



## Pipeline Control Systems: A Review of Surveillance Methods and Applications in the Nigeria Oil and Gas Sector

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### ABSTRACT

Pipeline is a very important infrastructure to the oil and gas industry that is used to transport petroleum and its associated products from one location to another. Improper monitoring, control and surveillance of pipeline infrastructures would lead to serious damages to the environment in the form of oil spillage and gas flare. This paper reviews existing surveillance methods and their applications in the oil and gas sector in Nigeria. The human/biological method employs dogs, human personnel, smart pigging and helicopters as its technique; having the highest industrial penetration of 47.5%. The Remote sensing method consist of satellite remote sensing and unmanned Aerial Vehicle (UAV) having 0% industrial penetration in the Nigerian oil and gas industry. The supervisory control method consists of Supervisory Control and Data Acquisition (SCADA), Distributed Control System (DCS), Wireless Sensor Network (WSN) and Internet of Things (IoT) with 16.9% industrial penetration in the Nigerian oil and gas sector. The robotics and artificial intelligence (AI) method is a very recent method yet to have any significant industrial penetration in the oil and gas sector but has a promising future in the industry. This paper will serve to guide stakeholders in choosing the appropriate surveillance methods for pipeline surveillance and control.

### ARTICLE INFO

Article History  
Received: May, 2021  
Received in revised form: June, 2021  
Accepted: July, 2021  
Published online: October, 2021

### KEYWORDS

Petroleum, oil and gas, supervisory control, wireless sensor network, pipeline control, monitoring

### INTRODUCTION

The major function of pipelines in the oil and gas industry is to transport petroleum and its associated products from one location to another. This made pipelines a very important infrastructure to petroleum industry (Rehman & Nawaz, 2017). The control, monitoring and protection of these pipelines is of paramount importance to attain maximum efficiency in the business of oil and gas both in the upstream, midstream and downstream sector of the petroleum industry (Boaz, Kajjage, & Sinde, An overview of pipeline leak detection and location systems, 2014) (Adegboye, Fung, & Karnik, 2019) (U, G, O, & Awotunde, 2016). Lack of such pipeline protection and control could cause serious damage to the environment through oil spillage and gas flaring. In 2015, Shell Petroleum Development Company (SPDC) reported a total of 131 spill incidents in the Niger Delta Region, and about 2,814,300 liters of oil was released into the environment (SPDC, n.d.). The key interest is to

transport crude oil and its products from various production points to designated markets safely and in the most economical manner possible. Over the years, pipeline systems have grown in size and complexity due to business requirements and the need for interconnections between pipeline systems as well as environmental concerns and safety issues requiring more sophisticated monitoring and control system. (Adegboye, Fung, & Karnik, 2019). An important aspect in the transporting of crude oil and its products through a pipeline system is the need to remotely monitor and carry out certain operations through a central control system. Functions of a complete pipeline control system include data acquisition and reporting, operator control, pump/compressor control, valve control, nominations, scheduling, custody transfer, imbalance measurement, billing, pipeline modeling, batch tracking for liquid pipelines, pump/compressor optimization and leak detection (Browne, 20001). Physical variables



such as pressure, temperature, gas composition, flow rate, pump/compressor status and valve status in a pipeline control system are measured at many locations by field instruments. This paper presents an overview of the various existing technologies that finds applications in a pipeline control system. It grouped existing methods in pipeline control systems viz: Human surveillance/Biological control, Remote sensing control, and Supervisory Control and Robotic systems.

### EXISTING METHODS OF PIPELINE CONTROL AND MONITORING

#### *Human Surveillance/Biological Control*

This method refers to the traditional means of inspection of pipeline infrastructures through human surveillance, trained dogs, personnel-manned helicopters and smart pigging (Boaz, Kajjage, & Sinda, An overview of pipeline leak detection and location systems, 2014).

#### *Human surveillance*

This method engages the services of company security personnel who are trained to walk along the pipelines to take meter readings of pipeline parameters at a given interval of time and equally looks out for anomalous conditions in the pipeline environment and for possible leakage detection along the pipeline through visual inspection. In the Nigeria oil and gas environment, these company security personnel liaise with other security stakeholders such as community dwellers, vigilantes etc. to secure the company's facility. (Chukwuemeka & Ngozi, 2017). State security outfits such as Nigeria Security and Civil Defense Corp (NSCDC), Nigeria Mobile Police Force, the military and the Nigerian Navy usually form a joint task force (JTF) operation in pipeline surveillance operations in conjunction with company security personnel. The company security personnel provide communication, organization, coordination and the necessary information needed for a smooth operation (M., 2014) (Quarter, 2914). Though human surveillance is slow in response and of average sensitivity of about 42%, it has

been of long use with industrial penetration of about 70% as shown in Table 1.

#### *Trained Dogs*

Trained dogs accompanied with personnel can recognize defects and leaks by visual observation and smells. Dogs are ineffective long operations not more than 30-120 minutes (Garner, et al., , 2001). This method applies only to onshore pipeline networks. (Murvay & Silea, 2012). This technique is very slow in response and has attracted low industrial penetration but presents a very low operational cost as seen in table 1.

