Development of Anti-Theft Monitoring System in IoT Environment

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1. Introduction

RFID is a technique of transmitting and receiving data wirelessly through electromagnetic transmission between two mobile devices, called an interrogator or an RFID reader and a transponder or an RFID tag. A standard RFID system consists of three major components: tags, reader, and middleware software acting as an interface between user and RFID system. Generally, RFID technology uses radio waves to transmit data from the reader to the tag, in return, reader will receives the modulated returned echoes from the tag via the reader. The tag modulates the electromagnetic waves and send the data back to the reader. RFID tags are classified into two broad categories: passive and active. Passive tag, operating without a battery, reflect the RF signal transmitted to them from reader and add information by modulating the reflected signal. In contrast to active tag, it contains a radio transceiver powered by an embedded battery. Due to the onboard radio, active tags have a longer working range than passive tag.

WSN on the other hand provide limitless potentials for the RFID with the capabilities to work in multi-hops environment that possibly extends the operation of RFID in a larger area. Consequently, by incorporating the RFID and WSN technologies on a single platform, the disadvantages of each technology can be overcome and the advantages can be combined and utilised in some important applications. Since, the proposed work is focused on developing an anti-theft monitoring system, therefore a literature study on previous development conducted by other researchers are gathered and summarised in Table 1.

Table 1 - Review of previous work

Author	Technology	Mobile	Mesh Network	M2M	Sensor	Real Time	Long Range	Integrated Platform	Latency
Animal Situation Tracking Service Using RFID, GPS, and Sensors [1]	Active RFID, GPS and Sensor	Yes	No	Yes	Yes (Temperature)	Yes	No	Yes	Not Stated
Bicycle management systems in anti-theft, certification, and race by using RFID [2]	Passive UHF RFID, GPS and GSM	Yes	No	Yes	No	Yes	No	Yes	Not Stated
Design and implementation of RFID-based anti-theft system [3]	433 MHz Active RFID and Motion Sensor	Yes	No	Yes	Yes (Motion)	Yes	Yes	Yes	Not Stated
Motion sensitive RFID in wireless sensor network platform [4]	2.4 GHz Active RFID and WSN	Yes	Yes	Yes	Yes (Motion)	Yes	Yes	Yes	> 1s
Vehicle anti-theft tracking system based on Internet of things [5]	Passive RFID, GSM and Android Mobile Phone	Yes	No	Yes	No	Yes	No	Yes	Not Stated
Design and implementation of anti-theft module for ATM machine [6]	Rapsbery Pi, Fingerprint module and Embedded Web Server, CCTV	No	No	Yes	No	Yes	No	Yes	Not Stated
Improving motorcycle anti-theft system with the use of Bluetooth Low Energy 4.0 [7]	Bluetooth Low Energy (BLE) 4.0, Passive RFID	Yes	No	Yes	No	Yes	No	Yes	Not Stated
An RFID Based Smartphone Proximity Absence Alert System [8]	Low Power Passive RFID, Samsung Galaxy Note 2 Mobile Phone	Yes	No	Yes	Yes (Accelerometer)	Yes	No	No	Not Stated
Anti-theft and tracking mechanism for vehicles using GSM and GPS [9]	GSM and GPS	Yes	No	Yes	No	Yes	No	Yes	Not Stated
Proposed System	2.4 GHz Active RFID and WSN	Yes	Yes	Yes	Yes (Vibration)	Yes	Yes	Yes	<1s

From the review, it can be seen that most of the systems are not using active RFID and WSN as their main technology and unable to work in wireless mesh network environment with short range communication between transmitter and receiver. In addition, the latency between transmission and reception is not a major concern in their work which will reduce their overall system performance. Therefore, an anti-theft monitoring system that combining 2.4 GHz active RFID, WSN and vibration sensor is proposed to real timely monitor the movement of an equipment placed inside laboratory. The system provides a unified mesh networking between tag and reader which able to perform transmission and reception in long range communication (unlimited range with hopping technique) with improved algorithm that provides low latency less then 1s. The proposed system consist of embedded active RFID tag with motion sensor and a modified active RFID reader communicating in WSN environment as shown in Figure 1. It is capable to monitor objects in indoor and outdoor environment with machine-to-machine (M2M) capabilities. It merges 2 great technologies which are RFID and WSN on a single platform that are controlled by a single processing unit.

