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Design and Implementation of Pipeline Monitoring System Using Acceleration-Based Wireless Sensor Network

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--ABSTRACT--
A Micro-Electro-Mechanical Systems (MEMS) based wireless sensor network (WSN) is developed for nondestructive monitoring of pipeline systems. It incorporates MEMS accelerometers for measuring flow-induced vibration on the surface of a pipe to determine the change in water pressure caused by rupture and the damage location. This work presents an experimental investigation of the relationship between flow-induced vibration and the pressure fluctuations. Measurements of vibration were performed in pipe sections of a water-filled loop subjected to a wide range of flow rates. Experimental observations show that a sharp change in pressure is always accompanied by a sharp change of pipe surface acceleration at the corresponding locations along the pipe length. Statistical analysis of the measurement showed that there is a non-linear but proportional relationship between the water flow rate and flow induced vibration. Therefore, water pressure-monitoring can be transformed into acceleration-monitoring of the pipe surface. The latter is a significantly more economical alternative due to the use of less expensive sensors such as MEMS or other acceleration sensors.

KEYWORDS : *Acceleration, Vibration, Wireless Sensor Network, pressure fluctuations*

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I. INTRODUCTION

Everything from water to crude oil even solid capsule is being transported through millions of miles of pipelines in the Nigeria. The pipelines are vulnerable to losing their functionality by internal and external corrosion, cracking, third party damage and manufacturing flaws. If a small water pipeline bursts a leak, it can be a problem but it usually doesn't harm the environment.However, if a petroleum or chemical pipeline leaks, it can be environmental and ecological disaster [1]. To ensure the continued safe operation of the pipelines, continuous, remote, and real-time monitoring and assessment of the integrity of the pipelines is necessary. In pipeline monitoring and inspection, the ultimate objective is to identify the locations that have defects, and obtain an accurate measurement and assessment of the defects so that human operators can take appropriate actions to prevent further damage. Therefore detecting leakage and containing its negative effect is very important.The traditional physical patrolling system of pipeline monitoring is difficult and only provides observation where the patrolling team is present. Furthermore, current systems involve mobile equipment and significant manpower. Wireless Sensor networks (WSN) can be invaluable in providing a comprehensive, economic and effective solution [2]. This research work demonstrates an experimental investigation on the relationship between piping vibration and the pressure fluctuations, such that water pressure-monitoring can be transformed into acceleration-monitoring of the pipe surface. The latter is a significantly more economical alternative due to the use of less expensive sensors such as MEMS (Micro-Electro-Mechanical Systems) or other acceleration sensors and the use of non-invasive acceleration measurement facilitates the simple and cost-effective identification of damaged pipe.

II. RELATED WORKS

The use of Wireless Sensor Network to continuously monitor water system performance to detect any failure or security breach has been explored and studied by many researchers. The research approaches varied in their sensing techniques, mathematical formulation, data acquisition methods, and data processing algorithms. But the concept of modeling leak detection using the flow-induced vibrations of the pipe surface is rarely reported in the literature. Equally, there are little or none reported studies on experimental validation of the concept using Wireless Sensor Network, hence the need for this current work which aims at the verification of the concept of detecting leakage using flow-induced vibrations of the pipe experimentally.Bilman L in [3] shows that the methods of leak detection can be divided to external and internal leak detection systems. Leaks detection system of the gas pipelines should comply to leak detection, alarm generation, leak localization and estimation of the flow rate of leaking medium.

A sensor network platform for pipeline monitoring has been developed by Jin and Eydgahi [4] using acoustics sensing devices such as Lead Zirconate Titanate (PZT) sensors. Signals generated by the acoustic sensors propagate along the pipeline and can be used to infer defects in the pipeline such as corrosion. Defects are discovered when the signal generated does not show the cross-correlation values with a reference signal stored for the monitored region. Then, when a defect is detected and identified, an alarm message is sent to the human operator through communication links. Since this solution is based on the transmission and the detection of lamb waves and uses a simple triangulation method based on the time-of-arrival concept, several drawbacks can be noticed. First, the acoustic sensors are customized to the structure of the pipeline, making the solution inappropriate for other types of pipeline technologies. Second, the topology of the pipeline is made very simple, making the localization technique inefficient for complex pipeline topologies.

