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Wireless Sensor Network in Niger Delta Oil and Gas Field Monitoring: Issues and Database Abstraction

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ABSTRACT: *The IEEE 802.15.4 enabled Wireless Sensor Networks (WSNs) have found useful applications in mission-critical environments especially in Nigeria oil and gas field monitoring, Niger Delta region, to perform real-time monitoring and surveillance of critical oil and gas pipelines, plants, wells and flow stations. Outputs from quantitative sensors such as pressure,* ***vibration****, Passive Infra Red (PIR) movement, flowrate, Infrared thermo (temperature) sensors and qualitative sensors such as wireless IP cameras (triggered by actuators) when certain threshold conditions are breached. The integration of sensors and actuators can be combined effectively to detect instant intrusion, leakage, rupture or vandalisation of oil facilities such as pipelines in such a manner that sensed data can be passed to the control room or intelligent actuators for immediate actions. In this paper, we propose a database abstraction framework using tinydb database management system (DBMS) that can enable real-time data coming from these sensors to be stored, updated and queried by a client-server system so that visualizations can be performed using a standard client-based browser interface (www or http://).*
KEYWORDS: *WIRELESS SENSOR NETWORK WSN, NIGER DELTA REGION, NIGERIA, OIL PIPELINES, OIL AND GAS FIELD MONITORING, MISSION-CRITICAL, DATABASE ABSTRACTION, EVENT-TRIGGERED MONITORING, PERIODIC MONITORING, TINYDB.*

I. INTRODUCTION

Wireless sensor networks are IEEE 802.15.4 enabled devices capable of robust and reliable multi-hop communications [1],[2]. Wireless sensors can be deployed in unattended environments and can enable collection of data from there to distant base stations and then to control room [3], [4].

Wireless sensors have found useful applications in varying number of civilian and military applications because of their low-cost and ease of deployment [2],[5],[6]. Because of these inherent and other advantages, wireless sensor networks have found useful applications in environmental monitoring applications especially in oil and gas fields. Wireless Sensor Networks (WSNs) exists in various quantitative and qualitative sensor types to enable samplings and measurements of oil and gas field parameters such as temperature, pressure, vibration, flow rate etc. These quantitative and qualitative sensors cannot work alone; they need actuators to be attached to them as well as means of communication so as to transfer their sampled data to the control station for immediate action to be taken in the event of detection of leakage, rupture or intentional vandalisation of oil and gas facility from the remote field. Some sensor nodes are just sensors only while some are sensors with attached actuators [7]. Some WSNs can assist in the communication or transfer of the sampled data from the remote oil fields and to the base station and then to the control room or station. In Nigeria Niger Delta region, the greatest challenge facing the oil and gas sector is that of physical security – vandalisation of oil and gas pipelines by hoodlums and criminal-minded individuals to steal crude oil and other refined petroleum products. Quantitative and qualitative wireless sensors have replaced traditional-based monitoring technologies such as wired fibre optics and satellite because these technologies are difficult to deploy, maintain and operate. Wireless sensor networks (WSNs) are resource-constrained communication devices that have low power, low memory, low computing capability, utilizes wireless communication and have inbuilt sensing units. Figure 1 depicts the diagram of a typical WSN node with low battery power, CPU with limited computing capability, wireless aerial antenna or transceiver etc. Figure 2 depicts a high-level schematic representation of a WSN node hardware with attached environmental sensors and actuators.

