize uptime and improve productivity seems vital. Adapting the capabilities of RFID technology and Wireless Mesh Sensor Network (WMSN) through web-based monitoring system might solve this problem. Thus, an embedded system namely ERFIDC was developed as a potential solution in addressing this demand. This paper reports the proposed embedded system architecture and evaluation of its reading range in point-to-point and WMSN setup at the selected production plant.

Keywords: Production monitoring, real-time, Wireless Mesh Sensor Network, RFID

Abstrak

Pada masa kini, dalam industri pembuatan, kelewatan pemantauan hasil pengeluaran telah menyebabkan ketidak aturan dalam pengeluaran industri. Oleh itu, komunikasi yang cekap dan maklum balas masa nyata perlu untuk memaksimumkan tempoh masa dan meningkatkan produktiviti sangat penting. Penggunaan teknologi RFID dan Wireless Sensor Network Mesh (WMSN) berasaskan pemantauan menggunakan web sistem dapat menyelesaikan masalah ini. Oleh itu, sistem gabungan iaitu ERFIDC dibangunkan sebagai penyelesaian yang berpotensi dalam menangani permintaan ini. Kertas kerja ini melaporkan *embedded system architecture* yang dicadangkan di dalam sistem dan penilaian pelbagai bacaan dalam *point-to-point* dan setup WMSN di kilang pengeluaran yang dipilih.

Keywords: Production monitoring, real-time, Wireless Mesh Sensor Network, RFID

1.0 INTRODUCTION

Wireless Mesh Sensor Network (WMSN) can significantly extend network coverage to regions that are difficult to reach with conventional wired networks (e.g. presence of environmental obstacles), while offering data rates up to 108 Mbps [1]. In recent years, WMSN has emerged with the increasing use of wireless sensor network in industrial environment. The total revenues for wireless sensors and transmitters in industrial applications in 2009 reached $526.7 million [2]. This market revenue is likely to reach $1.8 billion in the next four years [2]. The size of the wireless pressure sensors and transmitters market alone is expected to reach $132.9 million in 2012 [2]. This clearly indicates the emergence of the sensor technologies in the industries.

Wired connections might cause cluttered environment, which could contribute to uncomfortable working condition. Moreover, running cable to new or relocated equipment can interrupt production, especially in large industrial settings. Cabling, distance and cost limitations associated with wired system setup could hinder the industries in preferring this solution. Consequently, these hardwiring drawbacks have led many to seek a longer range and more flexible alternative with wireless sensor network. Wireless sensor network is a network that consists of spatially distributed nodes comprising sensors that monitor physical or environmental conditions, such as temperature, humidity, speed, pressure, motion or pollutants, at different locations [3]. It is a network with low cost sensing and processing devices that are connected through a wireless medium in order to perform distributed and cooperative sensing tasks [4]. The use of ZigBee mesh network in industrial manufacturing is still rare, specifically in production zone. This might due to the absence of appropriate architecture for this specific purpose (i.e. production). Mostly, users consider wireless sensor network as a standalone technology which can be operated with its own components [5]. However, this assumption is not relatively true. Apparently, integrating wireless sensor network with RFID technology offers promising benefit in improving accuracy, reducing number of transaction errors, better asset tracking and easier detection of counterfeit products [6]. By utilizing sensor networks in industrial process control can significantly reduce the cost and even save lives [7].

RFID does not provide information about the condition of the detected objects; in contrast, WSNs not only provide information about the condition of the objects and the environment, but also enable multi-hop wireless communications. Combination of RFID technology and wireless sensor network could provide identity and condition information of items and it is a real-time application, which is best to be used for monitoring. Taking this into consideration, WMSN system architecture specifically for production zone was developed in this study, mainly through enhancing and up scaling active RFID technology.

The proposed system architecture comprises WMSN, active RFID, counter system and web-based monitoring system, which is applicable as real time output monitoring system in industrial assembly. Most of the traditional wireless systems, such as cellular telephone networks and wireless local area networks (WLAN), use either point-to-point or point-to-multipoint network topologies [8]. However, mesh network topology will be the topology of choice in the proposed architecture, since mesh network is a suitable model for large-scale networks with wireless sensors distributed over a geographic region [3].

2.0 SIMILAR WORK

The history of RFID is integrated with the history of other automatic data capture devices, such as bar codes. RFID was first used during the Second World War in extended range systems. In the 1970s, RFID was developed for applications such as personnel access, animal and vehicle tracking, and factory automation. In the 1980s, RFID technology became fully implemented in various parts of the world for transportation and personnel access, and then the 1990s saw a wide-scale deployment of electronic toll collection in the United States, as well as the installation of over 3 million RFID tags on rail cars in North America [9]. There are currently many commercial applications of RFID for monitoring and tracking systems, which in turn require improved accuracy and efficiency.

Literature shows that RFID is already driving shifts in supply chain and retail capabilities by improving logistic efficiency and reducing costs. In addition, both a car-tracking system for charging and a central car-parking tracking system have been developed, which can monitor the efficiency and functionality of RFID-enabled parking-lots [10]. RFID tags (e-tickets) have also been used to speed up identification in conferences and exhibitions, and the authors provide evidence that the application of RFID to Exhibition Logistics is workable. Some intelligent RFID applications have been suggested, such as collecting customer data in the retail industry as well as access control.