Stoianov et al. [5] proposed wireless sensor network, called PipeNet, with fixed nodes. It integrates sensors that are able to generate acoustic vibration and collect hydraulic and acoustic/vibration data at high sampling rates. It also provides algorithms to analyze this data to detect and locate leaks. The wireless network is set up to collect events and controls the sensors. It also allows every sensor to monitor its local area leak status signal, to detect leakage and locate it via cross-correlation of acoustic/vibration signals. Detection and localization are done through long term sampling and comparing collected data with previously leak-free data, cross-correlating the readings collected by closed nodes, and locating the maximum peak in the cross-correlation. In addition to the drawbacks mentioned for the first work, the uniformity of the liquid characteristics is very important for the efficiency of the location computation.Kim et al. [6] proposed a low cost, unmanned, fully automated in-sewer gas monitoring system, called SewerSnort. This system uses floating sensors for sewer gas concentration measurement. The floating sensors are introduced at the upstream station and drifted to the end pumping station, collecting location tagged gas measurements. The collected data provides gas exposure profiles to be used for preventive maintenance and/or repair. The localization of events detected by the sensors is based on the availability of fixed beacons set up on the manholes in the pipeline structure. The localization of the defects is simply determined by the identity of the manholes delimiting the segments containing the defects. This generates large errors, needs for more precise localization in the segment, and efforts for continuous power support (for the beacons, for example). In addition, one can notice that the floating sensor's ability to measure the gas exposure is limited because the flow level of the transported liquid, leaks, and dumps in the pipeline may reduce the gas concentration in the vicinity of their locations drastically.

In another approach focusing on the transport layer, Medidi et al [7] deployed a multi-hop wireless sensor network and proposed a transport protocol consisting of monitors and senders. Monitors in the network work as watchdogs to detect congestion and recover lost packets. Lin et al [8] studied the radio propagation and the determination of the path loss encountered between nodes in a wireless underground sensor network (WUSN) installed on fire hydrants and its above-ground relay nodes in a setting very similar to the ones carried by authors in [9] Finally, Misiunas et al [10] validated and tested the use of pressure transient for detecting water pipe breaking in lab setting and real networks. The study adapted the continuous monitoring technique and used a modified two-sided cumulative sum algorithm to detect abrupt break-induced changes in the pressure data. Although the technique successfully detected the location of the break, this technique is applicable to single pipelines under two conditions, the side pipe has to be smaller in diameter than the pipeline and the reflection characteristics of the end boundaries can be derived, which limit its application in the real field.
This work explores the possibility of developing a low-cost, nonintrusive, pipeline monitoring system based on the signal received from an accelerometer attached to the outside surface of the pipe, instead of pressure sensors that are traditionally installed invasively.

III METHODOLOGY

This thesis introduces a rupture detection method based on a wireless MEMS (Micro-Electro-Mechanical Systems)-sensor network that monitors the pipe surface acceleration typically at each network joint in a non-invasive manner and computes in real-time a measure of acceleration-change. In the experiment, MEMS sensors are installed at all the joints in the pipe network so that at least two end joints of every link of the network are monitored. When a rupture occurs in the network, the sudden disturbance in the water flow and pressure induces corresponding sudden change in the acceleration of pipe vibration. This change in the pipe acceleration is measured, and on the basis of these acceleration data, the location of the pipe rupture can be found in the pipe segment between the two end joints where the acceleration gradient values form local maxima. For the field test, rupture was simulated in the developed experimental pipeline testbed using a valve, the simulated events; include valve opening and closing, switching on and off the pumps, and water discharge. The result of these field measurements is validated using a flow meter.

III. COMPONENTS USED

Each component was carefully selected to ensure it was the correct choice for the sensor node and there would be no compatibility issues. This section details the choice of each component, especially the microcontroller and transceiver, and discusses the various features, interfaces components. A sensor node is made up of four basic components as shown in Figure 1: a sensing unit, a processing unit, a transceiver unit and a power unit. The Sensing unit is usually composed of two subunits: sensors and Analog Digital Converter (ADC)s. The analog signals produced by the sensors based on the observed phenomenon are converted to digital signals by the ADC, and then fed into the processing unit. The processing unit, which is generally associated with a small storage unit, manages the procedures that make the sensor node collaborate with the other nodes to carry out the assigned sensing tasks. A transceiver unit connects the node to the network. The power unit is one of the most important components of a sensor node and may be supported by a power scavenging unit such as solar cells.

