

Research Article

A Model of Pipeline Flow Monitoring in Wide Area Wireless Sensor Network

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Abstract: Designing a model for pipeline flow monitoring using Wide Area Network (WAN) as well as low power wireless sensor nodes has been the general goal of design engineers. Such network desires to have a Wide Area Wireless Sensor Network (WAWSN) that will run on little power (if possible, none at all) thereby saving cost, and the inconveniences of having to replace batteries in some difficult to access areas of usage. This paper then developed a Structural Monitoring Hierarchy (SMH) starting with pipeline design considerations, pipeline energy models, fluid pressure losses, fluid flow modelling, event location model and WAN WSN output or battery model for sustainable transceiver energy consumption for a typical node deployment architecture. By studying the energy consumption map of the transceiver of a WSN node battery model, this research developed an energy consumption model of the transceiver unit of a typical sensor node battery. Important metrics like Depth of Charge (DOC), State of Charge (SOC), Load current and Load Voltage were derived and plotted using MATLAB. The mathematical characterizations for the pipeline designs, flow equations, and pipeline leak detection and localization parameters (event location) were captured in the simulation using a standard reference guide and related design assumptions. Proteus 7.6 ISIS was used to implement the unified behavioural model of the Wide Area Wireless Sensor Network based pipeline monitoring. Simulations done on the model shows that the model can work.

Keywords: Power, Sensor, SMH, WAWSN, WAN, WSN, Transceiver, Pipeline, DOC, SOC, Battery or Output model

INTRODUCTION

Pipeline flow monitoring using WAN based Transceiver WSN is novel. This approach seeks to propose a more reliable, economical monitoring system that involves a damage detection process known as Structural Health Monitoring (SHM). In general, SHM refers to the discipline of damage detection as applied within the areas of aerospace, civil, and mechanical engineering. The process of SHM involves the use of an array of sensors distributed over a structure to make periodic observations of the system's dynamic response. The observations are evaluated to determine if damage is present in the system, and statistical analysis is then used to determine the current status of the system's health [1,2].

The authors in [3] outlined and classified existing pipeline monitoring techniques into two categories based on the positions of the sensors, i.e., inside or outside the pipeline. The work in [4] discussed sensor monitoring outside pipelines. To detect the leakage of underground pipelines, the ground penetrating radar (GPR) is adopted in [5,6,7,8]. Also, monitoring techniques based on sensors inside pipelines was discussed in [3].

After an extreme event, such as a bridge experiencing an earthquake, a SHM system can be implemented "for rapid condition screening and to provide, in near real time, reliable information regarding the integrity of the structure [2]. Ultimately, the output from a SHM system provides the operator with an assessment of the ability of the structure to safely and reliably perform its designated function given the accumulation of damage from prior service and the potential for future operation to create additional damage.

In this research, the structure of interest is a pipeline monitoring system. There are numerous elements to a pipeline system, including the main body of the individual pipe segments, flanged and welded joints, valves, fittings, and pumping stations. Specifically, this paper places emphasis on monitoring the structural integrity of the main body of the pipeline segments and of the flanged joints between the segments.

To implement a SHM system with a pipeline, an array of sensors deployed at various locations along the axis of the pipeline is used to make observations regarding the damage state of the structure. The sensor

array must be designed such that damage features corresponding to the structural integrity of the pipeline can be efficiently extracted from the observations.

Ideally, the damage features should at least include the most common causes of pipeline incidents including corrosion damage and excavation damage. These adverse changes in the system can be material or geometric properties of the system, but they can also be changes to the boundary conditions or system connectivity.

The relative time scale associated with damage must also be considered. Some forms of damage accumulate over long periods of operation. Hence, the development of a more reliable, cheaper monitoring system would have countless advantages for pipeline operators.

METHODOLOGY

Modelling and Simulation Methodology.

This paper used MSM in developing the pipeline monitoring framework. The steps that are involved in the modelling simulation methodology are:

- **Specification model definition**, using formal mathematical derivatives,
- **Model-checking**: On the completion of the system specification model, model-checking is used to validate the model properties.
- **Model Simulations**: After model-checking, the same models are then used to run the simulations of the behaviour of the different sub-models under specific conditions. Recall that the various system and properties are first analytically verified with proofs before simulation implementation.
- **Test case derivation**: The system specification model is used to derive test cases, which can be also used to further explain the system. Deriving test cases from both the model and from the simulation results validates the models in the context of requirements satisfaction
- **Model Prototype Execution**: Once satisfied with both analytical and simulated results, the models are incrementally moved into a target platform. If the hardware is not readily available, the software components can still be developed incrementally and tested against a model of the hardware to verify viability and take early design decisions. In our case, the simulation parameters we used for our pipeline simulation and evaluation were gotten from a real-time traffic data.