#### *Helicopter surveillance*

Helicopter carrying security personnel is flown across pipeline network tracts to look out for possible leak or illegal activities on the pipelines by oil thieves. This technique only works for visible pipelines and is ineffective in areas covered with bush as this can cause visibility problems for the pilot (Quarter, 2914). The use of helicopters is moderate in response time and quite expensive hence attracting low industrial penetration.

#### *Smart Pigging*

Another technique used under this method is smart pigging. Smart pigging is a technique in which an inspection probe (referred to as the pig) is made to flow through a pipeline while gathering information on pipeline condition (S.N, J.P, E, & A, 1996). In the use of pigging, the pig is equipped with sensors and data loggers to record pipeline parameter readings. This technique is fast, sensitive (about 60%) and has about 60% penetration into the industry as shown in table 1. Up till now, human surveillance remains the most used method in the Nigerian oil and gas industry. Workers and security dogs move round designated pipeline routes to detect possible leaks. The method is difficult to detect hidden leaks. (Batzias F A & M, 2011). Table 1 and Figure 1 show the characteristics of the human surveillance/biological control method.

**Table 1:** Characteristic Comparison of Human surveillance /biological control

Technique	Dogs	Humans	Smart pigging	Helicopters	References
Response time	Very slow	Slow	Fast	Moderate	(Garner, et al., , 2001)
sensitivity	40%	42%	60%	47%	(Murvay & Silea, 2012)



Technique	Dogs	Humans	Smart pigging	Helicopters	References
Operational time	120 mins	180 mins	1176 mins	168 mins	(Garner, et al., , 2001)
Industrial penetration	30%	70%	60%	30%	(M., 2014) (Quarter, 2914)
Maturity	15 years	50 years	30 years	35 years	(Garner, et al., , 2001) (Government, 1990)
Operational Cost	NGN 1 million per annum	NGN 20 million per annum	15 million pe annum	15 million per annum	(M., 2014) (Garner, et al., , 2001) (Quarter, 2914)

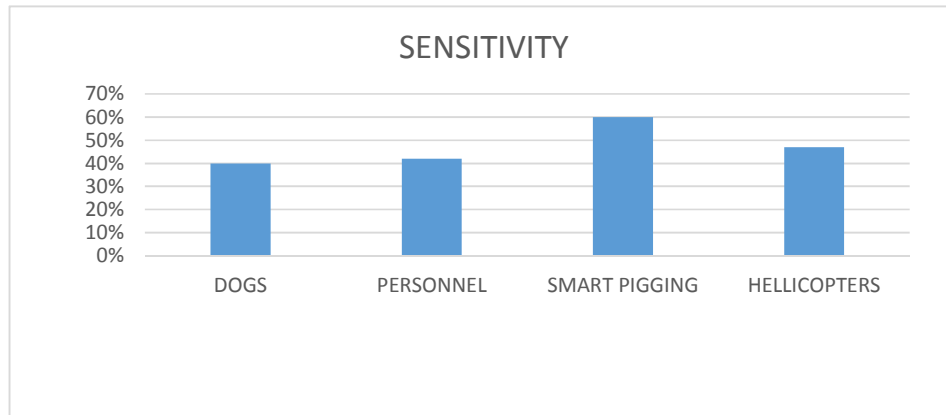


Figure 1a: Sensitivity of Humna/biological technique

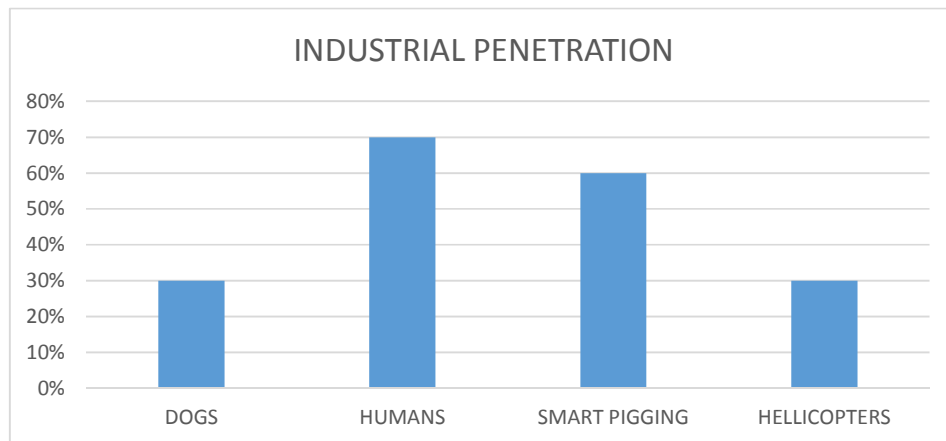


Figure 1b: industrial penetration of human/biological technique

#### Remote Sensing

This method deals with the use of unmanned aerial vehicles (UAV) and satellite in pipeline control systems.