The main contribution is on the system design, development, implementation and testing of the proposed RFID system to evaluate the system effectiveness. Table 1 shows a brief description of previous inventions done by other inventors related to the anti-theft application. It is shown that the proposed RFID system is better than other patented systems since it is designed with an ability to track and monitor the movement of object in indoor and outdoor environment on the same platform.

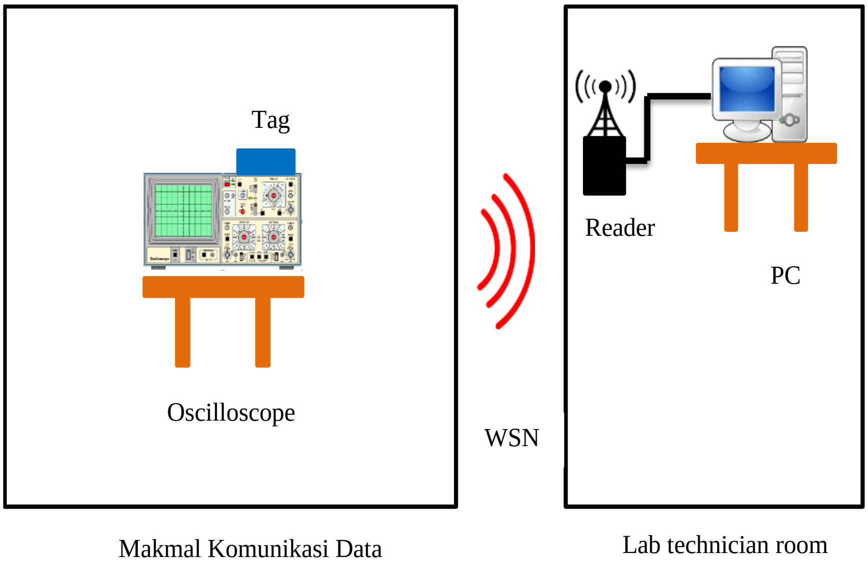

Fig. 1 - Overview of the anti-theft monitoring system

2. System Development

The proposed active RFID system for anti-theft application combines both active RFID, ZigBee and sensor technologies to provide identification, extend the capabilities of existing RFID system and sense the environment that complied with ISO 18000, Part 4 (2.45 GHz) standard. The RFID system components use a unified wireless mesh-networking infrastructure to trace and monitor object in indoor and outdoor environments which can reduce difficulties of implementation and provide reliable identification reporting. The system comprises of three categories which are hardware, software and network development which will be explained in the later subtopic.

3. Hardware Architecture

The proposed system hardware architecture comprises of 2 parts which are tag and reader. Basically, the proposed system works by detecting the movement of equipment using motion sensor. Once the movement is detected by the sensor, it will trigger the embedded active RFID tag from sleep state mode to wakeup mode. The embedded tag will process the information given by motion sensor before sending the information along with unique identification number to the reader via WSN platform. The information will be converted into meaningful information before display on the Graphical User Interface (GUI) and save into data logger system. The embedded active RFID tag will turn into sleep mode once the communication between tag and reader is completed and only wakeup if receiving interrupt from the motion sensor to conserve the energy. Figure 2 shows the embedded active RFID tag with vibration sensor utilizing Arduino Uno platform that is powered by 12 V battery. In this work, the tag will be attached to the equipment to be monitored in the laboratory.

As for tag, the active RFID reader circuit as shown in Figure 3 consists of a RF transceiver connected to USB serial communication. The reader is connected to the monitoring station to display data during transmission and reception process.