The proposed study is closely related to the work of [11], which designed an application that integrates RFID with wireless sensor network technology. Young design, develop and implement the Power-Facility-Management-System with RFID tags and sensors in Korea Electric Power Corporation (KEPCO) [12]. However, the significant differences of the proposed architecture and Young *et al.* are, Power-Facility-Management-System uses LAN protocol communication between the nodes to the access points using TCP/IP, whilst the proposed application is up scaling an active RFID with WMSN infrastructure using ZigBee platform. Wu *et al*. [13] work attached the RFID reader to the hand-held device. Whereby, after the inspections, the operators need to connect the hand-held device to the computer in order to monitor the output. Meanwhile, the proposed system architecture introduced in this study embeds WMSN, active RFID, counter system and web-based monitoring system as an application that provides real time output monitoring in industrial applications.

Wireless mesh network represents an effective solution for indoor and outdoor applications, due to its extensive network coverage. The conventional wired network infrastructures have limitation in reaching certain physical areas due to the environmental factors and it also imposes higher cost in installation aspects. Some current applications of WMSN are presented in Table 1.

Table 1 Current applications of Wireless Mesh Network [14]

Applications Areas	Example	Indoor	Outdoor
Hospitality and entertainment	Resorts, shopping centers and museum	✓	✓
Warehousing and manufacturing; this applications involves integrated RFID system	Factories, moving equipment, monitoring people and products, conveyor system, machine control and alarm system	✓	
Transportation and shipping; this applications involves integrated RFID system	Moving peoples or pallets, inventory tracking, security and logistics	✓	✓

Applications Areas	Example	Indoor	Outdoor
Public Internet Access Hot zones	Public guest network, restaurant, offices and hotels	✓	✓
Government, Public Safety and Military; To connect their Computers in field operations. It enables troops to know the locations and status of every soldier or marine, and to coordinate their activities	United State military forces, community networks and projects	✓	✓
Educational	Universities, schools and colleges	✓	✓
Health care; this applications involves integrated RFID system	Hospitals, clinics and pharmacies	✓	✓

"✓" Applicable

Adding to these, Chandra-Sekaran, *et al.*, proposed a new system based on a location-aware WSN with RFID-tags, to overcome emergency response impediments like overflowing victims, paper triaging, extended victim wait time, and transport; also to assists the emergency responders (ER) in providing efficient emergency response [15]. The authors developed an energy efficient ZigBee-ready sensor node to collect real time data for patient/emergency doctor tracking. The ZigBee board included a power supply, TI (Texas Instruments) CC2431 System on Chip (SOC), Arm Processor, chip antenna, and high and low frequency oscillators [15].

Medagliani *et al.*, proposed an innovative radio-switched Zigbee network, where remote sensor nodes are selectively turned off [16]. Additionally, the radio control was based on the use of RFID technology, leading to hybrid ZigBee/RFID architecture. The authors considered two logically overlapped networks, ZigBee and RFID, in order to maximize the network lifetime by turning off all nodes that are not needed. Furthermore, they proposed a deep sleep algorithm, which picks the nodes to be activated by their residual energy. The authors used simulated environments (Opnet Simulator Structure) for their tests, and the RFID reader initiated and managed the network, while the tag needed to be synchronized to the RFID reader [16].

Basically, a WSN allows low-power, low-cost, and wireless multifunctional sensor devices that communicate over short distances and are small in size [17]. Sensing and communication are the two major functions of the WSN, while energy conservation and routing mechanism are two hot topics [18]. A WSN is composed of a significant number of sensor nodes that can be deployed on the ground, in the air, in vehicles, or inside buildings [19]. A sensor node consists of a sensor to monitor and control physical parameters at different locations, a radio transceiver, a microcontroller and a power source. The WSN node microcontrollers are reprogrammable, which enables easier modification to suit application requirements [20]. Currently there is a huge need for WSN, especially a robust protocol enabling self-configurable devices that can form a self-healing network. The bandwidth requirement for a wireless personal area and sensor networks is not prohibitively high; 250Kbps is more than enough. Meanwhile, the coverage area of wireless communication is restricted by the ability of the wireless device used, and a device that gives a large coverage area will be very costly. Also, the more powerful a wireless device is, the more power it will consume. Moreover, it will produce high amounts of electromagnetic radiation, which can be hazardous to human health [21].

Even though most of the previous works attempted to overcome the problems currently troubling RFID readers, a study tackling all the aforementioned problems in a real time environment is still lacking. Thus, the goal of this project is to demonstrate the ability to create a new embedded architecture for RFID system network for the monitoring purpose in the manufacturing industry, utilizing the ZigBee data communication standard that facilitates communication between the RFID elements on one hand, and between the RFID reader and the work station on the other hand. Also to this end, a multi-hop active RFID tag must be designed and implemented to address the limitations of power consumption. Then, an analysis of the system should be presented, demonstrating reliable communication in terms of latency, power consumption, transition overhead, and throughput. Numerous experiment series have been done, however, in this paper, the experimental result is mainly focused on the capabilities of the read range.

3.0 SYSTEM ARCHITECTURE

Figure 1 depicts the complete system's components and interaction namely ERFIDC. Embedded counter system with RFID tags installed in multiple production lines will communicate via WMSN with the readers and database server which finally could be analyzed and monitored through internet or intranet service.