#### Unmanned Aerial Vehicles (UAV)

Airborne remote sensing involves using sensors on an airborne platform such as an unmanned aerial vehicle (UAV) to monitor the state of a pipeline and equally detect spills on the



ground or at sea. The sensors attached to the UAV provide the necessary data signal for extensive analysis of the pipeline. Fixed wing UAVs can cover a wide area of pipeline route with respect to its flying speed as well as energy consumption rate. Multi-drone UAVs makes it possible to obtain maximum details for medium and small areas to ensure detailed scanning of subsurface pipelines (Benyeogor, Olatunbosun, & Kumar, 2020). RGB photo and/or video cameras as well as spectral cameras and thermal imaging cameras are installed on the UAVs for analysis of the infrared spectrum band of the pipeline region (Ejofodomi O. , 2020) (Kochetkova, 2018). Mbadiwe et al. (Benyeogor, Olatunbosun, & Kumar, 2020), Ejofodomi and Ofualagba (Ejofodomi O. , 2020) (Kochetkova, 2018) and other indigenous researchers have done extensive research on UAV remote sensing method. They have made attempts to present their research breakthrough to relevant regulatory bodies in the oil and gas sector for possible adoption and industrial application. This technique has a fast response time of about 15 minutes with a sensitivity of about 60% as shown in Table 2 and Figure 2.

#### Satellite Sensing

Satellite remote sensing involves utilizing sensors on a space-based platform.

Satellites orbiting the earth capture images of the surface of the earth. This technique has been employed in recent times for pipeline monitoring especially in the area of pipeline leak detection. The delivery time of satellite images is between 3-5 hours and can pass over a land area once a day. Attempts have been made to replace airborne sensing with space-based sensing, but not many sensors can be used in space. Also satellite remote sensing requires a clear sky and good weather conditions. The frequency and timing of the overpass is also a major challenge with satellite remote sensing. (Ejofodomi O. , 2020)

The detection, mapping and monitoring using the remote sensing method are problematic in regions like the Niger Delta because of canopy cover, cloud cover, inaccessible nature of the ecosystem, and insecurity (Ejofodomi & Ofualagba, 2016). Satellite sensing has a very slow response time of about 300 minutes, maturity of about 10 years and has about 33% sensitivity as shown in Table 2. The industrial penetration of the remote sensing method has less impact in the Nigeria oil and gas sector as none of these existing oil companies (local and international oil companies) has adopted this method for the control and surveillance of pipeline infrastructure.

**Table 2:** Characteristic Comparison of Remote sensing

	UAV	SATELLITE REMOTE SENSING	References
Industrial Penetration	Not in use	Not in use	(Ejofodomi O. , 2020) (Kochetkova, 2018) (Benyeogor, Olatunbosun, & Kumar, 2020)
Response time	15 mins	300 mins	(Benyeogor, Olatunbosun, & Kumar, 2020) (Ejofodomi O. , 2020) (Ejofodomi & Ofualagba, 2016)
Operational cost	NGN 10 million	NGN 700 million	(corporation, 2011) (ACL, n.d.) (GROUP, n.d.)
Maturity	12 years	10 years	(ACL, n.d.) (GROUP, n.d.)
Sensitivity	67%	33%	(Be.Do, n.d.) (corporation, 2011)