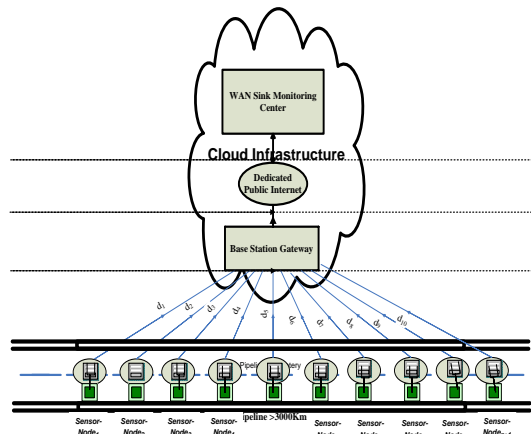


Fig1: Proposed Pipeline Monitoring Architecture

In this research, the framework focus is on the communication network model, pipeline design for the fluid flow, the battery model for excellent power dissipation and tracking of pipeline vandalization or breakage at randomly mapped distance of 500m to 1500m while sensing and reporting events via the WAN aggregation unit to the sink for emergency response by remote operatives as shown in figure 1.

PIPELINE STRUCTURE SYSTEM DESIGNS

Design Model for WSN Pipeline Deployment

Figure 2 shows a pipeline deployment layout carrying fluid *x* with a density *dx*. The design of the pipeline involves the determination of the inside diameter of the pipe *D* and its wall thickness *t* for the fluid flow.

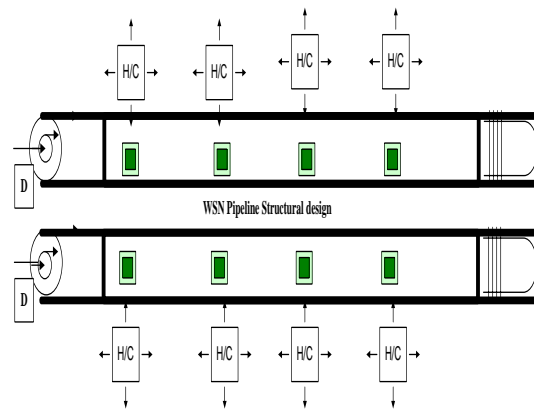


Fig-2: Structural Pipeline Deployment and Design

Equation for Inside Diameter of the Pipe

This depends on the quantity of the oil fluid to be delivered, as such, Let,

- A represent the cross sectional Area of the pipe
- D represents the diameter of the pipe
- V represents the velocity of pipeline fluid per minute
- Q represents Quantity of fluid carried per minute

But the Quantity Q of fluid flowing per minute is given by:

$$Q = A * V = \frac{\pi}{4} * D^2 * V \quad (1)$$

Solving for D in Equ.1 gives

$$D = \sqrt{\frac{4 * Q}{\pi * V}} = 1.13 \sqrt{\frac{Q}{V}} \quad (2)$$

Wall Thickness of the Pipeline t

From figure 2, t is considered next in order to withstand the internal fluid pressure p in the thin or thick cylindrical pipeline.

Essentially, the thin cylindrical equation will be applied when:

- i. Stress across the pipeline section is uniform
- ii. The internal diameter of the pipeline section D is $>20t$ ie $D/t > 20$
- iii. The allowable stress σ_t is more than six times the pressure inside the pipe P ie. $\sigma_t > 6P$

According to the thin cylindrical equ, wall thickness t of the pipeline is given by

$$t = \frac{P * D}{2 \sigma_t} = \frac{P * D}{2 Q_t \eta_t} + C \quad (3)$$

Where, η_t is the Efficiency of longitudinal joint and C is the Weishack constant

A. Design Model for WSN Pipeline Stress

Consider a cylindrical shell of a pressure vessel carrying oil fluid which was subjected to a high internal fluid pressure p , the wall of the cylinder must be made extremely thick t .

Assuming that the tensile stresses are uniformly distributed over the section of the walls, let,

r_0 represent outer radius of the cylindrical shell

r_i represent inner radius of the cylindrical shell

t represent thickness of the cylindrical shell = $r_0 - r_i$

$r_0 - r_i$

p represents intensity of internal pressure

μ represent poisson's ratio

σ_t represents tangential stress

σ_r represents radial stress

Using lame's law which states that assuming that the longitudinal fibers of the cylindrical shell are strained, the tangential stress at any radius x is give by

$$\sigma_t = \frac{p_i(r_i)^2 - p_0(r_0)^2}{(r_0)^2 - (r_i)^2} + \frac{(r_i)^2(r_0)^2}{x^2} \left[\frac{p_i - p_0}{(r_0)^2 - (r_i)^2} \right] \quad (4)$$