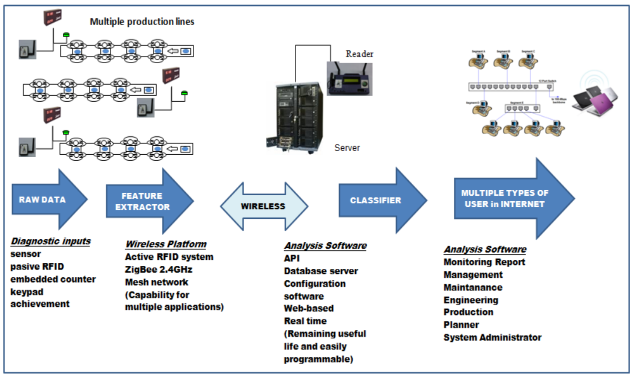

Figure 1 ERFIDC Architecture

RFID is automated contactless technology, which are capable in capturing and transmitting data using electromagnetic radio frequency (RF) wave [12]. There are two categories of RFID technology, namely passive RFID and active RFID. In this study, the active RFID system was mainly used, which was deemed suitable with the application's requirement; that is enhancing the system to function as wireless sensor network. Typically, RFID system consists of three major parts that are interlinked in an appropriate relationship. These three major parts are reader, tag and host computer or microcontroller for customized embedded system.

3.1 Counter System Architecture

In particular, the function of RFID tag embedded in the counter system architecture is to capture the input from the counter, which is attached at the completion segment of the production line. The output of the counter system is connected to the input of microcontroller. Figure 2 shows the mechanism of serial communication interface between the counter system and the active RFID tag in block diagram. The key component used in the embedded system to process and enable communication between counter and RFID tag is microcontroller; that also acts as a brain for the counter to function with USART serial communication.

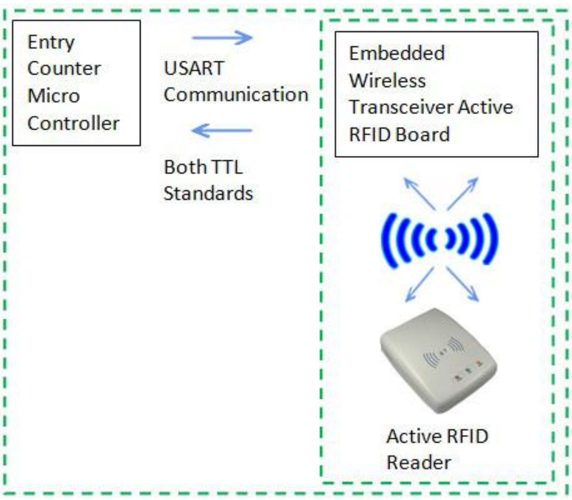

Figure 2 Serial Communication Mechanisms for Proposed Embedded System

3.2 Wireless Mesh Sensor Network (WMSN)

The proposed WMSN application operates in the IEEE 802.15.1 PHY layer and the ZigBee platform operates in the IEEE 802.15.4, which are the standard protocol for short range wireless communication. Whilst, RFID technology uses RF technology for communication, which typically used for object identification and tracking system. In this proposed system, a new design by integrating RFID technology and WMSN was developed to suite the indoor application, primarily in providing robust and efficient data delivery in the manufacturing environment. In deciding which standard is the best choice, the accessible wireless standards are evaluated based on preferred criteria. For monitoring and tracking application of RFID system, reliable end-to-end communication, low power consumption, end-to-end delay of packet (latency), delivery ratio (throughput) and long range are crucial requirements, while support for a large network size and low cost are additional advantages [22]. Some applications need to constantly sample the environment and transfer many packets. In other applications, such as fire detection, it might be enough for a single report to be received by the sink [4], [23].

Taking these into consideration, the WMSN developed comprise three main components, which are ZigBee end device or tag (ZED), ZigBee reader or coordinator (ZC) and ZigBee router (ZR). ZigBee is sufficient for the proposed architecture, since it offers a bit rate of 250 kb/s, which is suitable data transmission rate for the RFID system designed. The system designed in this work is an embedded system, whereby data delivery depends on the input from the counter system and the RFID tag or ZED. The complete system is composed of multiple integrated counter system and tag, a small number of routers, which are applicable to expand the communication and one reader that is connected to the host computer via USB connector. Figure 3 depicts the hardware-dependent function working collectively in an integrated mesh network.

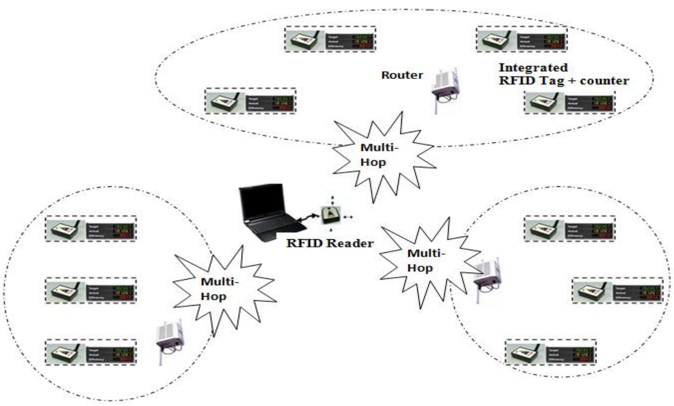

Figure 3 Embedded RFID with Counter and WMSN

RFID tags can be embedded in different types of sensor to monitor the change of conditions, such as temperature and pressure. In this work, RFID tags are embedded in the counter system that functions to transmit data in real time, specifically the output in production zone. Referring to the ZigBee components, this is the role of ZED. Meanwhile, ZigBee RF includes a transceiver, which transmits unique identification number to identify the nodes. Therefore, the counter system function to process the input data, and then passes it to the ZED and thus, RFID system shall function spatially with multi-hop networking and sends the information to the RFID reader. The activity framework of RFID reader works as such a signal is received by one ZED directly; this is called a single hop. ZigBee also supports synchronous multiple nodes communication in multi hop setup.