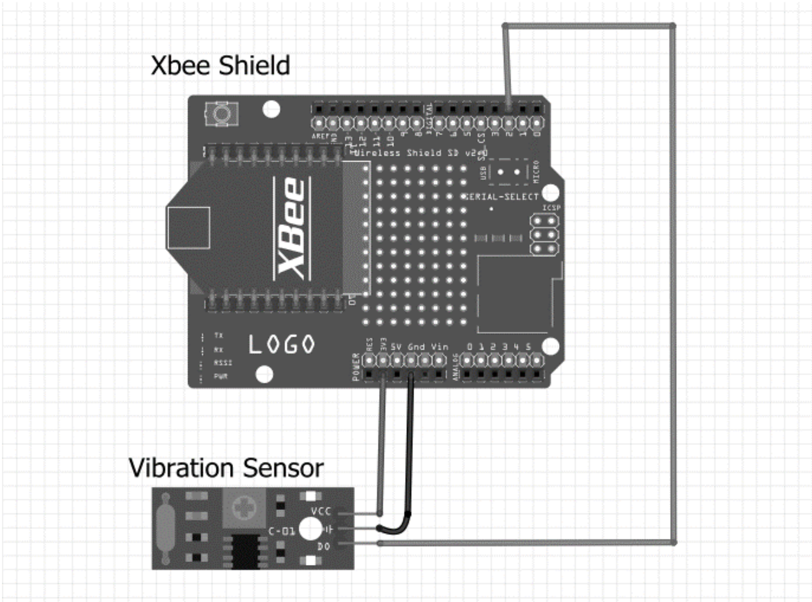

Fig. 2 - The circuit diagram of the tag section of the system

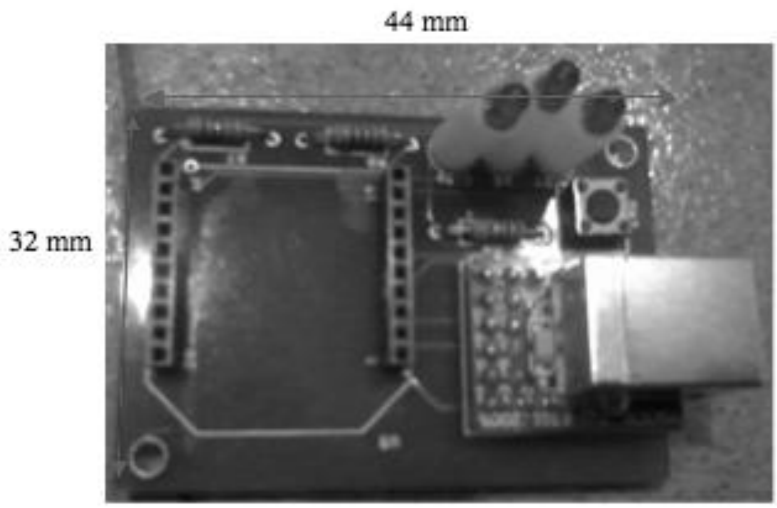

Fig. 3 - The circuit diagram of the reader section of the system

4. Software Architecture

Machine to machine (M2M) communication is a unique deployment that can be used for remote monitoring and to describe any technology that enables networked devices to exchange information and perform actions without the manual assistance of humans. There are five basic stages of communication are implemented in the proposed active RFID system as shown in Figure 4. The first stage refers to the reception of data from the vibration sensor. The data received from the vibration sensor is in the form of digital number "0" (not vibrate) and "1" (vibrate).