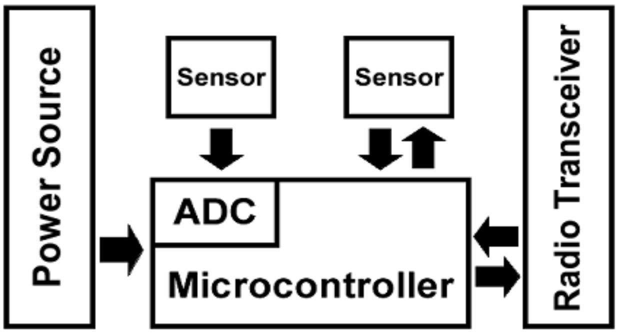

Figure 1 Node Hardware

The principal hardware used in this development includes;

- PIC18F2620 microcontroller
- Accelerometer (MMA7361 Model: 1156)
- Liquid flow sensor
- KYL-500S Transceiver
- 9V battery terminal for mobile operation
- LM7805CV voltage regulator
- RS232 serial port connector for connection to PC COM port

Theory of Operation : To understand how flow rate and vibration in a pipe are related, the basics of its micro-model are detailed. Water molecules on average all travel in the main direction of flow, as depicted in Figure 2. However, many molecules collide against the pipe wall. According to the first law of thermodynamics, some part of this kinetic energy converts to heat as the turbulent eddies dissipate, but most of it translates into potential energy in the form of pressure [11]. The pipe, in turn, deforms converting potential to kinetic (during deformation) and back to potential as deformation completes. The elasticity of the pipe material applies a restoring force. Evans shows [12] that vibration in a pipe results from this energy conversion cycle and is proportional to the average flow rate within the pipe.

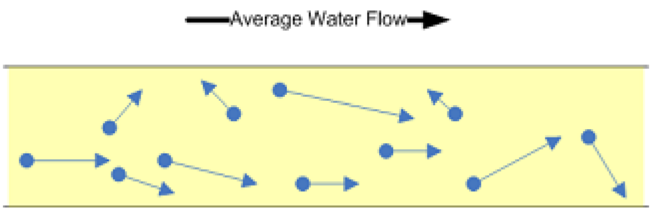

Figure 2: Microscopic view of the water flow in a pipe

When describing turbulent flow, it is convenient to recognize that the local velocity at a point may be regarded as superposition of an average value and instantaneous fluctuating value. The instantaneous velocity, u can then be written in terms of the time average velocity, $\bar{u}$, also called the mean velocity, and a fluctuation velocity u' as shown by Eq. (1)

$$u = \bar{u} + u' \quad (1)$$

The time average velocity $\bar{u}$ is defined as shown by Eq. (2). Where T_1 is a time large enough that $\bar{u}$ is the same for any longer time for steady flow. Therefore, the mean is independent of time and the time averages of the fluctuations are equal to zero.

$$\bar{u} \equiv \frac{1}{T_1}\int_0^{T_1} u\,dt \quad (2)$$

As stated earlier, as the molecules of the fluid approach the wall, they have kinetic energy. This kinetic energy must be converted to another form of energy as the molecules reach the pipe wall. According to the first law of thermodynamics, some of the kinetic energy is converted to heat as the turbulent eddies dissipate, but most is converted into potential energy in the form of pressure

Consider a turbulent flow through a horizontal pipe of circular cross section as shown in Fig.2. The velocities of the fluid can be expressed in terms of a time average and a fluctuation as shown by Eqs. (1) and (3).

$$v = \bar{v} + v' = v' \quad (3)$$

In Equations (1) and (3) u is the velocity in the direction of the primary pipe axis and v is the velocity perpendicular to the pipe axis. Since there is no net flow in the direction perpendicular to the pipe axis, the time-averaged flow in that direction is zero and so the instantaneous flow is just equal to the fluctuation. Although the time averages of the fluctuations in any direction are zero, the time average of the products, such as $u'v'$ are not equal to zero.

Prashun [13] states that in general, it can be shown that the time average of the product of the velocity fluctuations is less than zero as shown by Eq. (4)

$$\overline{u'v'} < 0 \quad (4)$$

The author also demonstrated that for a circular conduit of radius,r the shear stress,τ at the wall can be related to the pressure,p as shown by Eqs. (5) and (6)

$$\tau = -\frac{r}{2}\frac{dP}{dx} \quad (5)$$

$$\frac{dp}{dx} = P' = -\frac{2\tau}{r} \quad (6)$$

From the Navier-Stokes equations, Prashun also demonstrated that for turbulent flow, the turbulent shear stress can be expressed as shown by Eq. (7)

$$\tau = -P\overline{u'v'} \quad (7)$$

Combining Equations (6) and (7) shows that the pressure fluctuation, P', is proportional to the fluctuation of the fluid velocity as shown by Eq. (8)

$$P' \propto \overline{u'v'} \quad (8)$$

It can also be shown that the pipe vibration is proportional to the pressure fluctuations in the fluid. For this analysis, the fluid-filled piping system can be depicted as a one-dimensional model of a beam as shown in Fig .3.