Now, radial stress at any radius x is given by

$$\sigma_r = \frac{p_i(r_i)^2 - p_0(r_0)^2}{(r_0)^2 - (r_i)^2} - \frac{(r_i)^2(r_0)^2}{x^2} \left[\frac{p_i - p_0}{(r_0)^2 - (r_i)^2} \right] \quad (5)$$

Considering the internal pressure only $P_i = P$ and let external pressure, $P_0 = 0$,

From Equation 3, the tangential stress at any radius x is given by.

$$\sigma_t = \frac{p_i(r_i)^2}{(r_0)^2 - (r_i)^2} \left[1 + \frac{(r_0)^2}{x^2} \right] \quad (6)$$

$$\sigma_r = \frac{p_i(r_i)^2}{(r_0)^2 - (r_i)^2} \left[1 - \frac{(r_0)^2}{x^2} \right] \quad (7)$$

From Equ 6 and 7, the tangential stress is a tensile stress whereas the radial stress is a compressive stress.

Again, the tangential stress is Maximum at the inner surface of the pipeline ie. $x = r_i$ and it is minimum at the outer surface of the shell ie. $x = r_0$

By taking the value of $x = r_i$ and $x = r_0$ in Equ. (6) and (7), the Maximum tangential stress at the inner surface of the pipeline is given by,

$$\sigma_{(t_{Max})} = \frac{P[(r_0)^2 + (r_i)^2]}{(r_0)^2 - (r_i)^2} \quad (8)$$

While the minimum tangential stress at the outer surface of the shell is given by,

$$\sigma_{(t_{Min})} = \frac{2P[(r_i)^2]}{(r_0)^2 - (r_i)^2} \quad (9)$$

$$\sigma_{(t_{Max})} = -p(\text{Compressive}) \text{ and at } \sigma_{(t_{Min})} = 0$$

Therefore, Equ. (8) and (9) becomes the major maximum and minimum stress equation for the WAN WSN pipeline design.

B. Design Model that will Handle WSN Pipeline Joints

In pipeline monitoring, for a circular flanged pipeline joint, it is assumed that the fluid pressure acts in between the flanges and tends to separate them with a pressure existing at the point of leaking.

In this regard, bolts are required to take up tensile stress in order to keep the flanges together. Now, let, the effective diameter on which the fluid pressure acts just at the point of leaking be the diameter of a circle touching the bolt holes.

Let this diameter be D_l . If d_l is the diameter of bolt hold and D_p is the pitch circle diameter, then,

$$D_l = D_p - d_l \quad (10)$$

Hence, from Equ. (10), force trying to separate the two flanges is given by,

$$F = \frac{\pi}{4} * (D_l)^2 * P \quad (11)$$

Now, to compute the resistance of the tearing of bolts,

Let n = Number of bolts,

d_c = Core diameter of the bolts

$\sigma_{(t)}$ = permissible stress for the material of the bolts

Hence, resistance R , is then given by,

$$F = \frac{\pi}{4} * (d_c)^2 * \sigma_{(t)} * n \quad (12)$$

**Fluid Flow Models for WSN Pipeline
Pipeline Energy Governing Equation**

Understanding the dynamics of the pipeline fluid flows before discussing on the event location tracking is the focus of this section. In a real pipeline deployment, fluid flows have equivalent mathematical models. Now, fluids possess viscosity, hence loses energy due to friction. These fluid properties interact with one another as well as with the pipe walls. Since our emphasis is on monitoring fluid flow leakages and location using WSN transceiver WAN cloud, we shall however, consider the mathematical representations of these fluid flow dynamics.

Now, the shear stress induces in a fluid flowing near a boundary is given by Newton's law of viscosity, viz:

Shear stress τ in a fluid is proportional to the velocity gradient- ie the rate of change of velocity across the fluid path, hence,

$$\text{Shear Stress } \tau \propto \frac{du}{dy} \quad (13)$$

$$\tau = \mu \frac{du}{dy} \quad (14)$$

Where μ is the coefficient of viscosity,

Flows in Pipelines can be classified into laminar or turbulent flow, but a non-dimensional number, called the Reynolds number, Re is used to determine the type of flow that occurs.

This is given by

$$Re = \rho \frac{U_d}{\mu} \quad (15)$$

Generally, in a pipeline,

Laminar Flow: $Re < 2000$

Transitional flow: $2000 < Re < 4000$

Turbulent Flow: $Re > 4000$

By determining the flow type from Equ.15, this governs how the amount of energy lost to friction relates to the viscosity of the flow. Hence, how much energy must be used to move the fluid.

i. Pipeline Pressure Loss Due to Friction

Consider a cylindrical element of incompressible fluid flowing in the pipe as shown in figure 3

The pressure of the upstream end L_1 is P and at the downstream end L_2 , the pressure has fallen by

$$P = \Delta p \text{ to } (P - \Delta p) \quad (16)$$

The driving force F_d due to pressure ($F_d = \text{Pressure} \times \text{Area}$) can be represented by

Driving pressure, D_p .