Working with multiple sensors in a network, whereby each sensor forms a node on the network, which send or receive data to and from any other nodes, enables the nodes to form a mesh or an ad hoc network that can self-configure and self-heal, maximizing reliability and minimizing the cost of network deployment and maintenance. ZigBee mesh network permits data packets to pass through multiple hopes in a network to route data from any source in any direction in different average traffic load [5]. In the proposed system, the RFID reader is capable to communicate with any ZR in the network and vice versa.

As well known, Zigbee system offers sleep mode for effective power saving, since most of the active RFID application uses battery. However, in this design, the ZED power supply is no longer dependent on battery. Hence, the power management for the ZED is included within the counter system designed. Whereby, the power supply for the RFID reader is provided by the host computer.

3.3 Radio Frequency Identification (RFID)

RFID consists of a transponder, a reader, and a software application. The RFID tag has a microchip with data storage, logical functions, and antenna, which receives radio frequency waves produced by the reader or transceiver to permit wireless transmission of data. The RFID reader consists of a radio frequency module, a control unit, and a coupling element to question the tags via radio frequency communication.

Readers are usually connected through middleware to a back-end database. The RFID middleware refers to special software that park between the reader network and the application software to help on processing significant amount of data generated by the reader network. Middleware is responsible for cleaning the data, eliminating false reads apart from performing aggregation and filtering of data. By monitoring multiple readers, middleware can also detect the movement of RFID tags as they pass from the read range of one reader to another.

RFID technology is available in two main types: passive RFID, where the tag is small, low cost, low range, and relies on the reader to provide the energy to power the tag; active RFID, the tag is larger and offers greater detection range and rich data capacities because it contains its own power source (i.e., battery, or any energy harvesting system). The application of RFID now not only meant for person to machine or machine to person, but more demanded for machine to machine communication. Thus, the trait is appropriate to be used in proposed system since it is applied for industrial automation environment which is prompting the communication market to adopt machine to machine communication via RFID.

Real time monitoring system application in industry may require long range tag detection. Since Active RFID has the ability to transmit on its own accord on a regular basis for a long range hence active RFID is the choice. It also provides larger memory capacities, making it a solution to the industry automation. In this proposed system, we are applying in-house built in, 2.45 GHz Active RFID which adopts through the Zigbee technology to support wireless mesh network.

Both ZigBee and active RFID use RF technology for communication, but each has a different implementation. ZigBee is not a substitute for active RFID, but is actually a network platform enabling device. Active RFID tags can communicate data at long range and operate under harsh conditions for years at a time without human interference. They can be integrated with different sensor types to monitor the change of conditions such as temperature, humidity, and pressure. This is similar to the components of ZED in a ZigBee system.

A ZigBee radio includes a transceiver, which sends a unique identification number, a microprocessor to store and process data, and sensors attached to the device link tool. The overall activity of an active RFID reader is received by a number of active RFID tags at one time in a single hop, although clarification may be directed to a single tag. In this application, it was demonstrated that active RFID technology has many advantages, such as capability of embedded with counter system, real-time collection of large quantities of data with high efficiency and accuracy, contactless collection, etc.

3.4 Proposed Web-based Monitoring System

Software development is one of the main elements in this valuable research. Designing and development of the complete software package called MCDAS (Managerial Control and Data Acquisition System) in this study comprises of five main elements which is Microcontroller Programming, Application Programming Interface, Web System, Databases, and Software for hardware platform and tools. MCDAS is an interoperability web package development software that involves hardware communication, data acquisition, application, MIS (Management Information System) and database web server that is accessed over the internet or and intranet. MCDAS that hosted in a browser-controlled environment and coded in Java Script as a browser supported language and reliant on a common web browser to render the application executable. Special novelty is the architecture of MCDAS, have been design with the various resources and capabilities shared by multiple machines on a network to enable the user to interface to the machine and all of it related resources. More over the MCDAS is integrating to the Wireless Mesh Sensor Network to deliver the meaning of information from embedded RFID and technological proficiency hardware design. A real time system requires the system behaviour that not only depends on the logical results of the computations, but also the important of physical time when the results are prodused [24].

4.0 EXPERIMENTAL SET-UP

The purpose of the evaluation is as a proof of concept of the system developed. The evaluation was conducted in actual production plant. This is to ensure that the system could operate effectively in the actual condition. The evaluation done was mainly to identify the maximum accessible range of the reader, which was tested with several transmit power output settings. Figure 8 show that the read range is increases with an increase of output power as defined in Friss Equation (Chen and Huang, 2009). The Friss transmission equation is denoted as when the transmit power is increased; the reading range of the reader should also increase automatically. This is equivalent with the Friis Equation, which is defined as follows.

$$P_R = \frac{P_T G_T G_R \lambda^2}{(4\pi R)^2} \quad \text{OR} \quad P_T = \frac{P_R (4\pi R)^2}{G_T G_R \lambda^2}$$

P_R = Received power,
P_T = Transmit power,
G_T = Transmitter antenna gain,
G_R = Receiver antenna gain,
λ = Wavelength,
R = distance separating RFID tag and reader antennas,

From the equation, it can be seen that distance, *R* will be increased with an increased transmitted power, *PT*.