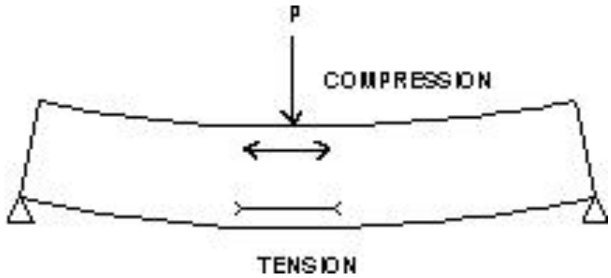

Figure 3: Fluid-filled pipe as a one-dimensional Beam

It is well known from structural mechanics that the rate of change of the moment along a beam is equal to the shear and the rate of change of shear,$\frac{dV}{dx}$, along the length of the beam and this is equal to the pressure fluctuations, $P'(x)$, per unit length as shown by Eq.(9) [14].

$$\frac{d^2M}{dx^2} = \frac{dV}{dx} = P'(x) \quad (9)$$

When a beam is subjected to bending, one side of the beam is in tension while the other side is in compression. Differentiating the well known Flexure Equation, given by Eq. (10), twice with respect to x, then using the relationship for $P'(x)$ from Eq. (9) gives the results in Eq. (11).

$$M = EI\frac{d^2y}{dx^2} \quad (10)$$

$$\frac{d^2M}{dx^2} = EI\frac{d^4y}{dx^4} = P^{'}(x) \qquad (11)$$

In order to relate the pressure fluctuations to the pipe acceleration, $\frac{d^2y}{dt^2}$, consider the differential equation of motion for transverse vibration of a beam as given by [15] in Eq. (12).

$$\frac{d^2y}{dt^2} = -\frac{EIg}{A\gamma}\frac{\partial^4y}{\partial x^4} = -\frac{g}{A\gamma}EI\frac{\partial^4y}{\partial x^4} \qquad (12)$$

Where:
A =cross sectional area of the beam
γ =Specific weight of the beam
g =acceleration of gravity
EI = flexural rigidity
Since g, A, and g are constants, Eq. (12) can be rewritten as shown by Eq. (13)

$$\frac{d^2y}{dt^2} = -CEI\frac{\partial^4y}{\partial x^4} = -CP^{'}(x) \qquad (13)$$

Where $C = \frac{g}{A\gamma}$

Equation (13) indicates that the acceleration of the pipe is proportional to the pressure fluctuations in the fluid. This experimental research is based on this premise. The principle of operation is based on the relationship between the standard deviation of the pipe vibration and the mean flow rate of the fluid in the pipe. Blake stated in [16] that the generation of vibration by fluid motion involves the reaction of fluids and solids to stresses imposed by time-varying flow. For dynamically similar flows, the ratio of the flow fluctuations to the average flow is constant. Bird shows [17] this relationship by noting that the oscillatory term is the time average of the absolute magnitude of the oscillation, given by $\sqrt{m}$ where m = $u^{'2}$. This is defined as "intensity of turbulence", which is a measure of the magnitude of the turbulent disturbance, and is given by $\frac{\sqrt{m}}{\bar{u}}$. From the definition of turbulent flow, the intensity of turbulence expression is rearranged as

$$\frac{\sqrt{m}}{\bar{u}} = \frac{m}{\bar{u}^2} = \frac{\frac{1}{N}\sum_{i=1}^{N}[u_i(t)-\bar{u}]^2}{\bar{u}^2} = C \qquad (14)$$

where,
$\bar{u}$: average velocity
u: instantaneous velocity.
Multiplying both side by the number of points N and $\bar{u}^2$, and dividing by N − 1, results in

$$\frac{1}{N-1}\sum_{i=1}^{N}[u_i(t)-\bar{u}]^2 = \frac{NC}{N-1}\bar{u}^2 = k\bar{u}^2 \qquad (15)$$

This shows that the flow fluctuations are proportional to the pressure fluctuations and the pressure fluctuations are proportional to the pipe vibration. It follows that the standard deviation of the pipe vibration is proportional to the average flow rate. This result does not necessarily imply that the water flow rate in a pipe is linearly proportional to the vibration of the pipe. Instead, it implies that it has a non-linear but proportional relation due to the non-linear characteristics of vibration sensors, pipe structure, turbulence, etc.