$D_p = \text{Pressure Force at } L_1 - \text{pressure force at } L_2$, given by

$$D_p = PA - (P - \Delta p)A = \Delta p A = \Delta p \frac{\pi d^2}{4} \quad (17)$$

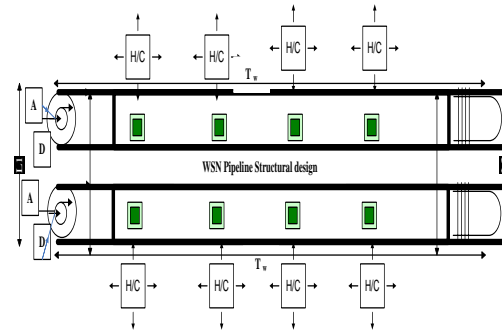


Fig-3: Element of fluid in a Pipeline

The retarding force due to the shear stress by the walls is given by,

$Fr = \text{Shear Stress} \times \text{Area over which it acts}$

$Fr = \tau_w \times \text{Area of Pipewall}$

$$Fr = \tau_w \times \pi dL \quad (18)$$

As the flow gets to equilibrium, the driving force = retarding force, ie Equ 17 = Equ 18

$$\Rightarrow \Delta p \frac{\pi d^2}{4} = \tau_w \times \pi dL$$

$$\Rightarrow \Delta p = \frac{\tau_w \times \pi dL}{d} \quad (19)$$

Equ (19) gives an expression for the pressure loss in a pipe in terms of the pipe diameter and the shear stress at the wall of the pipeline.

Hence, shear stress will vary with velocity of flow and hence with Re

ii. Pipeline Pressure Loss During laminar Flow in a Pipeline

For laminar flow, the pressure loss in a pipe is given by the Hagen Poiseuille Equation:

$$\Delta p = \frac{32\mu LU}{d^2} \quad (20)$$

In terms of head,

$$hf = \frac{32\mu LU}{\rho g d^2} \quad (21)$$

Where hf = head loss due to friction and U = velocity.

iii. Pipeline Pressure Loss During Turbulent Flow in a Pipeline

Figure 4 shows a bounded fluid flow scenario flowing in a channel with $Re > 2000$, ie turbulent flow in both closed (pipes and ducts) and open (rivers and channels).

In this case, consider the element of fluid shown in figure 4 where the flow via the channel have length L and with perimeter P . The flow is steady and uniform, so that acceleration is zero and the flow area at sections L_1 and L_2 is equal to A .

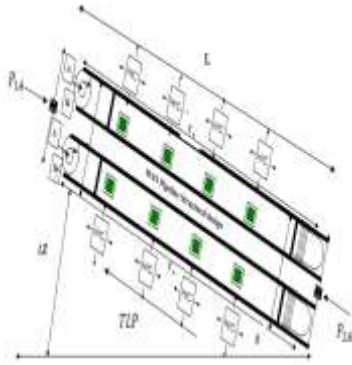


Fig-4: Element of Fluid in a channel flowing with uniform flow

From figure 4,

$$P_1A - P_2A - \tau_w * LP + W \sin\theta = 0 \quad (22)$$

By arranging the weight term as $\rho g A l$ and $\sin\theta = -\Delta z/L$

$$A(P_1 - P_2) - \tau_w * LP - \rho g \Delta z = 0 \quad (23)$$

Hence,

$$\frac{[(P_1 - P_2) - \rho g \Delta z]}{L} - r_0 \frac{P}{A} = 0 \quad (24)$$

Where the first term represents the piezometric head loss of the length L

$$r_0 = m \frac{dp}{dx} \quad (25)$$

Where $m = A/P$ is referred to as the hydraulic mean depth

By writing piezometric head loss as

$$P = \rho g h f \quad (26)$$

Then, shear stress per unit length is given as

$$r_0 = m \frac{dp}{dx} = \frac{[m * \rho g h f]}{L} \quad (27)$$

Equ (27) gives a relationship of shear stress at the wall to the wall of change in piezometric pressure.

But by introducing friction factor f given by

$$r_0 = \frac{f \rho \mu^2}{2} \quad (28)$$

Where μ is the mean flow velocity,

$$\text{Hence, } \frac{dp}{dx} = \frac{f \rho \mu^2}{2m} = \frac{\rho g h f}{L} \quad (29)$$