To evaluate the system performance, the communication range test is performed in two categories with two different methods for each category, that are the line-of-sight (LOS) method and non-line-of-sight (NLOS) method as listed below:

1. Reading range measurement using point-to-point mechanism for proposed ERFIDC system.
2. Reading range measurement using WMSN platform for proposed ERFIDC system.

The network set up is based on ZigBee, 2.4 GHz platform, which operates on IEEE 802.15.4 protocol. The minimum and maximum programmable transmit power range of XBEE series 2 is -7dBm and +3 dBm, as recommended by DIGI International [25]. The transmit power programmed for the ERFIDC reader (ZC) and ERFIDC tag (ZED) is identical for all conditions. The production plant have two separate buildings, which is plant 1 with partition and cubicles settings and plant 2 is a flat area with no partition but with the same spacious; approximately 10,500 m^2. For the communication test in LOS condition, the experiment was conducted in plant 2. Meanwhile, for the NLOS condition, the experiment was conducted in plant 1; where a certain degree of interference takes place.

The whole mesh network consists of 5-hops. Figure 4 depicts the scenario of network components deployment. The RFID reader or ZC acts as a parent and the four ZRs act as children. The ZC need to communicate with the nearest ZR to receive the data transmitted by other ZR; which can't directly communicate with the ZC due to location being outside of the permitted range. However, in the proposed system, the ZC could communicate with any ZR in the network and vice versa. Based on this condition, machine-to- machine wireless communication is realized such that the PC can control the counter wirelessly through proposed network components capabilities.

Initially, ZR is placed in a maximum distance of 30 meter between others. As an example, the distance from the ZR1 in plant 1 to ZR2 in plant 2 is about 30 meter; with wall partition that divides these two areas. The reason of placing ZRs in distance less than the maximum distance permitted is because of the need to maintain the quality of path in the network. The scenario of ZigBee mesh network operation provides lower RF output power due to the continuity between network components. In the multi-hop operations, all ZEDs transmit the identification report packets to the respective ZRs, and the related router transmits the data to the neighboring router and so on to the ZC that is connected to the PC. In ZigBee mesh networks, the ZR and the ZC locate the route to the destination point by using messages at network level as route request and route reply. Figure 4 shows the ZigBee mesh network setup. The messages will pass through the ZRs until they reach the destination, even if there is no direct communication. Nevertheless, the ZR will look for a new route for the sake of sending the information to the destination.

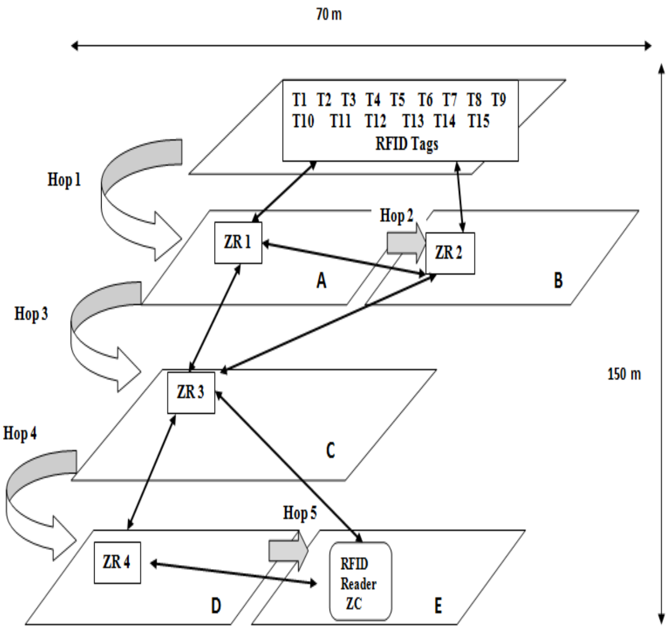

Figure 4 WMSN layouts in multi-hop environment

4.1 Result and Analysis of Read Range Measurement in Point-To-Point

In the first stage, the experiment setup uses single-hop mechanism to perform the communication test in LOS condition (point-to-point). The embedded RFID tag with counter and known as ZED is placed at the end of production line. RFID reader known as ZC connected to the host computer is gradually moved further away from the fixed ZED at the same production area until the signal became significantly weak, whereby the data could no longer be accepted by the Application Programming Interface (API). The condition of experimental set up is illustrated in Figure 5. The same experimental set up had also been applied in NLOS condition, except for the location; which is in plant 1 where certain degree of interference takes place.