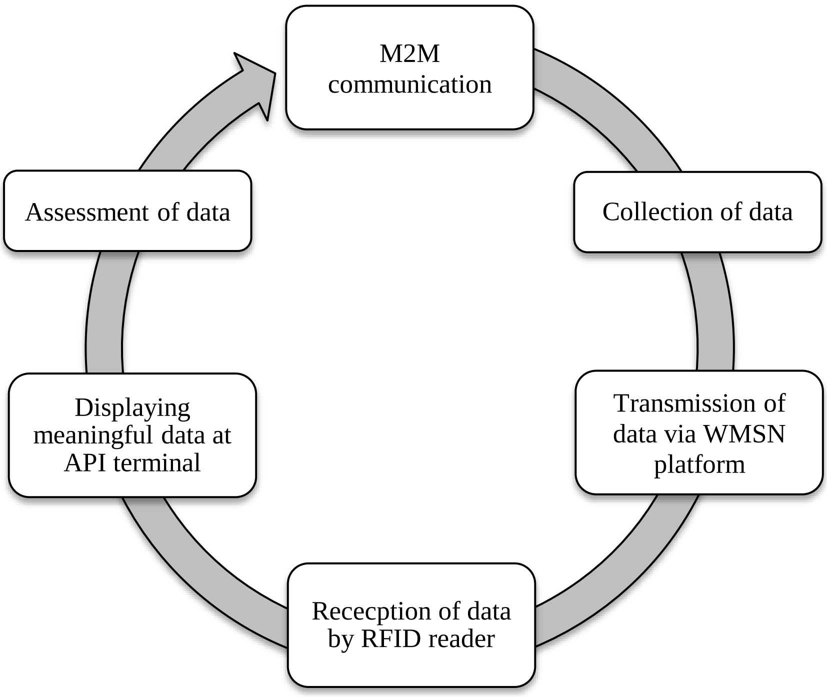

Fig. 4 - M2M stages for proposed system

When the sensor detects vibration or movement, it will trigger the microcontroller and wakeup the system before collects and processes the data from the vibration sensor. The tag send the information in real time through wireless mesh network to the RFID reader. In this case the ZigBee platform based on IEEE 802.15.4 standard for the communication of 2.4 GHz is used in mesh network architecture. The tag will enter sleep mode when there is no vibration or movement detected by the sensor to conserve energy since it is powered by a battery. The data received by the reader is transferred via USB port communication and is processed into meaningful data before displayed on GUI and saved into data logger system. The goal of this communication method is to automate the process of collecting data to user and machine remotely. The overall active RFID system working mechanism as shown in Figure 5.