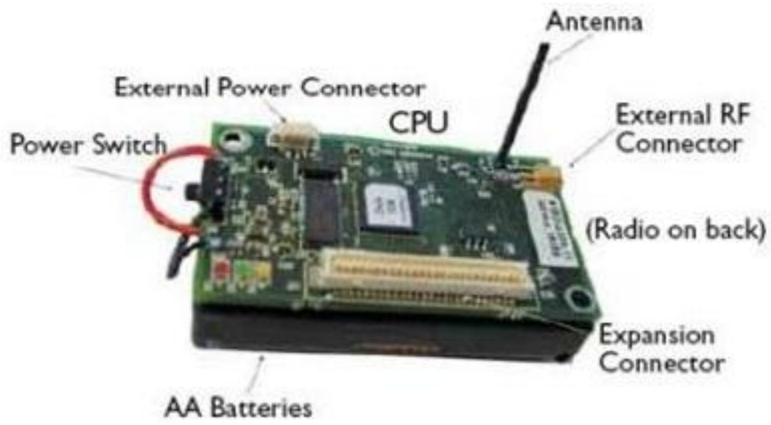

Figure 1. Hardware unit of a Wireless Sensor Network node[8]

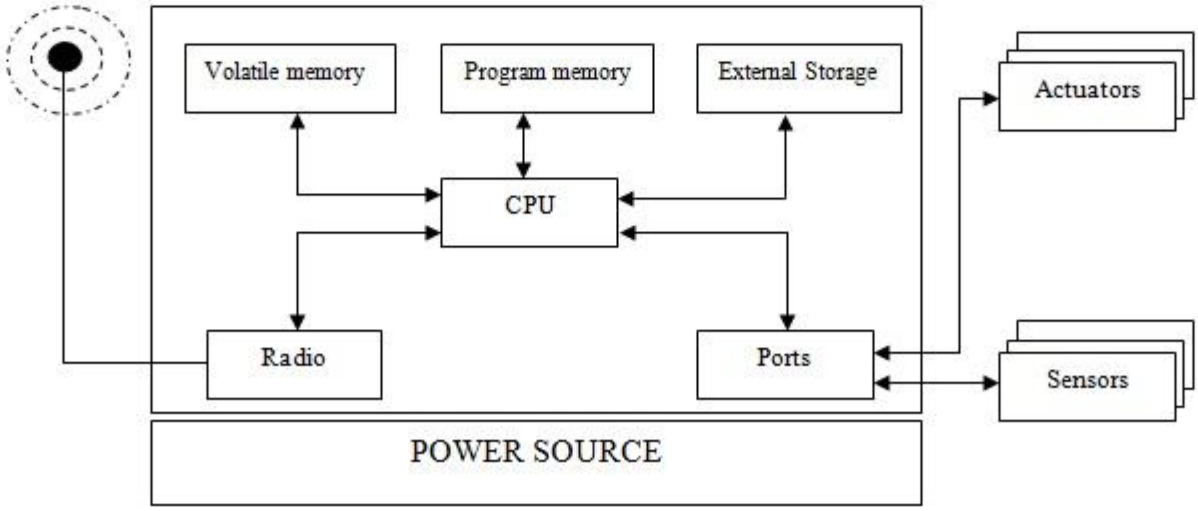

Figure 2. A high-level schematic representation of a WSN node hardware [9]

For a distributed processing network such as Wireless Sensor Actuator Network (WSAN), periodic and event-triggered monitoring/actuation is required to effectively use WSN to monitor oil and gas pipelines and facilities. *Periodic monitoring/actuation* involve continuous processing of sensed remote data from the oil fields. The application performs periodic tasks to gather sensor readings, coordinates with other parts of the system, and possibly performs actuation as needed. *Event-triggered monitoring/actuation* in applications are characterised by two phases: 1) during event detection, the system is largely quiescent, with each node monitoring the values its samples from the environment (oil field) with little or no communication involved: 2) if and when the event condition is met (e.g. a pressure sensor value lowers below a certain threshold or a vibration or infrared temperature sensor raises above a threshold value or when an intrusion is detected using a Passive Infrared (PIR) motion detector or sensor), the WSN begins its distributed processing.