IV. EXPERIMENTAL TESTBED

To demonstrate the concept of Leak detection using the flow-induced vibrations on the pipe surface as shown in Eq.(13);

$$\frac{d^2y}{dt^2} = -CEI\frac{\partial^4y}{\partial x^4} = -CP^{'}(x) \qquad (13)$$

a mini water pipeline testbed was setup behind the block A wing of Prof. Gordian Ezekwe Faculty of Engineering building, Nnamdi Azikiwe University Awka Anambra State, Nigeria with longitude and latitude of 6.258°N,7.103°E The asymmetrical testbed has the dimension of 36 x 18 ft with 6 PVC pressure pipes of 2 inch diameter with 3 valves and also 6 PVC pipes of ½ inch diameter. The acceleration-based sensor is attached on each wing of the network and the valves are used to emulate multiple ruptures. The ½ inch water pipe is equipped with a commercial water flow meter that generates a pulse train proportional to the flow rate. This pulse train is connected to the developed customized wireless sensor node that provides the base station with real-time flow rate measurements. To verify the theory as explained above, simple experiments were carried out. In the experiments, rupture was simulated by the opening and closing of the valves. The valves were adjusted manually to three different stages: closing, half-opening and complete opening, where closing means high pressure and no water flow; half-opening means medium pressure with water flowing; and complete opening means low pressure with water flowing. The accelerometers were attached on the 2 inch pipes, and pipe accelerations were measured during the process of opening and closing of the valves. We measured the vibration occurring on the pipes while changing the flow rate of the water running through it. Figure 3 shows the engineering of the testbed drawing drawn to scale and the outline of the developed testbed

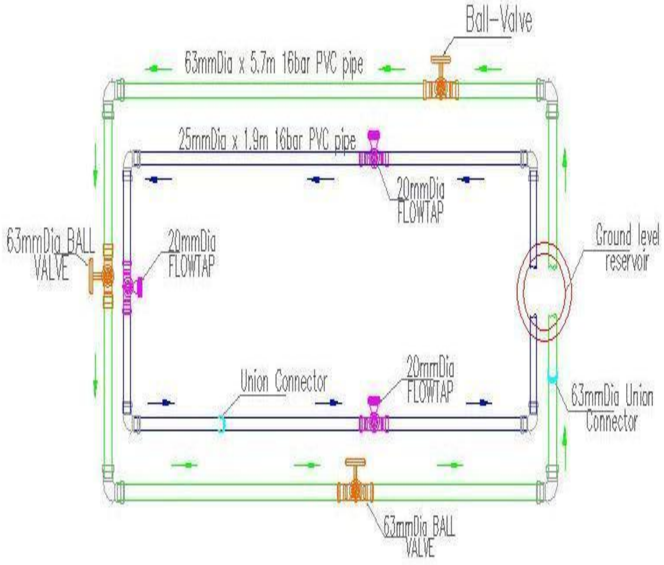

Figure 4: Experimental Testbed Outline.

V. RESULT AND ANALYSIS

The acceleration (vibration) and Flow rate data were measured and recorded (see Table 1) using the customized wireless sensor nodes developed for the experimental testbed. The experiment was done in stages corresponding to various degrees of rupture that were emulated. The valves were adjusted manually to three states: closing, half-opening, and complete opening, where closing means high pressure and no water flow; half-opening means medium pressure with water flowing in the pipe network; and complete opening means low pressure with water flowing. The half-opening case is similar to normal water distribution system with ambient noise. Initially, the valves were closed to allow the pressure to build up gradually, and after 20seconds the valves were half opened and allowed to stay in that position for about 10seconds before closing, and subsequently the valves were completely opened after another 20seconds after staying in that position for about 10seconds the valves were closed. This procedure provided not only a semi steady state water pressure inside the pipe network but also an ambient noise due to water flowing inside the pipe. Recording of the acceleration of the pipe surface and the flow rate of the water began after the water has been injected into the network and reached steady state, and recording was stopped a few seconds after valves have been closed when the valves were forced opened completely to simulate a pipe rupture. These data were processed in the form of distribution charts and graphs and subsequently analyzed to lay credence to the set objectives of the study.