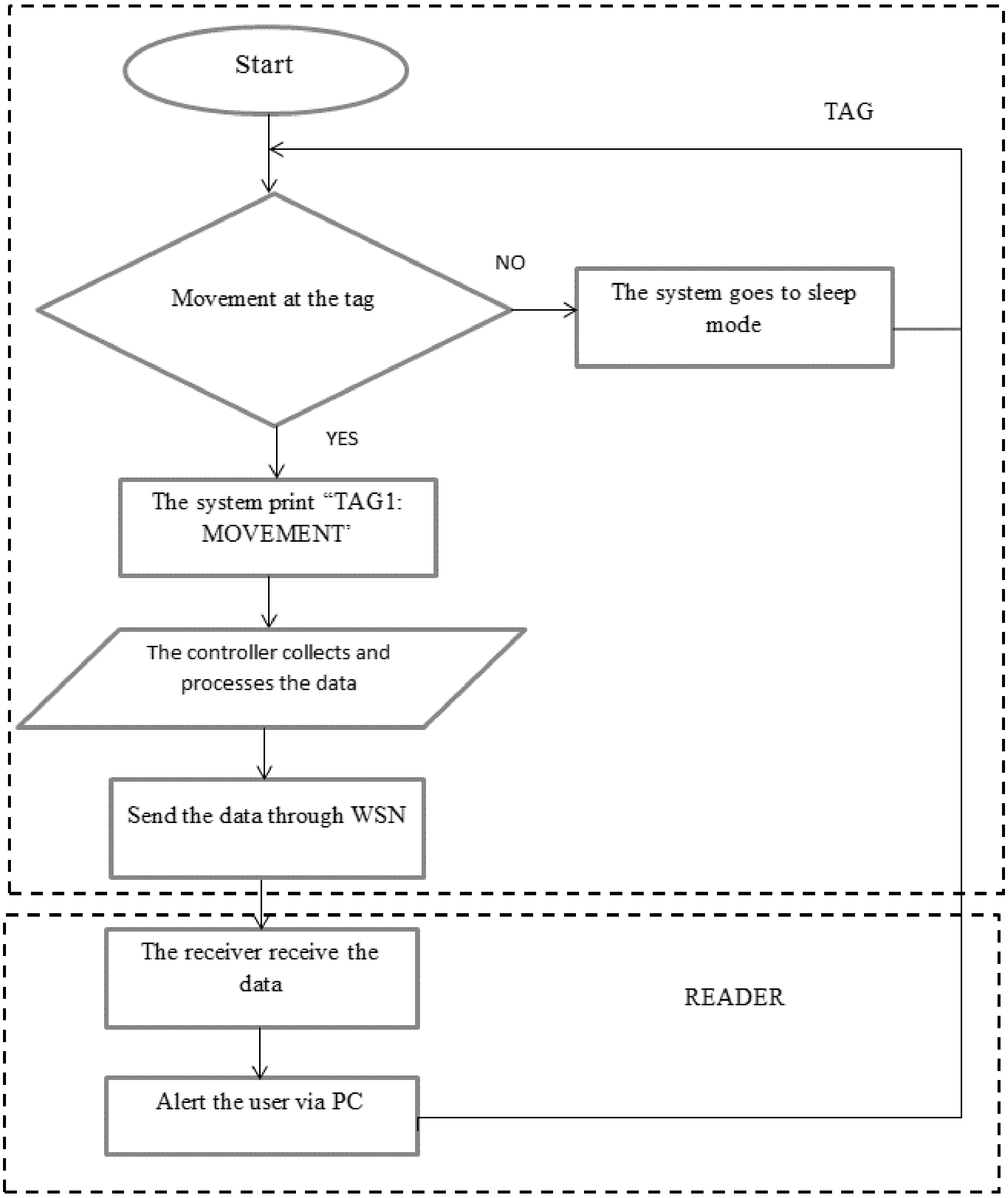

Fig. 5 - Overall active RFID system working mechanism

5. Network Architecture

For the purpose of developing a communication network that suits the application requirements, a point-to-point (P2P) communication test is conducted between one RFID tag and one RFID reader to confirm that the proposed active RFID system components are functioning well before going in depth to complex network. The successful of transmission or reception totally depends on the speed of data transmission, PAN ID and channel applied in the WMSN network. Figure 6 illustrates the testing configuration for the proposed active RFID system.

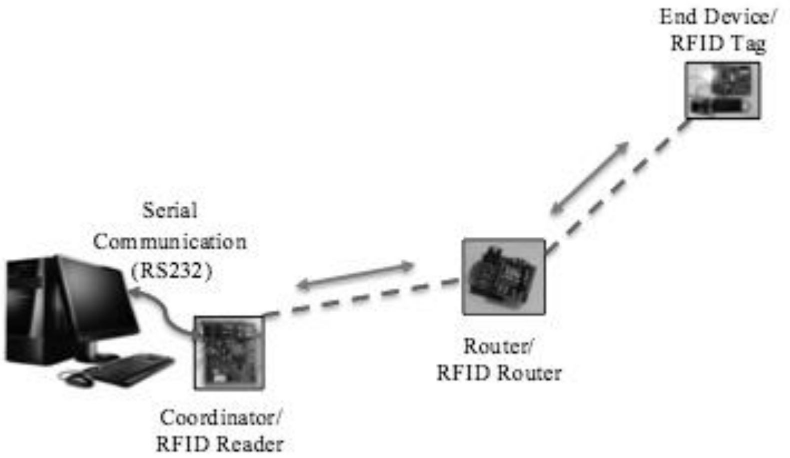

Fig. 6 - Basic ZigBee mesh network configuration

6. Monitoring System

The monitoring system consists of an active RFID reader connected to a Personal Computer (PC) that is link to a GUI developed using Visual Basic (VB) software to view, store and retrieve the incoming and outgoing data easily. The GUI will alert user if there is any movement of equipment based on the data given by the vibration sensor. The sequences of data displayed is based on the format as "DD-MM-YYYY HH:MM:SS:SSS TAG#: STATUS". Figure 7 shows the GUI terminal developed in the proposed active RFID system.