To successfully monitor the remote oil and gas installations and facilities in the Niger Delta region, periodic as well as event-triggered monitoring/actuation is required. The sensed remote data from the quantitative and qualitative wireless sensors units installed in the oil and gas fields must be sampled and the sensor data transmitted or communicated to either installed actuators to take pre-emptive response to the vandalisation such as raising continuous audible alarm to scare away the vandals using a mobile robots or recording video scenes of the vandalisation and transferring the same data to the Supervisory Control And Data Acquisition (SCADA) control room via a wireless base station proactively.

The real-time data from the wireless sensors and the actuators must be stored in a database in an embedded PC or microcontroller and then parsed to the internet (www) or to the intranet of the oil company that installed it using *http:// interface* in the SCADA software. Figure 3 shows the workflow datagram for the database abstraction from oil and gas sensors to the WSN source nodes to the actuator nodes and then to the WSN source nodes and finally to the wireless base station in the WSN Gateway. Figure 4 depicts the data flow diagram (DFD) of the proposed WSN-Actuator monitoring system with backend software tools.

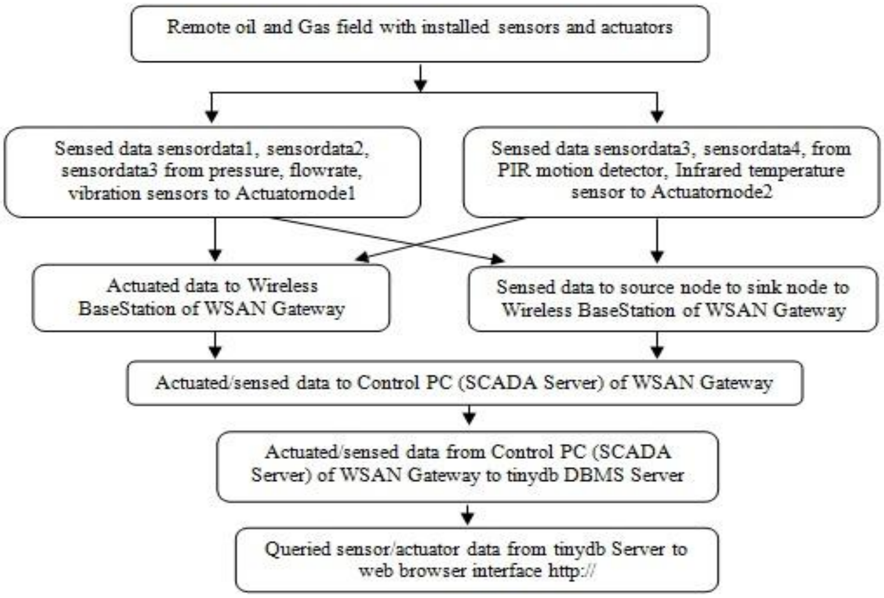

Figure 3. Workflow d*iagram of the proposed WSAN monitoring system for oil and gas field*