So far, a general bound flow, head loss due to friction can be written as

$$h_f = \frac{f L \mu^2}{2m} \quad (30)$$

More specifically, for a circular pipe,

$$m = A/P = \frac{\pi d^2}{4\pi d} = \frac{d}{4} \quad (31)$$

This then gives

$$h_f = \frac{4f L \mu^2}{2gd} \quad (32)$$

Equ. (32) gives Darcy-Weisbach Equation for head loss in circular pipes. By rearranging Equ.(32) in terms of discharge Q_1 using $Q = A u$, this implies that

$$U = \frac{4Q}{\pi d^2} \quad (33)$$

Substituting for U in Equ (32) gives

$$h_f = \frac{64f L Q^2}{2g\pi^2 d^5} = \frac{f L Q^2}{3.03 d^5} \quad (34)$$

$$\text{With 1\% Error} \rightarrow \frac{f L Q^2}{3d^5} \quad (35)$$

i. Pipeline Friction factor For Laminar Flow

From the foregoing, the equ.derived for head loss in turbulent flow is equivalent to that derived for laminar flow with the difference being the empirical f . From Equ (34) and (35) Hagen Poiseuille and Darcy-weisbach equations give:

$$\frac{32\mu Lu}{\rho g d^2} = \frac{4f L u^2}{2gd} \quad (36)$$

Hence

$$f = \frac{16\mu}{\rho g v d} = \frac{16}{Re} \quad (37)$$

ii. Pipeline Losses at Sudden Enlargement

Consider the flow in the sudden enlargement shown in the pipeline structure in figure 7 with the fluid flow from section 1 to section 2. The velocity must reduce and so the pressure increases. The sensor nodes are placed as shown also. At position 1, turbulent eddies occurs which give rise to the local head loss.

Applying the momentum equ. Between section 1 and 2 gives,

$$P_1 A_1 - P_2 A_2 = P * Q (U_2 - U_1) \quad (38)$$

Now, by using continuity equ. To remove Q ie. (Substitutue $Q = A_2 U_2$)

$$P_1 A_1 - P_2 A_2 = P A_2 U_2 (U_2 - U_1) \quad (39)$$

$$\text{Rearranging gives } \frac{P_2 - P_1}{P_g} = \frac{U_2}{g} (U_2 - U_1) \quad (40)$$

By applying the Bernoulli equ from point 1 to point 2 with the head loss term h_l

$$\frac{P_1}{P_g} + \frac{U_1^2}{2g} = \frac{P_2}{P_g} + \frac{U_2^2}{2g} + h_l \quad (41)$$

$$\text{By re-arranging gives } h_l = \frac{U_1^2 - U_2^2}{2g} - \frac{P_2 - P_1}{P_g} \quad (42)$$

By combining Equ 39 and 41,

This gives

$$h_l = \frac{U_1^2 - U_2^2}{2g} - \frac{U_2}{g} (U_1 - U_2), \text{ this implies that}$$

$$h_l = \left(\frac{U_1^2 - U_2^2}{2g} \right)^2 \quad (43)$$

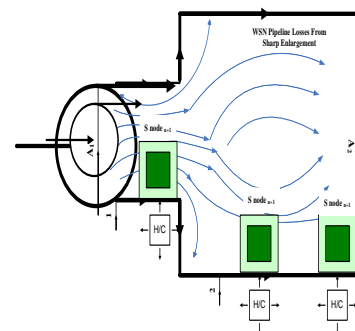


Fig-5: WSN pipeline Sudden Expansion Model

Substituting again for the continuity equ. to get an expression involving the two areas ie.

$Q_2 = U_1 A_1 / A_2$, gives
 $h_{l=} (1 - \frac{A_1}{A_2})^2$ (44)

When a pipe expands into a large tank $A_1 \ll A_2 = 0$, so $K_1 = 1$, ie the head loss = Velocity head just before the expansion into the tank.

iii. **Pipeline Energy Analysis for Flow Monitoring**

Using Bernoulli equ. which is a statement of conversion of energy along a streamline. By this principle, the total energy in the system does not change; hence the total head does not change. So the Bernoulli equ can be written as

$\frac{p}{\rho g} + \frac{U^2}{2g} + Z = H = \text{Constant}$ (45)

Ie. Total Energy Per Unit Weight = \sum (Pressure Energy Per Unit Weight + Kinetic Energy per Unit Weight + Potential Energy Per Unit Weight)

Where pressure head = $\frac{p}{\rho g}$

Velocity head = $\frac{U^2}{2g}$

Potential head = Z

Total head = H

From Equ (45), Bernoulli equation has some restrictions in its applications viz:

- Flow is Steady
- Density is Constant ie fluid is incompressible
- Frictional losses are negligible.

WAN WSN Node battery Model

The sensor nodes depend on the battery model for effective data communication and life span sustainability. This is developed in this section having carried out a survey on the main components of the composition of a node for a wireless sensor network viz: Controller, radio modem, sensors/actuators, memory and batteries as shown in figure 6. For the SHM architecture, this paper develops the relevant model for WSN battery and event location in our proposed system in the later section.