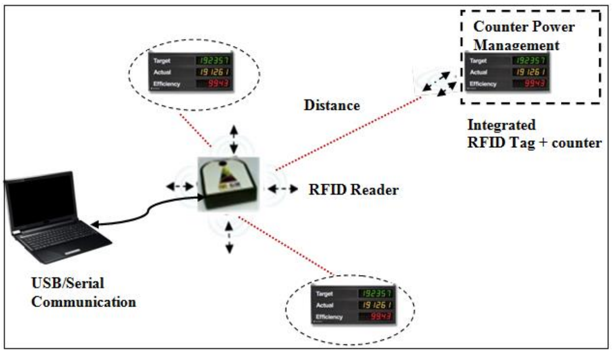

Figure 5 Point-to-point for ERFIDC system

For the communication of the ZED of ERFIDC system in LOS condition, the ZC detection range is about 40 meter with transmit power of +3 dBm, as the specification for standalone communication proposed by DIGI International Standard. Table 2 summarized the test results with maximum transmit power of +3 dBm is used for both system and Figure 6 depicted the result. In this experiment, we compare the performance of the proposed ERFIDC system with the existing/typical/standard RFID system (ZED and ZC) provided by DIGI International. The result shows that in NLOS condition, both systems achieve lower reading range than in LOS condition. In NLOS communication the reading range for ERFIDC system reached 38 meter and existing RFID system by DIGI International achieved 36 meter; whilst in LOS communication the reading range for ERFIDC system reached 46 meter and existing RFID system by DIGI International reached 40 meter. This result indicates that the obstacle such as wall partition or machinery do affects the read range of the ERFIDC communication. Nevertheless, the overall results indicate that the reading range of ERFIDC is wider than the standard set by DIGI International, for both NLOS and LOS conditions.

Table 2 Results of maximum read range measurement for ERFIDC

Environment	ERFIDC System Outcome		DIGI International 2008 Specification	
Propagation	NLOS	LOS	NLOS	LOS
Maximum Distance (m)	38	46	36	40

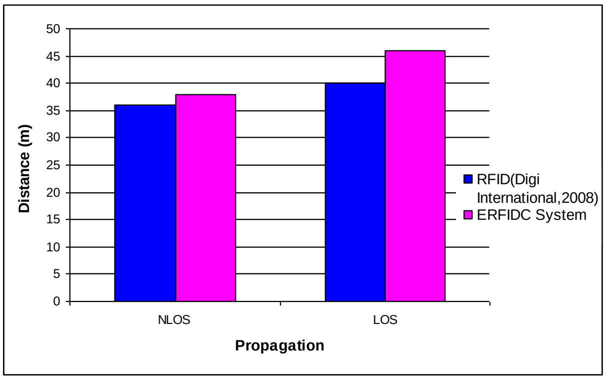

Figure 6 Comparison of maximum read range between RFID Digi International [25] and ERFIDC System

4.2 Result and Analysis of Read Range Measurement In WMSN

In the second experiment, the reading range capabilities of the proposed system have been tested in WMSN platform. This experiment consist communication test between the ZED of ERFIDC system to the ZC in LOS and NLOS condition by applying various transmit powers. Mainly, one ZR is placed in between the fixed ZED and ZC, in which the range from these two points is the maximum detectable value. The ZC connected to the host computer was gradually moved further away from the fixed ZED until the signal became significantly weak; whereby the data can no longer be received by API. As a result, the maximum range can be determined by the router; where the range was decided by the limited amount of signal received by the reader. Thus, as the illustration of experimental set up in Figure 7, node 3 (ZED3) can communicate directly with a reader (ZC) which is located 40 meter away, whereas node 1 (ZED1) needs router 1 (ZR1) to be in touch with reader due to the longer distance of 60 meter. Based on the network set up, for instance, node 6 (ZED6) will then attain router 2 (ZR2) as parent since it is the nearest available router for it. This indicates that, in mesh network principle, the nearest ZR is automatically attained the ZED as a parent. Mesh network is a robust topology, which has the ability to incorporate a large number of nodes into a self-healing network.

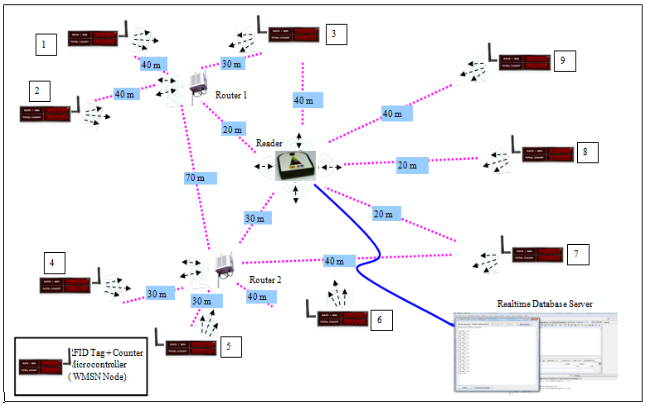

Figure 7 WMSN Layout in the production plant

The power transmits (Tx) for router and tag were also varied to obtain the whole range of receiving packets. The router enables extended network communication range in RFID system components. Table 3 is the summarized results of the testing in the WMSN environment. With the maximum power of +3 dBm in LOS condition the ERFIDC system has achieved 22 meter higher read range in comparison to ERFIDC system in NLOS condition. This result indicates that the obstacles, such as wall partition or machinery do affect the read range of the WMSN communication. The result in Figure 8 shows that, when the power transmits is increased; automatically the reading range of the reader increases. This is equivalent with the Friis Transmissions Equation [26].

The capabilities and reliability of the ERFIDC system proposed are very dependent to the architecture design of the integrated and embedded system components. From the reading range test outcome, clearly indicates that the proposed ERFIDC architecture has shown better performance in WMSN environment. In the point-to-point communication, ERFIDC system could communicate up to 46 meter with maximum transmit power of +3 dBm, in comparison to reading range proposed by DIGI International for RFID tag and reader, which is limited to 40 meter; with the same transmit power. In WMSN environment, with the maximum power of +3 dBm in LOS condition, the ERFIDC has achieved 22 meter higher read range compared to ERFIDC in NLOS condition. The same situation happen when minimum transmit power of -7 dBm is applied in multi hop communication, the ERFIDC system could communicate up to 41 meter in LOS condition, compared to reading range in NLOS condition, which is about 38 meter at same transmit power rate. This result shows that the obstacle such as wall partition or machinery do affects the read range of the WMSN communication.