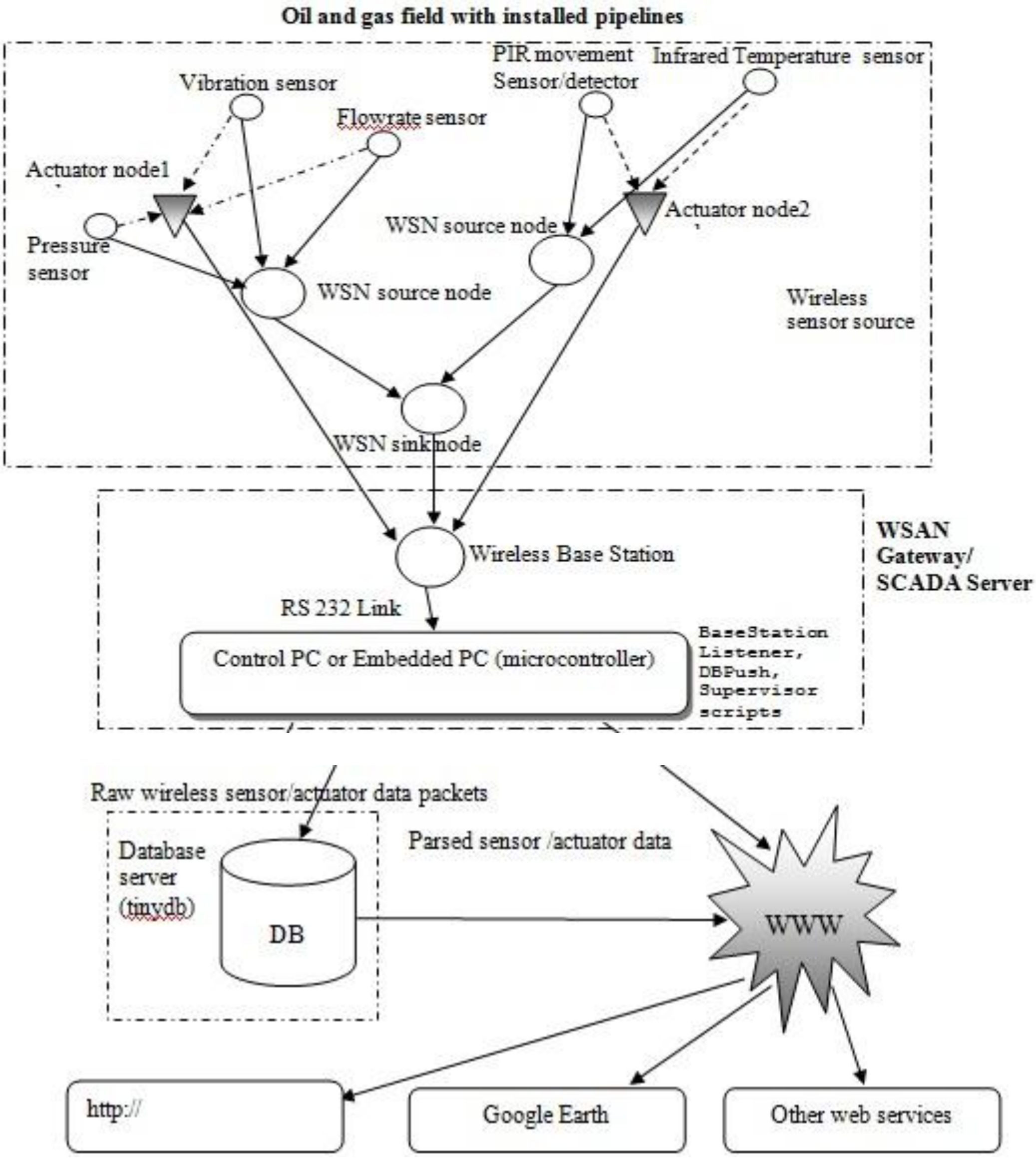

Figure 4. Data Flow Diagram (DFD) of the proposed WSN-Actuator monitoring system for oil and gas field Niger Delta region with backend database abstraction.

II. THE PROPOSED DATABASE ABSTRACTION FOR REMOTE DATA ACQUSITION FROM OIL AND GAS FIELD MONITORING

The proposed database abstraction framework will use Tinydb database management system (DBMS).

2.1. Tinydb Database Management System (DBMS)

Tinydb is a joint work from Massachusetts Institute of Technology (MIT), UCB and Intel Research Unit. It is a very powerful DBMS for resource-constrained embedded devices such as wireless sensors and microcontrollers and at such very suitable for data acquisition of environmental variables from remote locations. Tinydb is widely used in real world applications especially in real-time monitoring. According to [10], In Tinydb, sensed data are indeed made available as entries of a *sensors table*, and the user accesses the table using SQL-like queries. To cater with the peculiarities of WSN applications, however, further constructs are provided to express, for instance, the lifetime and period of queries.