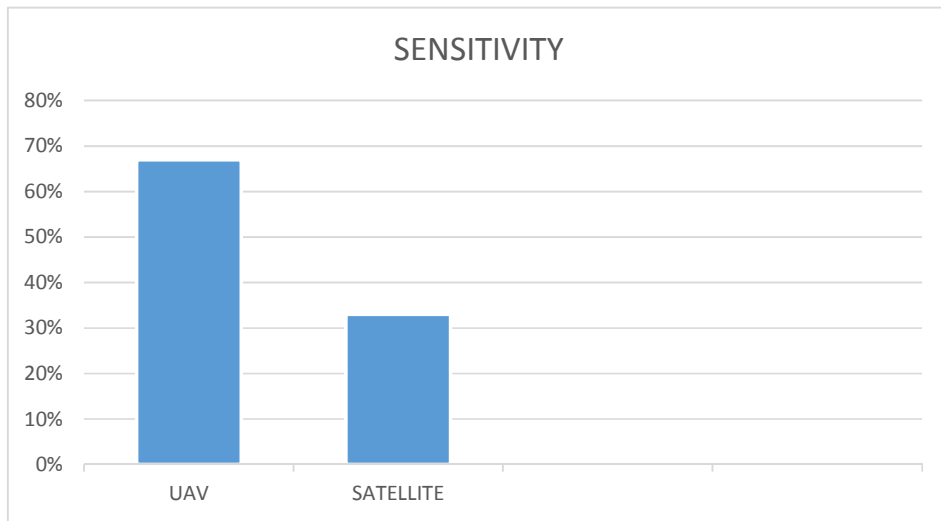


Figure 2a: Maturity of techniques used in remote sensing method

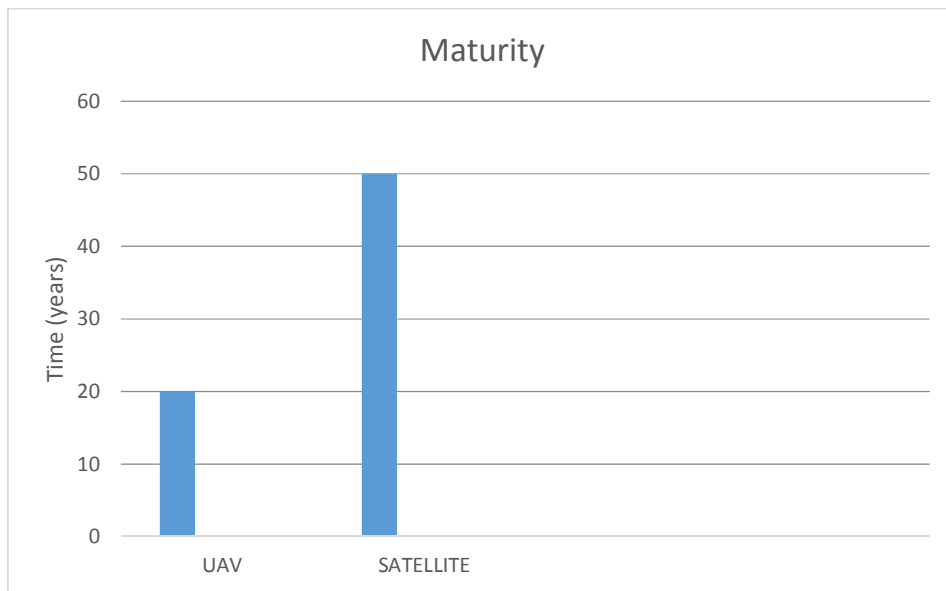


Figure 2b: Sensitivity of techniques used in remote sensing method

#### SUPERVISORY CONTROL

A Supervisory Control system is a system that has the ability and intelligence to perform controls with minimal or no human supervision. Supervisory Control and Data Acquisition (SCADA), Distributed control system (DCS) and Internet of Things (IoT) are supervisory systems employed in pipeline operations.

#### Supervisory Control and Data Acquisition (SCADA)

Supervisory Control and Data Acquisition (SCADA) is an intelligent system which performs supervisory control and data acquisition on control systems such as pipeline control systems. Pipelines require a control system which is very different from other types of control systems require a low speed, limited bandwidth communications over long



distances; hence SCADA system is employed. In a SCADA system, data is transferred in small packets. Constant data such as controller ID data are stored in the central database, not in the field controller. Operating data is stored in controllers for intermittent polling and communications are minimized by designing controllers to report by exception for a change of status.

Communication links must be verified with each report and the sequence of events is often recorded in the controllers so that history can be re-established if communication links are interrupted. The Data Acquisition part of the SCADA system is responsible for collecting data from the field and storing in a database where it is available to other functions on the system. Each item of data is generally called a tag and SCADA systems can collect data from hundreds of thousands of points many times each day. A standard requirement of pipeline control systems is the collection of large amounts of historical information about each point. The Human Machine Interface (HMI) is responsible for much of the Supervisory Control part of the SCADA system. At this point, an operator can call up graphic displays showing the current values of the point in database and send changes to field devices for appropriate control actions on the pipeline in the field (Browne, 20001) (Subramanian, 2008) (SystemsAcad, n.d.).

Subsidiaries of Nigeria National Petroleum Corporation (NNPC) such as Nigeria Gas Company (NGC), Warri Refining and Petrochemical Company, Port Harcourt Refining and Petrochemical Company and Kaduna Refining and Petrochemical Company all uses SCADA system for oil and gas monitoring (NNPC, n.d.) as well other International oil companies such as TOTAL, Chevron Nigeria Limited (CNL), Shell Petroleum Development Company (SPDC) uses SCADA for pipeline monitoring (SPDC, n.d.) (CNL, n.d.) (NIGERIA, n.d.).

So far, SCADA systems has attained a maturity of about 20 years and has 40% of industrial penetration in the oil and gas industry in Nigeria; with a response time of about 12.5 minutes and about 150million naira as its operational cost but has a security challenge of being subject to hacking by cyber hackers as shown in Table 3.

#### *Distributed control system (DCS)*

A distributed control system (DCS) is a computer-based control system for a process or plant usually with multiple control loops and autonomous controllers distributed without a central supervisory control in a system. (D'Andrea & Raffaello, 2003) (Massiaoni, 2009). DCS are reliable for pipeline monitoring and control because. If any processor fails, it only affects one section of the system and not the entire system. This distribution of computing power ensures fast control processing time by removing possible network delays. DCS is divided into a hierarchical structure which includes the field level, direct control level, plant supervisory level, production level and production scheduling level. DCS performs automatic detection, monitoring and protection on pipeline systems. (Feng, 2017). Only very few international oil companies in Nigeria implements DCS in their facilities; TOTAL in their OML 42 facility (NIGERIA, n.d.) and CNL in their Escravos Gas-To-Liquid Project (EGTL) in Delta state Nigeria uses DCS in full implementation (CNL, n.d.). DCS systems have maturity of about 10 years and have 20% of industrial penetration in the Nigerian petroleum industry; with a response time of about 5-10 minutes and high operational cost as shown in Table 3.

#### *INTERNET OF THINGS (IoT)*

Internet of Things (IoT) as an advanced technology uses internet connectivity to detect, control and monitor pipeline systems in real-time remotely (Ayeni & Ayogu, 2020) (J Ammar & Samer, 2017). Oil and gas companies in recent times are utilizing IoT to ensure pipeline safety in the course of petroleum product transportation. In the use of IoT, sensors are fixed at a regular distance of the pipeline for effective control and transmission of signals from the field to the base station via the internet. (K.Lalitha, V, S, K.M, & V, 2020).

Though not yet adopted by any company at the moment in the petroleum industry in Nigeria, IoT has a maturity of around 5 years in the global industrial arena and has about 0.5% of industrial penetration in the oil and gas industry with a fast response time of about 12.5 minutes as indicated in Table 3. IoT is however, posed with a security challenge of being subject to hacking by cyber hackers.