Table 1: Recorded data for the flow rate, vibration and node voltage

Time (s)	Flow rate (L/min)	Vibration (g)	Voltage (V)
1	0	-0.156	8.98
2	0.534	-0.109	8.98
3	1.578	-0.054	8.98
4	2.586	0	8.98
5	4.509	0.058	8.96
6	6.505	0.123	8.96
7	8.806	0.158	8.93
8	10.570	-0.158	8.93
9	10.518	-0.105	8.91
10	10.525	-0.058	8.90
11	10.530	0	8.90
12	10.575	0.057	8.87
13	10.580	0.109	8.85
14	10.580	0.157	8.85
15	10.580	-0.157	8.36
16	10.580	-0.103	8.34
17	10.580	-0.056	8.30
18	14.908	0	8.08
19	15.108	0.056	8.08

20	15.257	0.109	8.08
21	15.509	0.158	7.94
22	15.665	-0.158	7.92
23	15.804	-0.107	7.92
24	15.805	-0.059	7.92
25	15.805	0	7.88
26	15.805	0.059	7.82
27	15.805	0.108	7.82
28	15.805	0.156	7.79
29	15.805	0.209	7.73
30	10.988	0.250	7.72
31	10.656	-0.250	7.72
32	10.580	-0.204	7.72
33	10.580	-0.157	7.65
34	10.580	-0.106	7.63
35	10.581	-0.054	7.49
36	10.581	0	7.42
37	10.581	0.053	7.35
38	14.985	0.109	7.32
39	15.106	0.156	7.31
40	16.897	-0.156	7.22
41	17.504	-0.108	7.20
42	18.798	-0.054	7.20
43	19.560	0	7.17
44	21.566	0.053	7.12
45	22.504	0.107	7.11
46	22.504	0.154	6.98
47	22.506	-0.154	6.98
48	22.505	-0.102	6.97
49	22.505	-0.056	6.92
50	22.505	0	6.87
51	22.505	0.059	6.84
52	20.098	0.108	6.70
53	19.805	0.158	6.68
54	17.006	0.204	6.62
55	16.987	0.251	6.58
56	15.525	0.306	6.53
57	14.894	0.400	6.53
58	13.073	-0.400	6.51
59	12.157	-0.305	6.46
60	11.455	-0.256	6.40
61	10.982	-0.153	6.39
62	10.851	-0.106	6.35
63	10.580	-0.053	6.30
64	10.580	0	6.26
65	10.580	0.058	6.21
66	10.580	0.107	6.15
67	10.580	0.159	6.09
68	10.580	-0.159	6.01
69	10.580	-0.104	5.98
70	10.580	-0.054	5.93
71	10.581	0	5.90
72	10.581	0.053	5.88
73	10.581	0.109	5.83
74	10.581	0.155	5.80
75	10.581	-0.155	5.80

Figure 5 below shows that according to the theory supporting the design of the system for monitoring of rupture in water pipeline using information from the pipe accelerations, that pressure fluctuations along the pipe occasioned by a rupture is always accompanied by a sharp change in pipe surface acceleration at the corresponding locations along the pipe length. This relies on the hypothesis that rupture of considerable size in the system causes sudden expulsion of water, resulting in abrupt change in the force on the pipe internal wall to enhance the vibration of the system. From the figure it is shown that there is a sharp change in the acceleration of the pipe surface at 28seconds and 55seconds, when the valves were half opened and completely opened respectively.

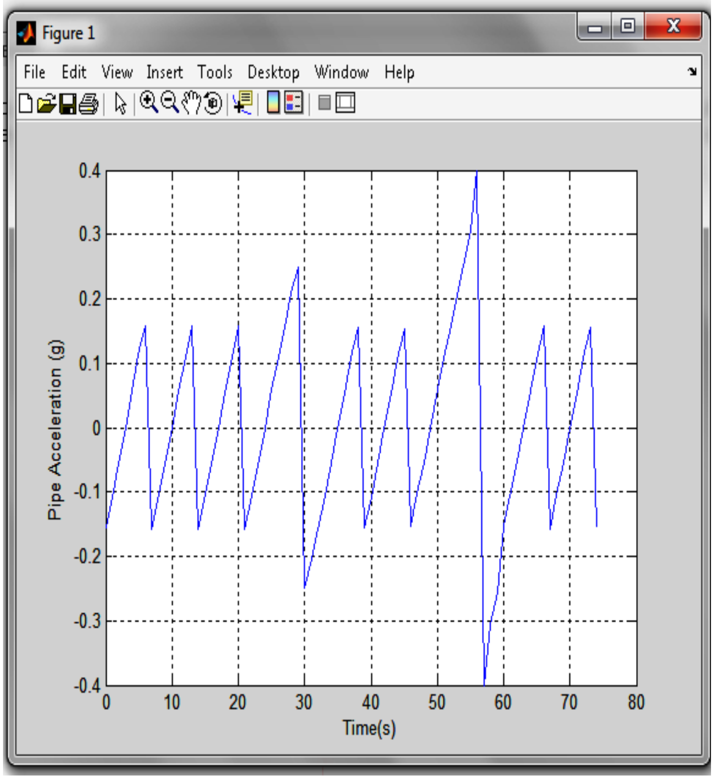

Figure 5: Plot of pipe acceleration (vibration)