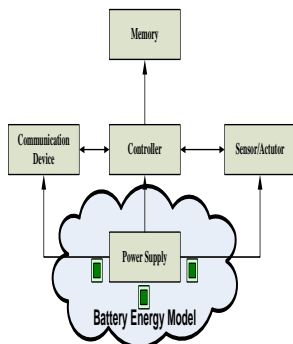


Fig-6: Battery Energy Model of a WSN

Energy supply of mobile/sensor nodes is from the battery. The goal of our model in figure 6 is to provide as much energy as possible at smallest cost/volume/weight/recharge time/longevity. The battery electrode in the battery connects with a dry electrolyte for energy harvesting. The requirements for both transmitter and receiver electronics include:

- Low self-discharge with low duty cycle
- Long shelf live
- Capacity under load
- Efficient discharging at low current
- Good relaxation properties (good self-discharging)
- Voltage stability

Figure 7 shows the implementation model of the WAN WSN battery cell using the Simscape language to implement the nonlinear equations of the equivalent circuit components. In this way, the connection between model components and the defining physical equations is more easily understood.

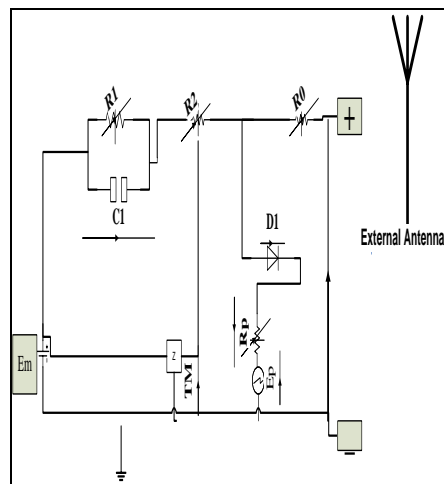


Fig-7: The Logical Model of the WSN battery

From figure 7, the details of the battery model was carefully realized using the Simscape language for the nonlinear equations of the equivalent circuit components. Primarily via convection, and that heating is primarily from battery internal resistance, R_2 . Using the MATLAB library which comes with built in battery and electric functions. The system was implemented with the plots shown in figures 7 to figure 11. This shows optimal results for remote WAWAN monitoring. The trade-off is the cost considerations for the WSN nodes.