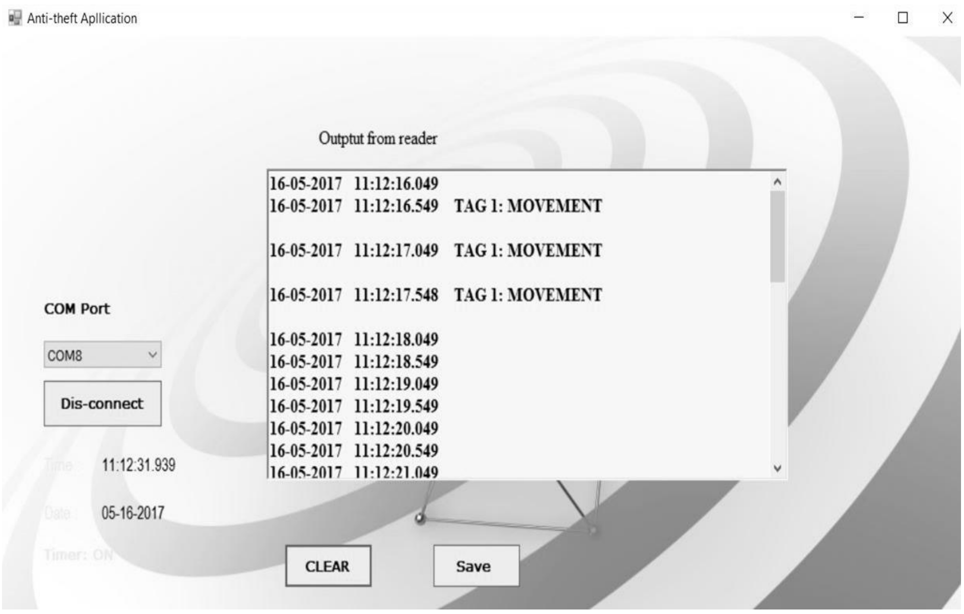

Fig. 7 - GUI using Visual Basic software

7. Performance Analysis

Several tests are conducted to evaluate the performance of develop system including power consumption and tags collection time. The results of the following evaluation are explained accordingly in each subtopic.

7.1 Power Consumption

The power consumption of the developed system is tested by measuring the current usage during wakeup and sleep mode. The current is measured by using multimeter that is connected in series with the power supply (9V battery) and Arduino. While, the voltage is measured from the supply voltage. The output of the measurement in the form of current and voltage are indicates in Table 2 which is measured for 10 times to get the average value of current and voltage.

Table 2 - Result for voltage and current in wakeup mode

No	Voltage (V)	Current (mA)
1	12.17	182.9
2	12.20	187.3
3	12.22	188.5
4	12.23	183.7
5	12.22	180.9
6	12.24	186.7
7	12.19	181.2
8	12.23	183.5
9	12.15	188.6
10	12.22	184.2
Average	**12.21**	**184.75**

Therefore, power is calculated by using $P = IV$ from the measured current and voltage, while the battery life is obtained by assuming that the efficiency of the system is 70 % after taking into account the external factor that might reduce the performance of the system.

$$P = VI = (12.21\text{ V}) \times (184.75\text{ mA}) = 2.26\text{ Watts} \quad (1)$$

Battery Life = (Battery Capacity in mAh/ Load Current in mA) x 0.70 efficiency
= (2000 mAh / 185.3m) x 0.7 efficiency (2)
= 7.57 hours

The sleep mode is introduced in the algorithm to save more power as the tag of system uses batteries to power up the circuit. The connection is similar from the previous test. The value of current and voltage measured is stored in Table 3. The system will wake up if there is movement detected from the sensor and return back to the sleep mode after the task is carried out.