2.2. Data Access modelling for the proposed abstraction

The data modelling for the proposed database abstraction framework for the sampling of remote data or data acquisition for the sampled environmental field data from quantitative and qualitative sensors monitoring the oil and gas field includes the following data:

- *sensordata1*,
- *sensordata2*,
- *sensordata3*,
- *sensordata4*, and
- *sensordata5*

Representing sensor data from *pressure*, *vibration*, *flowrate*, *PIR motion detection* and Infrared temperature sensors respectively. Actuator data actndata1, actndata2 represent actuated data coming from attached actuated-devices such as wireless IP camera to record surveillance video/image data from the scene(s) of the oil and gas pipeline leakage or intentional vandalisation and the captured data are passed to the WSAN Gateway for onward transmission to the Control PC or embedded PC (microcontroller) and then to the database server.

2.2.1. The table structures for the proposed database Abstraction

We propose two (2) database tables - *sensors* and *actuators* for the database *remote_data* to effectively capture and store the sampled remote data from the five (5) quantitative sensors and two (2) qualitative sensors attached to the two actuators respectively. The database table structures of the *sensors* and *actuators* tables are depicted in Table 1 and Table 2 below respectively but because the developers of Tinydb DBMS did not concern themselves about actuator data but concentrated on only sensor data [11]. This means that only *sensors* table can be used to sample and store sensor and actuation data.

Table 1. Sensors table without actuation data *sensors Table*

nodeid	*sensor_type*	*sensordata*	*sampled_time*
1	*Pressure*	*sensordata1*	*time1*
2	*Vibration*	*Sensordata2*	*time2*
3	*Flowrate*	*Sensordata3*	*time3*
4	*PIR movement*	*Sensordata4*	*time4*
5	*Infrared temperature*	*Sensordata5*	*time5*

Table 2. Actuator table actuators Table

actuatorid	*Video_data*	*sampled_time*
1	*actndata1*	*time1*
2	*actndata2*	*time2*

Hence we submerge the two proposed tables, *sensors* and a*ctuators* tables into one (sensors table) according to the specification of Tinydb. Data acquisition query syntax has been extended to support actuators using a new keyword. To solve declarative nature violations we need better query syntax for actuation tasks [7].

Hence the sensor table in Table 1can be modified to include actuator data (in Table 2) using UPDATE SQL command of Tinydb as contained in Table 3.

Table 3: New Sensors table including actuation data Sensors table

Node id	*pressure*	*vibration*	*flowrate*	*PIR movement*	*Infrared temperature*	*sampled _time*	*actuatornode1*	*actuatornode2*
1	*sensordata 1*	*NULL*	*NULL*	*NULL*	*NULL*	*time1*	*actndata1*	*NULL*
2	*NULL*	*sensordata2*	*NULL*	*NULL*	*NULL*	*time2*	*actndata1*	*NULL*
3	*NULL*	*NULL*	*Sensor data3*	*NULL*	*NULL*	*time3*	*actndata1*	*NULL*
4	*NULL*	*NULL*	*NULL*	*sensordata4*	*NULL*	*time4*	*NULL*	*actndata2*
5	*NULL*	*NULL*	*NULL*	*NULL*	*sensordata5*	*time5*	*NULL*	*actndata2*

Special keywords can be used in tinydb SQL to invoke a pre-determined action or response of the actuators once the threshold of a particular sensor is reached and surpassed. For instance, in our real-time monitoring of oil and gas field (oil pipelines) using the five sensors (see Figure 3) – pressure, vibration, flow rate, infra-rays and temperature, let's assume that leakage of pipeline is confirmed when pressure level is less than 50, vibration level is more 60, flow rate reduces below 122 then automatically means that there is leakage or pipeline rupture which can be caused by natural causes (like corrosion) or intentional causes like vandalisation. The *actuatornode1* is then activated or invoked to take action (maybe by switching on a video surveillance camera to start recording the scenes of the oil field to capture possibly the video footages of the vandals). The query execution processes using tinydb DBMS involving wireless quantitative sensor nodes (WSN) only and Wireless Sensor Actuator Network (WSAN) are shown in Figure 5 and Figure 6 respectively.