**WIRELESS SENSOR NETWORK (WSN)**

Wireless sensor network (WSN) is a group of sensors spatially dispersed for monitoring and recording purposes of the physical conditions of the environment and coordinating the collected data to a control station simultaneously. Over the years many researchers have explored the use of wireless sensor network for pipeline monitoring and inspection ranging from different sensing techniques, mathematical formulation, data acquisition methods, and data processing algorithms in developed countries as well as in Nigeria. Stoianov et al. proposed wireless sensor network with fixed nodes to collect acoustic vibrations in detecting pipeline vandalism as well as the location it is taking place (Stoianov, Nachman, Madden, & Tokmouline) (IJES, n.d.). Jin and Eydgahi also developed a WSN using acoustics sensing devices in which signals generated by the acoustic sensors propagate along the pipeline and is used locate defects such as corrosion.

When signals generated differ greatly from reference signals stored then a leak is recorded (Jin & Eydgahi., 2008). Imad I. et al. (Imad, Nader, & Khaled, 2007) carried research on Pipeline Infrastructure Monitoring Using Wireless Sensor Networks and covered the areas of network deployment, data collection and communication structure. Research on Fault Tolerant Wired and Wireless Sensor Network Nader, M., & Imad, J. (Imad, Nader, & Khaled, 2007), in their research work on WSN was able to look at the capability and reliability of using both wired and wireless for pipeline monitoring. The security of the system was not guaranteed in the work. Fawaz, A. worked on the use of WSN for oil pipeline surveillance but the security of the communication link was not put into consideration. (Fawaz, 2011). WSN systems have just about 7% of industrial penetration in the oil and gas industry on the global index; with a response time of about 20 minutes as indicated in Table 3.0 and Figure 3.

**Table 3.0:** Characteristic Comparison of supervisory control systems

	<b>SCADA</b>	<b>DCS</b>	<b>WSN</b>	<b>IoT</b>	<b>References</b>
Industrial Penetration	40%	20%	7%	0.5%	(CNL, n.d.) (NIGERIA, n.d.) (K.Lalitha, V, S, K.M, & V, 2020)
Response time	20 mins	7.5 mins	7.5 mins	2.5 mins	(D'Andrea & Raffaello, 2003) (Massiaoni, 2009)
Operational cost	NGN 150 Million	NGN 500 Million	NGN 5 Million	NGN 2 Million	(D'Andrea & Raffaello, 2003) (Massiaoni, 2009)
Maturity factor	20 years	10 years	6 years	5 years	(Erickson, Miller, Stanek, & Dunn-Norman, 2000) (Jin & Eydgahi., 2008)
Safety factor	Prone to hacking	Safe	safe	Prone to hacking	(D'Andrea & Raffaello, 2003) (Massiaoni, 2009)