From the equation governing the theory of operation which is given by Eq 13, as

$$\frac{d^2y}{dt^2} = -CP'(x)$$

Where

$\frac{d^2y}{dt^2}$ is the pipe acceleration (vibration)

$C = \frac{g}{A\gamma}$ with A =cross sectional area of the beam

γ =Specific weight of the beam

g =acceleration of gravity (9.81m/s^2)

$P'(x)$ is the pressure fluctuations. The minus sign comes from a decreased pressure along the direction of flow. Here, the water-filled pipe is modeled as a one dimensional beam and the specific weight of the beam defined as weight per unit volume is mathematically given as

$$\gamma = \rho g \qquad (16)$$

Where

ρ is the density of the water-filled pipe (beam) and

g is the acceleration due to gravity (9.8m/s^2)

But density is defined as mass per unit volume of the beam $\rho = \frac{M}{V}$ and the mass of the water-filled pipe is obtained from the relationship between the mass and weight of the water-filled pipe $M = \frac{W}{g}$ (17)

W is the weight of water-filled pipe given in standard Table [16] as 3Kg/m for a 2 inch PVC pipe, substituting for the weight and the acceleration due to gravity the mass is given as

$$M = {}^{3}/_{9.81} = 0.3058Kg.$$

The volume is obtained by using the relationship between the area of the pipe and a unit length of the pipe which is given as L=5.49m (18ft). The area of the pipe is given as

$$A = \pi\frac{d^2}{4} \qquad (18)$$

And from Table the outer diameter of a 2 inch PVC pipe is given as 60.3mm (0.0603m), and upon substitution the area becomes

$A = 2.856 \times 10^{-3}m^2$

Therefore, the volume is given as
$V = AL = 2.856 \times 10^{-3} \times 5.49 = 0.01568m^3$
The density of the beam will then be
$\rho = \frac{Mass}{V0lume} = {0.3058Kg}/{0.01568\,m^3} = 19.503Kg\,/m^3$
Finally, the specific weight of the water-filled pipe (beam) is given as
$\gamma = \rho g = 19.503 \times 9.81 = 191.32N/m^3$
Upon rearrangement of Eq.18, the pressure fluctuations is given as

$$P'(x) = -C\frac{d^2y}{dt^2} \quad (19)$$

And C becomes
$C = \frac{A\gamma}{g}$
With
$A = 2.856 \times 10^{-3}m^2$ and $\gamma = 191.32N/m^3$,
then C becomes
$C = \frac{A\gamma}{g} = {2.856 \times 10^{-3} \times 191.32}/{9.8} = {0.546}/{9.8} = 0.0557$
With the above value for C, equation (19) the will be given as

$$P'(x) = -0.0557\,\frac{d^2y}{dt^2} \quad (20)$$

To validate empirically the correspondence between the acceleration of the pipe surface (vibration) and the change in pressure, linear correlation analysis is performed on equation (20), using the recorded data for the vibration. Table 2 below shows the respective values of the acceleration and its pressure fluctuations.

Table 2: Measured acceleration and predicted pressure fluctuations.

Vibration(g)	$P'(x)$
-0.054	-0.003008
-0.058	-0.003231
-0.109	-0.006071
-0.123	-0.006851
-0.156	-0.008689
-0.158	-0.008801
-0.204	-0.011363
-0.209	-0.011641
-0.250	-0.013925
-0.256	-0.014259
-0.305	-0.016989
-0.400	-0.022280
0.054	0.003008
0.108	0.006016
0.159	0.00886
0.208	0.01159
0.251	0.013981
0.306	0.017044
0.404	0.022503
0.406	0.022614

Using the MATLAB code, the correlation coefficient of the data in Table 2 was obtained as 1.000. The correlation analysis, which is a method for establishing the degree of probability that a linear relationship exists between the variables, and the coefficient representing the normalized measure of the strength of the linear relationship between them. With a correlation coefficient of 1.00, it has confirmed empirically that there is indeed a positive linear relationship between the variables (pressure fluctuations and acceleration). This therefore, supports the idea that leaks in pipeline can be detected using acceleration of the pipe surface. As stated earlier and supported by equations 16-to-20, this theory is a function of pipe material and pipe diameter.