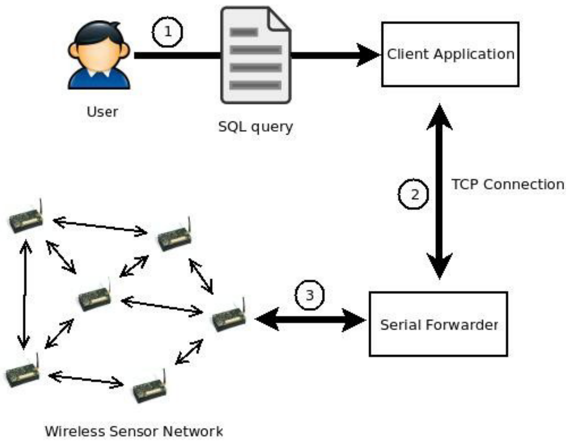

Figure 5. The query process using Tinydb using SELECT command involving Wireless Sensor Network (WSN) using TCP connection

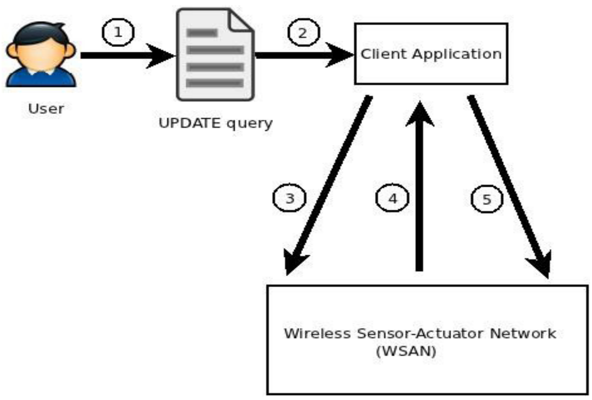

Figure 6. The query process using Tinydb using UPDATE command involving Wireless Sensor Network (WSN) using TCP connection

2.3. Sampling and data acquisition of the multiple sensors data and triggering actuation

Multiple sensors can also be combined to eliminate the possibility of false detection of pipeline leakages. For instance we can combine the output of the first three sensors- *pressure*, *vibration*, *flowrate* (attached to the *actuatornode1*) with that of the second set of two sensors- PIR motion detector, PIR temperature (attached to the *actuatornode2*) and the combination will really confirm if there is *leakage* or *vandalisation* in the oil pipeline and the two actuators (*actuatornode1* and *actuatornode2*) will be invoked to trigger the two attached wireless IP cameras to start recording the scenes in their immediate surrounding to enable the IOC to track and arrest the pipeline vandals. Let us assume that the threshold values for the second set of sensors are given as- PIR motion detector is less than 20, PIR temperature sensor is more than 75 units respectively.
The following SQL commands in tinydb can be used to accomplish the scenario described above involving the five sensors and two actuators:

```
UPDATE sensors AS sen, sensors AS act
SET act.actuatornode1='on' AND
        act.actuatornode2='on'
WHERE (nodeid=1 AND pressure<50) AND (nodeid=2 AND
vibration>60) AND (nodeid=3 AND flowrate<122) AND (nodeid=4 AND
pir_motion_detector<20) AND (nodeid=5 AND pir_temperature>75)
ONCE;
```

The tinydb SQL commands will automatically trigger the two wireless IP cameras actuators (*actuatornode1* and *actutornode2*, see Figure 3) to start recording the video footage of the oil fields (in order to possible capture the vandals) since the threshold values for the five sensors have been exceeded (either reduced or increased).