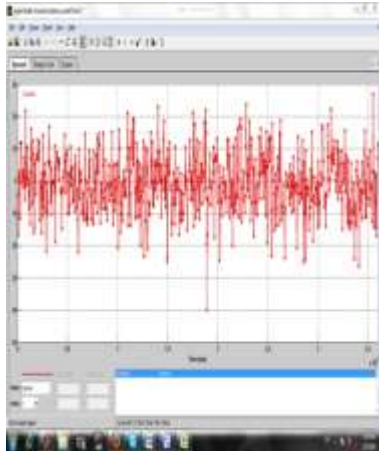


Fig-7a: The Logical Model plot of the WSN battery from Signal Builder

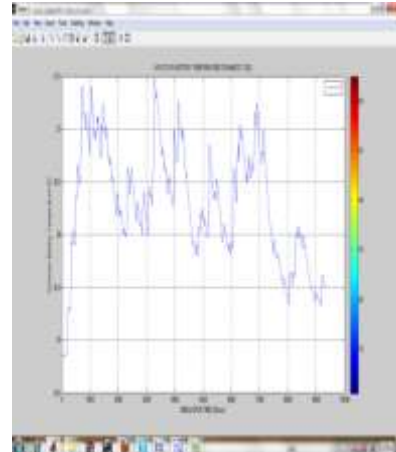


Fig-9: A plot WSN battery Temperature °C from workspace

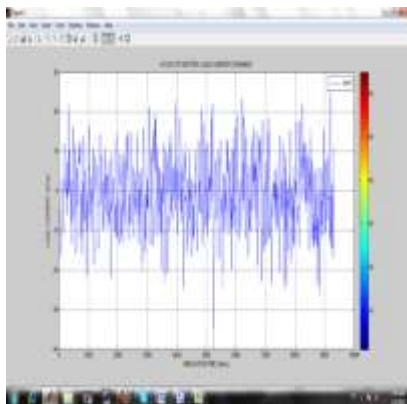


Fig-7b: A Plot battery load Current from the workspace

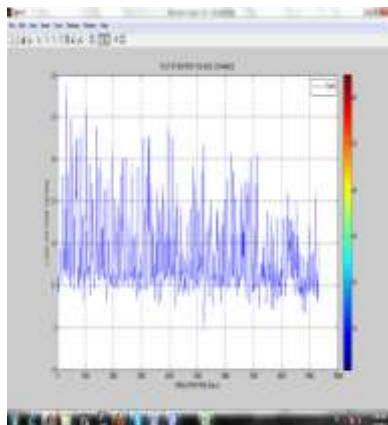


Fig-8: A plot of WSN battery Voltage from workspace

Considering figure 10 and 11, in battery taxonomy, Depth of Discharge (DOD) (%) is the percentage of battery capacity that has been discharged expressed as a percentage of maximum capacity as shown in figure 11. A discharge to at least 80 % DOD is referred to as a deep discharge. Depth of discharge (DOD) is an alternate method to indicate a battery's state of charge (SOC). The DOD is the complement of SOC: as one increases, the other decreases. While the SOC units are percent points (0% = empty; 100% = full), the units for DOD can be Ah (e.g.: 0 = full, 50 Ah = empty) or percent points (100% = empty; 0% = full). As a battery may actually have higher capacity than its nominal rating, it is possible for the DOD value to exceed the full value (e.g.: 52 Ah or 110%), something that is not possible when using SOC. See figure 10. Figure 10 shows the SOC giving an expression of the present battery capacity as a percentage of maximum capacity. SOC is generally calculated using current integration to determine the change in battery capacity over time.

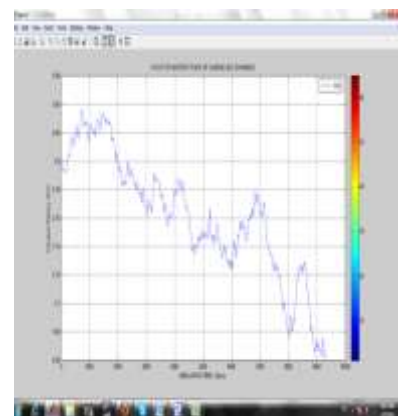


Fig-10: A Plot WSN battery SOC

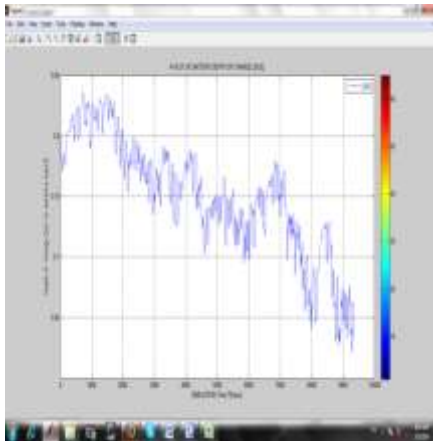


Fig-11: A Plot WSN battery DOC

SIMULATION DESIGN TOOLS AND ALGORITHM DESIGN TOOLS

The following tools were employed in this research, viz: Program Description Language (PDL), Matlab 2012a and PROTEUS 7.6 ISIS. While the PDL was used to establish the program algorithms, MATLAB was used to model the battery process model while observing the parametric variables as shown in the plots above. Proteus 7.6 ISIS was used to generate the unified behaviour. In the MATLAB environment, Simscape electronics along side with the sources and sink blocks sets were used in a data flow hierarchy for modelling, simulating and analysing the dynamic battery model in figure 7 while generating the plots (figure 8-figure 11). Its primary interface is a blockset diagramming tool with its customizable set of block libraries which it offers tight integration with the rest of the MATLAB environment and can either drive MATLAB or be scripted from it. This was consequently used to model the battery model which gave the plots above, while Proteus ISIS 7.6 was used to develop a unified behavioural model of the WWSN based Pipeline monitoring. The next section details the WAN WSN control algorithm used in the Proteus design simulations. Algorithm I below was used to implement event localization in Proteus ISIS 7.6 as shown in figure 12.

WAN WSN Control Algorithm

Algorithm I: WAN WSN Transmission Algorithm {SHM}

For $S_n = N(1)$ to $N(3)$

() Wait for predefined period and store any Ready information received during this period

() Calculate the leakage event for each ready message information that is to be stored in the sensor node Media Access Control (MAC) table

() Send engagement to the WAN gateway with the best transmit energy.

If (Engagement acceptance is received)
Then open gateway &&
 Calculate the Sensor node ID))

Go To 1

1 **IF** (sensor node is in fixed linear status)
 2 **THEN** check if (targets event have been sensed)

3 **IF** (next node exists around the targets)

4 **THEN** check if (node clock ready)

5 **IF** (Clock ready Ok)
THEN send data

frames as Packets

6 **ELSE** locate the next node and check its radius/position; check the buffer content;

7 **ELSE** check all the MAC layer parameters && get ready for a Direct multihop flow **END IF**

8 **ELSE** Continue to move with linear angle

9 **ELSE IF** (sensor is in active status)

10 **THEN** Recording; receiving data; change status; processing, checking pipeline &waiting time; select next node to sink; send update via the node to sink;

11. **ELSE** Recording; keep tracking the linear path

12. Keep forwarding data to WAN Sink

13. **END**

From line 1 to line 13, the algorithm defines the transaction processes involved in the WAN framework for WSN monitoring and signal transmission to the gateway considering a linear status and handshaking of the nodes with the gateways.