VI. CONCLUSION

In this research work, a novel water-pipe damage detection method based on time-correlated acceleration data collected using a wireless MEMS-sensor network from different joints of a water distribution system. It incorporates MEMS accelerometers for measuring vibration on the surface of a pipe to determine the change in water pressure caused by rupture and the damage location. Experimental observations show that a sharp change in pressure is always accompanied by a sharp change of pipe surface acceleration at the corresponding locations along the pipe length. Therefore, water pressure-monitoring can be transformed into acceleration-monitoring of the pipe surface. To enhance the accuracy of detecting damage location in a larger-scale water distribution system, many improvements are needed. Further study is needed to correctly analyze the situations in sharp bends and T-joints and to understand the pipe vibration under the ambient and transient hydraulic conditions.

REFERENCES

[1] Dr. p.c. Nwilo and O.T Badejo "Impacts of oil spillage along Nigerian coast". The Association for Environmental Health and Sciences. 2001

[2] Tapanes, E. " Fibre Optic Sensing Solutions For Real-Time Pipeline Integrity Monitoring", 2011

[3] Bilman L., Isermann R. Leak detection methods for pipelines, Automatica, 23, no. 3, 1987, pp. 381-385,

[4] Yuanwei Jin and Ali Eydgahi. "Monitoring of distributed pipeline systems by wireless sensor networks". In Proceedings of the 2008 IJAC-IJME International Conference, Nashville, TN, USA, 2008.

[5] Stoianov, I., Nachman, L., Madden, S., and Tokmouline, T. "PIPENETa wireless sensor network for pipeline monitoring." Proceedings of the 6th international conference on Information processing in sensor networks, ACM, 264-273, 2007.

[6] Jihyoung Kim, Jung Soo Lim, Jonathan Friedman, Uichin Lee, Luiz Vieira, Diego Rosso, Mario Gerla, and Mani B Srivastava. "sewersnort: A drifting sensor for sewer gas monitoring". In Sixth Annual IEEE Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks (SECON 2009), 2009

[7] Medidi, S., Miller, S. M., Cooper, C., and Medidi, M., "Efficient sensor network for monitoring water distribution and waste water collection systems," tech. rep., Boise State University and SPF Water Engineering, LLC, Boise, ID

[8] Lin, M., Wu, Y., and Wassell, I., "Wireless sensor network: Water distribution monitoring system," in [Proceeding of Radio and Wireless Symposium], (2008).

[9] Hunaidi, O. and Wang, A., "Acoustic methods for locating leaks in municipal water pipe networks," in [Proceedings of International Conference on Water Demand Management], (May 2004).

[10] Misiunas, D., Vitkovsky, J., Olsson, G., Simpson, A., and Lambert, M., "Pipeline break detection using pressure transient monitoring," Journal of Water Resources Planning and Management 131 (July 1 2005).

[10] Pittard, M. T., and Blotter, J. B, "Numerical modeling of les based turbulent flow induced vibration". ASME International Mechanical Engineering Congress & Exposition (2003).

[11] Evans, R. P., Blotter, J. D., and g. Stephens, "A. Flow rate measurements using flow-induced pipe vibration". Transactions on the ASME 126 (2004), 280.

[12] Prashun, A. L. Fundamentals of fluid mechanics.Prentice Hall, Englewoo Cliffs, NJ, pp. 202 222,Chap. 7. (1980)

[13] Thomson, W. T., and Dahleh, M. D., 1998, Theory of Vibration with Applications 5th ed., Prentice-Hall, Inc., Upper Saddle River, NJ, pp. 258–286, Chap.9.

[14] Seto, W. W., 1964, Theory and Problems of Mechanical Vibrations, Schaum Publishing Co., NY, pp. 128, Chap. 5.

[15] Blake, W. K., Mechanics of Flow-Induced Sound and Vibration, Academic Press Inc., Harcort Brace Jovanokich Publishers, Orlando, FL, pp. 1–43, 1, Chap. 1.

[16] Bird, R. B., Stewart, W. E., and Lightfoot, E. N., 1960, Transport Phenomena John Wiley and Sons Inc., NY, pp. 153–179, Chap. 5.

[17] Pipe Hanger Spacing & Weight Chart. Web: www.guenthersupply.com. Accessed on 21st July, 2014.