2.3.1. Triggering the actuator node attached to the first set of sensors:

If we want to trigger the actuator attached (*actuatornode1* only) to the first set of sensors – pressure, vibration and flow rate with the same threshold conditions (pressure<50, vibration>60, flowrate<122) to trigger one(1) wireless IP camera to start recording the scene of the oil field, we will use the following tinydb SQL commands to accomplish that:

```
UPDATE sensors AS sen, sensors AS act
SET act.actuatornode1='on'
WHERE (nodeid=1 AND pressure<50)AND (nodeid=2 AND vibration>60)
AND (nodeid=3 AND flowrate<122) ONCE;
```

2.3.2. Triggering the actuator node attached to the second set of sensors:

If we want to trigger the actuator attached (*actuatornode2* only) to the second set of sensors – PIR motion detector and PIR temperature sensor with the same threshold conditions (pir_temperature>75, pir_motion_detector<20) to trigger one(1) wireless IP camera to start recording the scene of the oil field, we will use the following tinydb SQL commands to accomplish that:

```
UPDATE sensors AS sen, sensors AS act
SET act.actuatornode2='on'
WHERE (nodeid=5 AND pir_temperature>75) AND (nodeid=4 AND
pir_motion_detector<20)
ONCE;
```

The resultant output from the query above will invoke the Wireless IP camera actuator to start it for video recording of the oil field scene once the thresholds values of temperature and motion detector sensors are breached.

2.3.3. Sampling and data acquisition of the sensors data individually:

Suppose we want to sample continuously each particular sensor (using periodic monitoring/actuation) installed in the remote oil field, we will use the following tinydb SQL to query the sensed data of *pressure sensor* at any time:

```
SELECT nodeid, pressure
FROM sensors
WHERE nodeid=1
SAMPLE PERIOD 10s;
```

This will sample only the pressure sensor and acquire the sensed data (*sensordata1*) from it at every 10 seconds time interval.

If we want to sample the *vibration sensor* to detect vandalisation of pipeline before it occurs using vibration threshold of say 22, we will use the following tinydb SQL query to query the *sensors table:*

```
SELECT nodeid,vibration
FROM sensors
WHERE nodeid=2
SAMPLE PERIOD 1s;
```

This will sample only the vibration sensor and acquire the sensed data (*sensordata2*) from it at every 1 second time interval.

It is better to combine inputs from multiple sensors such as pressure, vibration, flowrate, PIR motion detector and PIR temperature sensor in an oil and gas field so as to detect incipient leakage earlier and more accurately rather than input from single sensor which may indicate false information that there is leakage or vandalisation when in actual sense it is not.

3. Conclusions And Future Work

Sensed data from the installed quantitative and qualitative sensors in the oil and gas field can be transmitted from the oil field to a wireless Base Station and then to the Control Gateway and the sensed/actuated data passed to a DBMS server during data sampling and acquisition. This paper considered SQL primitives for handling data sampling and acquisition of remote sensed data from the oil field using Tinydb. Tinydb is easy for database abstraction for resource constrained embedded devices such as wireless sensors. Considering actuators as part of the data model in the database abstraction is convenient. SELECT query can be used to sample and perform data acquisition of sensed data from environmental quantitative sensors only while UPDATE query can be used to perform the combined sensing and actuation tasks in the network to handle the triggering of wireless IP cameras to start recording video scenes of the particular oil and gas fields in order to detect the biometric identities of the vandals. Executing actuation queries need more research to handle node movements, node failures, etc.

3.1. Future Work

We intend to carry out further works in the following area:

1. To design a client-server paradigm to sampling and data acquisition of remote data from the oil fields.
2. To develop scripts (programs) using server-side programming language to implement the server-side processing,
3. To develop command statements (*BaseStationListener*) to listen to data packets from the wireless BaseStation to the WSAN Gateway computer or control PC.
4. To develop command statements (*DBPush*) to enable tinydb connection and storage/extraction from WSAN Gateway computer or control PC to the Tinydb Server.
5. To develop command statements (Supervisor) to control and supervise all other scripts.
6. To develop scripts in server-side to query sensor/actuator data in WSN gateway computer to the database tinydb server.
7. To develop an experimental testbed and simulation model to implement and test the proposed framework.

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