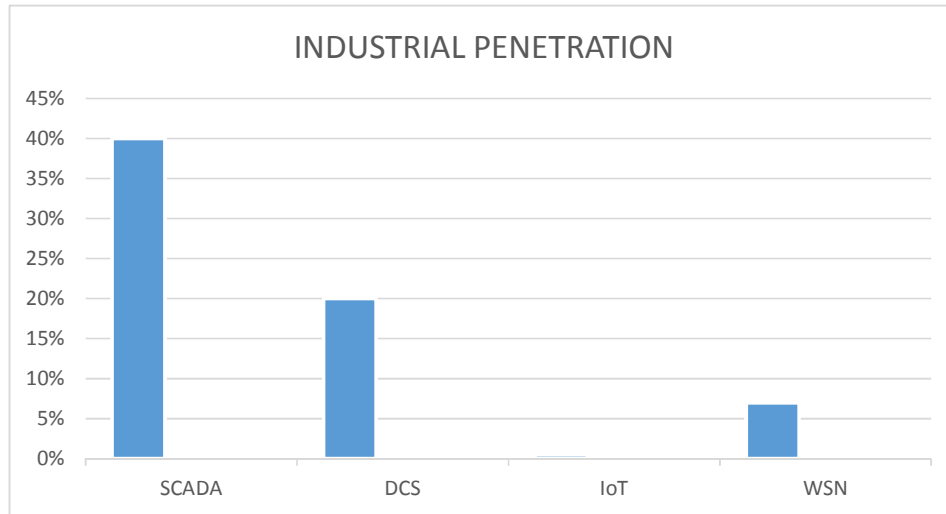


Figure 3a: Industrial penetration of supervisory control

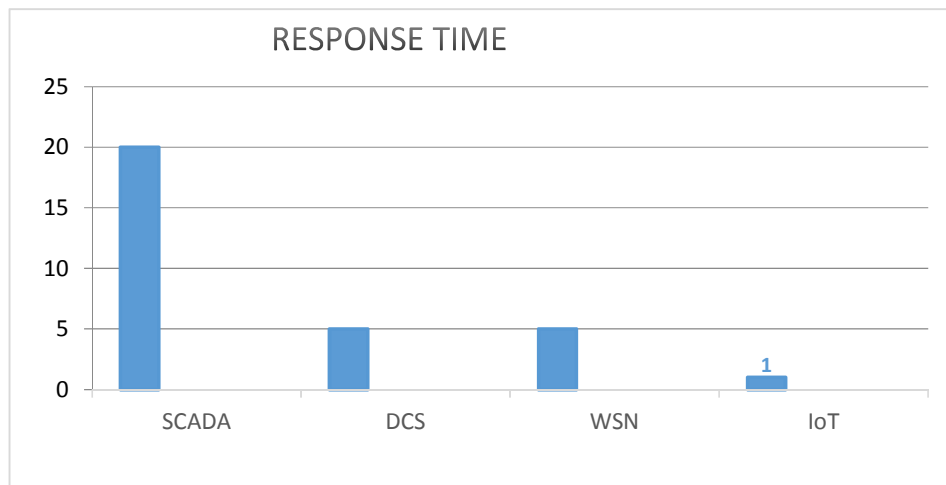


Figure 3b: Response of supervisory control

#### ROBOTIC AND ARTIFICIAL INTELLIGENCE (AI) SYSTEMS

The use of Robotics and AI for pipeline control is relatively a new area and has not gotten any industrial acceptance. Researchers in this region have been employing robotics to provide automatic surveillance and crude oil spill detection from crude oil pipelines. This is a relatively new technique and spills as little as 1L have been detected using this method (Ejofodomi O. , 2020). Robotic systems for pipeline control and monitoring comprises of crawl robots for in-pipe monitoring (Chen, Gao, Zhang, & Deng, 2006),

automated drone robots etc. The automated drone may be the future platform for remote oil spill sensing. This method is still virgin to the petroleum industry in Nigeria and is much available for researchers to explore.

#### EVALUATION OF PIPELINE CONTROL/SURVEILLANCE METHODS

Haven reviewed the various methods that exist in pipeline control and surveillance, it is clear that the biological method has an average of 47.5% industrial penetration in the Nigerian oil and gas industry with an average maturity of 32 years as indicated in Table 4. The



supervisory method with average maturity of 10.25 years has 16.9% industrial penetration as it has the second highest penetration into the industry. Most IOCs operating in Nigeria and the NNPC have since switched to supervisory method. Remote sensing, robotic and AI has not

yielded much result as these are still methods open to serious research and wide acceptance in the Nigerian oil and gas industry. Table 4 and Figure 8 show a summary of the performance characteristics evaluation of these methods.

**Table 4:** Pipeline control system methods performance characteristics

	BIOLOGICAL METHOD	REMOTE SENSING	SUPERVISORY METHOD	ROBOTIC AND AI
Industrial Penetration	47.5%	0%	16.9%	0%
Response time	180 mins	157.5 mins	9.4 mins	3.5 mins
Operational cost	NGN 12.6 million	NGN 355 Million	NGN 164.3 million	NGN 20 million
Maturity	32.5 years	11 years	10.25 years	3 years