The next section provides simulation snapshots that support the discussions in the previous section for necessary evaluation afterwards. The oil pipeline WSN sensors connects the linearly distributed pipeline network structure as depicted in figure 3. The simulation parameters follows a typical oil pipeline flow model as depicted in Table1 for both the battery model and the pipeline monitoring.

Simulation Configurations

This work used Proteus ISIS to implement the traffic design attributes which are listed in Table 1.

Table-1: Simulation Traffic Attributes (Authors Field Dataset)

S/N	CONFIGURATIONS /PARAMETERS	VALUES
1	No of Pipeline hierarchies	3-A,B,C
2	Rate Constant	1700
3	Centrifugal Pumps	6
4	Reference Angular Velocity	1.77e+03 rpm
4	Oil Pipe Line Type/Number	Resistive Pipes LP/21
5	Distances	500m-1500m
6	Pipeline Cross Section Type	Circular
7	Internal Diameter	Station_1.Pipe_diameter (1mm)
8.	Geometric Shape factor	1m
9.	Internal Surface Roughness Height	0.005mm
10.	Laminar Flow Upper margin	2e+03
11.	Turbulent Flow Lower margin	4e+03
12.	Reference Density	1000kg/m ³
13.	Number of Sensor Nodes	17sensors
16	Solver for Metrics	1-Linear Algebra (Sparse)
17.	No of Resistive Pipes – LP	21
18	Appendix I	Enabled

EVALUATION

In designing the proposed oil pipeline model, the main goals are to maintain convergence report event based on location action points, and create a real time reporting of triggered events from the base WSN to the WAN sink for auditing and profiling. The unified simulation subsystem for the WAN WSN monitoring is in two phases: the hardware subsystem at the remote WAN Sink and hardware subsystem at the pipeline network WSN end. Each of the subsystem is made up of the input, control and output interfaces.

Microcontroller embedded chip was implemented at the pipeline locations A, B and C, while logically connecting to the remote site-WAN Sink. An Algorithm was adopted in its full implementations

The output subsystem at the WAN Sink remote site (also encapsulated in figure 1) is made up the virtual terminal logically connected to the WSN controllers which displays the flow rate, pressure, temperature, etc on virtual terminal screen in real time . The output subsystem at the operator’s site (WAN Sink) shown in figure 1 is a virtual Graphical User Interface (GUI) comprising LED indicators, LCD, buzzer and Central Server. Proteus Virtual Simulation Module was used to develop the output subsystem.

The WAN WSN software that runs on the sensor controllers was implemented using the flow chart algorithm I. MIDE was also used to develop the program codes which is thereafter loaded in the virtual controller. Following the algorithm I, the central server

WAN receives the data sent from the remote WSNs, interprets it and displays the information on the virtual LCD. The server also compares the received data with predefined thresholds and activates alarm when the events for vandalization occurs signifying the danger state. Figures12 depicts the pipeline *monitoring* scenarios.

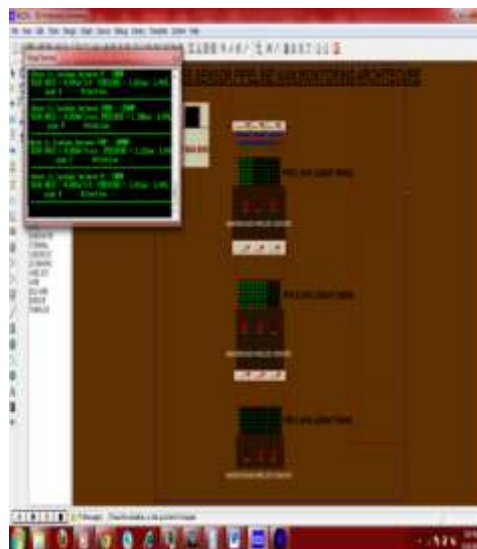


Fig-12 WAN WSN System Detection at Sink showing Vandalization at pipelines A, B and C

Conclusion/ Future Works

This paper has presented a framework for structural pipeline monitoring intended to be deployed in the existing pipeline facilities. The performance of

today's pipeline monitoring must satisfy the metrics of good energy conservation on the battery model, robust pipeline design, and WAWAN communication deployment. During the simulation, the data were captured via the Simevent "To Workspace block" for the battery model which inputs a signal and writes the signal data to the MATLAB workspace. The block writes the data to an array or structure that has the name specified by the block's variable name parameter while allowing for battery plot datasets. The data were collected and the plots were then generated. Using a remote network based facility; we obtained flexibility in monitoring, near precision, while noting the same distance. The pipeline model, the battery model and the unified model were shown to yield satisfactory results. This can be applied in oil and water managing scenario.

Future work will detail other practical application context where the proposed framework can be applied to solve immediate problems, while making recommendations for advancing research in this area.

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