Table 3 - Result of voltage and current in sleep mode

No	Voltage (V)	Current (mA)
1	12.22	153.04
2	12.23	151.2
3	12.31	154.6
4	12.33	157.6
5	12.22	155.8
6	12.23	155.9
7	12.22	152.4
8	12.19	153.6
9	12.20	153.5
10	12.18	154.3
Average	**12.233**	**154.194**

The value of current during sleep mode is in between 152 mA to 158 mA and when the interrupt function is activated in the system, the value of current rises up to194 mA. The battery reading during sleep mode is 12.23 V. Thus, power can be calculated from the recorded value. As previous, the battery life time is obtained by assuming that the efficiency of the system is 70 % after taking into account the external factor that might reduce the performance of the system. Thus, the power is equal to 1.88 W and battery live increase to 9.07 hours.

The total power saved during sleep mode is calculated as shown in equation (3).

$$\% \text{ Power saved} = \frac{P1-P2}{P1} \times 100\ \% \qquad (3)$$

$$\% \text{ Power saved} = \frac{2.26-1.88}{2.26} \times 100\ \% = 16.81\% \approx 15\ \%$$

7.2 Tags Collection Time

The tags collection time is the time taken for the reader to receive the response starting from sensor detect vibration, process the input, sending to the reader and received acknowledgement. The configuration of tags collection time measurement is shown in Figure 8, while the platform used to capture the tags collection time in milliseconds (ms), which is later saved in the data logger shown as in Figure 7.

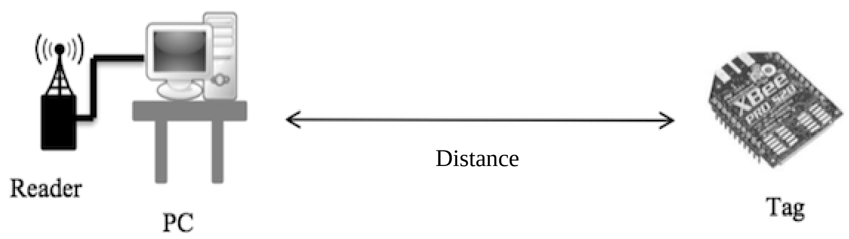

Fig. 8 - Tags collection time configuration

The measurement are taken for 5 times and the average value of tags collection time is obtained which indicates the time it takes to complete the transmission and reception between tag and reader. From the results shown in Table 4, it can be seen that the average latency is about 190 ms, which indicates that the tag takes a short amount of time to complete the transmission and reception compared to the work done by [4].

Table 4 - Tags collection time

No	Latency (ms)
1	189.92
2	190.00
3	190.08
4	190.00
5	190.00
Average	**190.00**

8. Conclusion

A prototype of the 2.4 GHz embedded active RFID for Anti-Theft Application utilizing Wireless Sensor Network (WSN) platform has been designed, developed and tested. The system able to detect any object movement using vibration sensor, send the movement data from the tag through WSN platform to RFID reader located at monitoring station to be displayed on the GUI and saved into data logger system. The project is successfully developed using the Arduino, 2.4 GHz RF transceiver and vibration sensor, while the GUI is developed using Visual Basic software. The power consumption of the tag is approximately 2.26 W during wakeup mode and 1.88 W during sleep mode. The percentage of power saving when the system enter the sleep mode is approximately 15%. The battery lifetime is about 7.57 hours during wakeup mode and 9.08 hours during sleep mode with 70 % efficiency. The average tags collection time is about 190 ms per transmission which is better than previous system developed by other researchers [4].

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