Table 3 Results of range test for ERFIDC system in LOS and NLOS condition in WMSN

System/Environment	ERFIDC (LOS)					ERFIDC (NLOS)				
Power Transmit(dBm)	-7	-3	-1	1	3	-7	-3	-1	1	3
Maximum Distance (m)	41	58	80	105	130	38	50	74	85	108

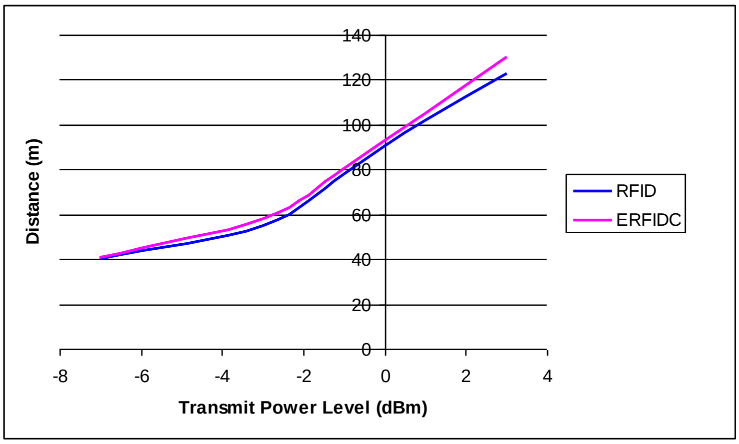

Figure 8 Comparison of maximum read range between LOS and NLOS condition with variance of transmit power level in WMSN

Table 4 shows the comparison of maximum read range for proposed ERFIDC system in LOS and NLOS with same transmit power in WMSN with other recent related works. Zanal, F. H. and Abdulla, R. proposed the active RFID system with the same specifications with the proposed active RFID system (ERFIDC) in this study [27], [28]. Only the implementation are difference, whereby Farah 2013 was integrated the active RFID with the motion sensor and Abdulla 2012 was implement the active RFID in tracking system. The result shows that, the ERFIDC system achieved higher read range for LOS and NLOS condition.

Table 4 Comparison of maximum read range for ERFIDC system in LOS and NLOS condition in WMSN with other recent related works

System/Environment	Maximum Distance (m) (LOS)	Maximum Distance (m) (NLOS)
ERFIDC	130	108
RFID System (Abdulla, R. 2012)	120	100
RFID System(Zanal,F.H. 2013)	42	72

5.0 CONCLUSION

This paper describes the new architecture design which merges four technologies into one solution for output monitoring application. The proposed embedded system expands the RFID technology forming a WMSN system that can be utilized in an industrial environment. The design of the proposed system does not use the RFID technology to just track the product but use it as ID nodes in a wireless sensor network environment. The capabilities of RFID technology platform are utilized by embedding this technology with other device platforms (counter) until it is able to process and send the meaningful data. The result presented focus on the reading range capabilities of the proposed system in LOS and NLOS condition in point-to-point and WMSN platform. In sum, in LOS condition, higher reading range was obtained than NLOS condition. This result shows that the obstacle do affect the reading range of the network communication. Even so, the results indicate that the reading range of ERFIDC is wider than the standard set by DIGI International, for both in NLOS and LOS conditions. Whilst, in WMSN, the reading range of the reader increases if the power transmits is increased. The results indicate that ERFIDC in the proposed WMSN architecture offer extended reading range in comparison with point-to-point communication at the same transmit power, in both LOS and NLOS conditions. With the purposed architecture, the monitoring performance in NLOS condition actually can be improved by adding the number of ZR or hop; if in the WMSN setup. However, further study is needed to affirm this solution, specifically in identifying the correlation between the reading range and various obstacle and interference.

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References

[1] Rosula, S. J., Joes, C. M., Marc, E. C., Lorlyn, A. M. and Roma, L. G. 2009. Throughput and Power Consumption Comparisons of Zigbee-based and ISM-based Implementations of WSAN. *International Journal of Communications*. 4(3): 96-104.

[2] Bekhet, H. A. and Harun, N. H. 2012. Energy Essential in the Industrial Manufacturing in Malaysia. *International Journal of Economics and Finance*. 4(1): 129.

[3] Maroti, M., Kusy, B., Simon, G. and Ledeczi 2004. The Flooding Time Synchronization Protocol. *Proceedings of the 2nd International Conference on Embedded Networked Sensor Systems.* Baltimore, Maryland, USA.

[4] Lu, G., Krishnamachari, B. and Raghavendra, C. S. 2004. An Adaptive Energy-efficient and Low-latency MAC for Data Gathering in Wireless Sensor Networks. *Proceedings 18th International Parallel and Distributed Processing Symposium*. SantaFe, NM, USA

[5] Abdulla, R. and Ismail, W. 2011. Extend active RFID with A ZigBee Network. *Microwaves & RF*. 50(2): 79.