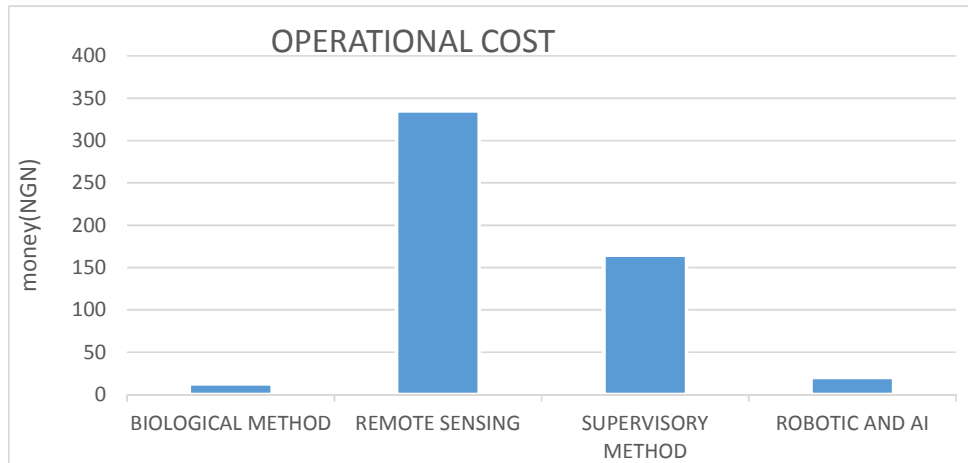


Figure 4a: Average operational cost

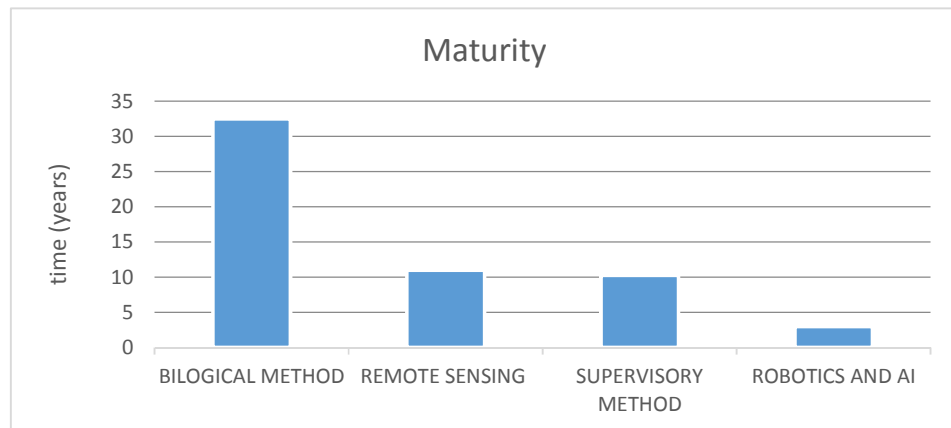


Figure 4b: Average maturity

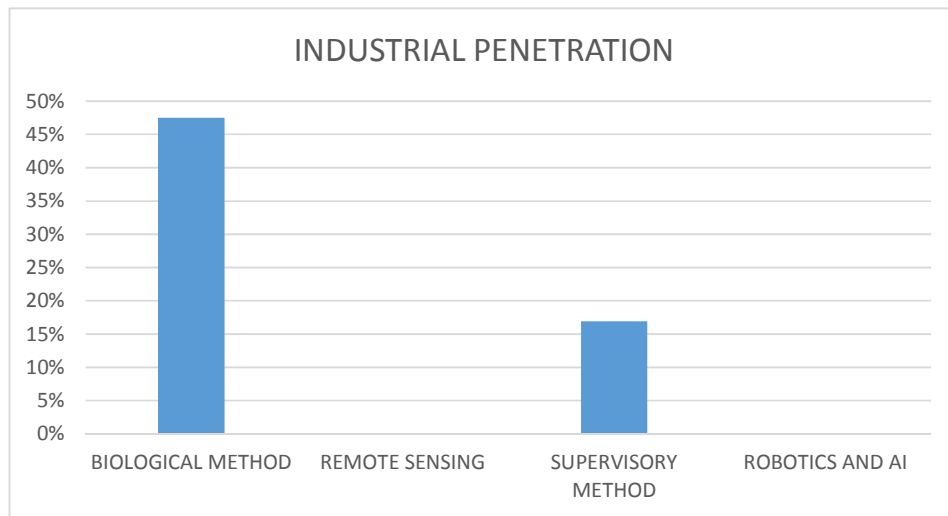


Figure 4c: Average industrial penetration

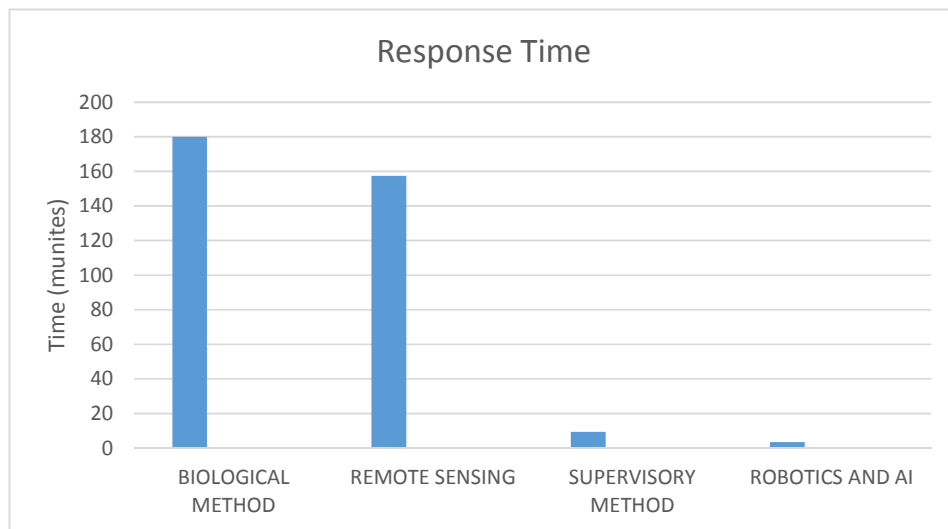


Figure 4d: Average response time

### CONCLUSION

This paper has set out to review the various techniques in use for pipeline control systems in the oil and gas industry in recent times and outlined these techniques and their characteristics in detail. This work is intended to broaden the knowledge of industry players on the most commonly used methods for pipeline surveillance and inspection in the Nigerian oil and gas industry; Also, to help in decision making on the appropriate method to apply in pipeline control projects. From Table 4, it is seen that the biological method so far has the highest industrial

penetration but has a very slow response as well as poor sensitivity, hence making it unfit to meet up with the recent challenges in pipeline surveillance and control. The remote sensing method has 0% industrial penetration as it has no acceptance yet in the petroleum industry in Nigeria basically due to its ineffectiveness in poor weather conditions and also due to the natural mangrove architecture of the Niger Delta environment, it is challenging to carry out proper pipeline monitoring in these areas that has natural cover which obstruct proper signal transmission. The supervisory method, with 16.9% industrial



penetration currently seem to be the most implemented method in recent times in the industry despite its security challenge of being subject to hacking but has a swift response time of about 9.4 minutes as seen in Table 4 and Figure 4. Robotics and AI, which is a recent method with 0% industrial penetration, will definitely be the future of pipeline surveillance and control. No known oil and gas company in Nigeria is implementing this method but serious research and awareness is still ongoing for wider acceptance especially due to its unique characteristics of very fast response and low operational cost. Robotics and AI is the future of pipeline surveillance and control.