[6] Abdullah, S., Ismail, W. and Zulkifli, C. Z. 2013. Integrating ZigBee-based Mesh Network for Production Management Automation with Embedded Passive and Active RFID. *Proceedings of 2013 IEEE RFID Technical & Applications Conference*, Johor Bharu, 4-5 September 2013, Malaysia.

[7] Zheng, J., and Jamalipour, A. 2009. *Wireless Sensor Network: A Networking Perspective*. John Willey & Sons.

[8] Zulkifli, C. Z., Abdulla, R., Ismail, W. and Rahman, M. G. 2011. Wireless Mesh Network in Integrated Web Base Monitoring Systems for Production Line Automation. In: *International Joint Conference on Advances in Signal Processing and Information Technology–SPIT 2011*. Springer, LNICST 62, Amsterdam. Netherland. 7-15.

[9] Castillo-Secilla, J. M., Aranda, P. C., Outeirin, X, O, F. J. B. & Olivares, J. 2010. Experimental Procedure for the Characterization and Optimization of the Power Consumption and Reliability in ZigBee Mesh Networks. *Third International Conference on Advances in Mesh Networks (MESH).* Venice/Mestre, Italy.

[10] Fulmek, P., Wegleither, H., Haumer, P. & Schweighofer, B. 2010. Measurement of The Time-Dependence of the Complex Magnetic Permeability of Soft-Ferrites. *Journal of Electrical Engineering*. 61(7): 54-57.

[11] Yang, H. 2010. Integrated ZigBee RFID Sensor Networks for Resource Tracking and Monitoring in Logistics Management. (*Doctoral dissertation*, © Huanjia Yang).

[12] Yang, H., Yao, F. and Yang, S. H. 2007. Zigbee Enabled Radio Frequency Identification System. *Proceedings of the IASTED International Conference, Communication System, networks, and Applications.* Beijing, China.

[13] Wu, W., Yang, H., Chew, D. A., Yang, S. H., Gibb, A. G., & Li, Q. 2010. Towards an Autonomous Real-time Tracking System of Near-miss Accidents on Construction Sites. *Automation in Construction*. 19(2): 134-141.

[14] Hai L., Bolic, M., Nayak, M. and Stojmenovic, I. 2008. Taxonomy and Challenges of the Integration of RFID and Wireless Sensor Networks. *Network*, *IEEE*. 22(6): 26-35.

[15] Chandra-Sekaran, A. K., Flaig, G., Kunze, C., Stork, W. and Muellerglaser, K. 2008. Efficient Resource Estimation During Mass Casualty Emergency Response Based on a Location Aware Disaster Aid Network. *European Conference on Wireless Sensor Networks.* Bologna, Italy.

[16] Medaglini, P., Ferrari, G. Marastoni, M. 2010. Hybrid ZigBee RFID Networks with Highest Energy Efficiency. *Remote Instrumentation and Virtual Laboratories,1st Edition.*

[17] Akyildiz, I. F., Weillian, S., Sankara Subramaniam, Y. and Cayirci, E. 2002. A Survey on Sensor Networks. *IEEE Communications Magazine.* 40(8): 102-114.

[18] Kenan, X., Quanhong, W., Hassanein, H. and Takahara, G. 2005. Optimal Wireless Sensor Networks (WSNs) Deployment: Minimum Cost with Lifetime Constraint. *(WiMob'2005), IEEE International Conference on Wireless And Mobile Computing, Networking And Communications.* Montreal, Canada.

[19] Culler, D., Estrin, D. and Srivastava, M. 2004. Guest Editors' Introduction:Overview of Sensor Networks. *IEEE Computer Society.* 37(8): 41-49.

[20] Estrin, D., Culler, D., Pister, K. and Sukhatme, G. 2002 Connecting the Physical World with Pervasive Networks. *IEEE Pervasive Computing.*1(1): 59-69.

[21] Zamanian, A. and Hardiman, C. 2005. Electromagnetic Radiation and Human Health: A Review of Sources and Effects. *High Frequency Electronics, in "Summit Technical Media.* 4(7):16–26.

[22] Sheridan, V., Tsegaye, B. and Walter, M. 2005. ZigBee-Enabled RFID Reader Network. *Bsc.Thesis,* WJ Communications, Inc. Worcester Polytechnic Institute

[23] Wei, Y., Heidemeinn, J. and Estrin, D. 2004. Medium Access Control with Coordinated Adaptive Sleeping for Wireless Sensor Networks. *IEEE/ACM Transactions on Networking*. 12(3): 493-506.

[24] Zhang, X. and Qiao D.2012. Quality, Reliability, Security and Robustness in Heterogeneous Networks. *Wireless Sensor Networks Journal*

[25] Chen, R. and Huang, S. L. 2009. A New Method for Indoor Location Base on Radio Frequency Identification. *WSEAS Transactions on Communications Magazine*. 8(7): 618-627.

[26] DIGI International. 2008. XBee/XBee-PRO - ZB OEM RF Modules datasheet'. [Online]. From: http://ftp1.digi.com/support/documentation/90000976_a.pdf.

[27] Zanal, F.H. 2013. Design and Implementation of Active RFID System with Motion Sensor on Wireless Mesh Network. *M.Sc. Thesis,* School of Electrical & Electronic Engineering, Universiti Sains Malaysia, Malaysia

[28] Abdulla, R. 2012. Design and Implementation of Multi-hop Active RFID System with Wireless Sensor Network. *PhD Thesis,* School of Electrical & Electronic Engineering, Universiti Sains Malaysia, Malaysia