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## Pipeline Control Systems: A Review of Surveillance Methods and Applications in the Nigeria Oil and Gas Sector

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### ABSTRACT

The Pipeline is a very important infrastructure to the oil and gas industry that is used to transport petroleum and its associated products from one location to another. Improper monitoring, control and surveillance of pipeline infrastructures would lead to serious damages to the environment in the form of oil spillage and gas flare. This paper reviews existing surveillance methods and their applications in the oil and gas sector in Nigeria. The human/biological method employs dogs, human personnel, smart pigging and helicopters as its technique; having the highest industrial penetration of 47.5%. The Remote sensing method consists of satellite remote sensing and unmanned Aerial Vehicle (UAV) having 0% industrial penetration in the Nigerian oil and gas industry. The supervisory control method consists of Supervisory Control and Data Acquisition (SCADA), Distributed Control System (DCS), Wireless Sensor Network (WSN) and Internet of Things (IoT) with 16.9% industrial penetration in the Nigerian oil and gas sector. The robotics and artificial intelligence (AI) method is a very recent method yet to have any significant industrial penetration in the oil and gas sector but has a promising future in the industry. This paper will serve to guide stakeholders in choosing the appropriate surveillance methods for pipeline surveillance and control.

### ARTICLE INFO

Article History  
Received: May, 2021  
Received in revised form: June, 2021  
Accepted: July, 2021  
Published online: October, 2021

### KEYWORDS

Petroleum, oil and gas, supervisory control, wireless sensor network, pipeline control, monitoring

### INTRODUCTION

The major function of pipelines in the oil and gas industry is to transport petroleum and its associated products from one location to another. This made pipelines a very important infrastructure to petroleum industry (Rehman & Nawaz, 2017). The control, monitoring and protection of these pipelines is of paramount importance to attain maximum efficiency in the business of oil and gas both in the upstream, midstream and downstream sector of the petroleum industry (Boaz, Kajjage, & Sinde, An overview of pipeline leak detection and location systems, 2014) (Adegboye, Fung, & Karnik, 2019) (U, G, O, & Awotunde, 2016). Lack of such pipeline protection and control could cause serious damage to the environment through oil spillage and gas flaring. In 2015, Shell Petroleum Development Company (SPDC) reported a total of 131 spill incidents in the Niger Delta Region, and about 2,814,300 liters of oil was released into the environment (SPDC, n.d.). The key interest is to

transport crude oil and its products from various production points to designated markets safely and in the most economical manner possible. Over the years, pipeline systems have grown in size and complexity due to business requirements and the need for interconnections between pipeline systems as well as environmental concerns and safety issues requiring more sophisticated monitoring and control system. (Adegboye, Fung, & Karnik, 2019). An important aspect in the transporting of crude oil and its products through a pipeline system is the need to remotely monitor and carry out certain operations through a central control system. Functions of a complete pipeline control system include data acquisition and reporting, operator control, pump/compressor control, valve control, nominations, scheduling, custody transfer, imbalance measurement, billing, pipeline modeling, batch tracking for liquid pipelines, pump/compressor optimization and leak detection (Browne, 20001). Physical variables



such as pressure, temperature, gas composition, flow rate, pump/compressor status and valve status in a pipeline control system are measured at many locations by field instruments. This paper presents an overview of the various existing technologies that finds applications in a pipeline control system. It grouped existing methods in pipeline control systems viz: Human surveillance/Biological control, Remote sensing control, and Supervisory Control and Robotic systems.

### EXISTING METHODS OF PIPELINE CONTROL AND MONITORING

#### *Human Surveillance/Biological Control*

This method refers to the traditional means of inspection of pipeline infrastructures through human surveillance, trained dogs, personnel-manned helicopters and smart pigging (Boaz, Kajjage, & Sinda, An overview of pipeline leak detection and location systems, 2014).

#### *Human surveillance*

This method engages the services of company security personnel who are trained to walk along the pipelines to take meter readings of pipeline parameters at a given interval of time and equally looks out for anomalous conditions in the pipeline environment and for possible leakage detection along the pipeline through visual inspection. In the Nigeria oil and gas environment, these company security personnel liaise with other security stakeholders such as community dwellers, vigilantes etc. to secure the company's facility. (Chukwuemeka & Ngozi, 2017). State security outfits such as Nigeria Security and Civil Defense Corp (NSCDC), Nigeria Mobile Police Force, the military and the Nigerian Navy usually form a joint task force (JTF) operation in pipeline surveillance operations in conjunction with company security personnel. The company security personnel provide communication, organization, coordination and the necessary information needed for a smooth operation (M., 2014) (Quarter, 2914). Though human surveillance is slow in response and of average sensitivity of about 42%, it has

been of long use with industrial penetration of about 70% as shown in Table 1.

#### *Trained Dogs*

Trained dogs accompanied with personnel can recognize defects and leaks by visual observation and smells. Dogs are ineffective long operations not more than 30-120 minutes (Garner, et al., , 2001). This method applies only to onshore pipeline networks. (Murvay & Silea, 2012). This technique is very slow in response and has attracted low industrial penetration but presents a very low operational cost as seen in table 1.

#### *Helicopter surveillance*

Helicopter carrying security personnel is flown across pipeline network tracts to look out for possible leak or illegal activities on the pipelines by oil thieves. This technique only works for visible pipelines and is ineffective in areas covered with bush as this can cause visibility problems for the pilot (Quarter, 2914). The use of helicopters is moderate in response time and quite expensive hence attracting low industrial penetration.

#### *Smart Pigging*

Another technique used under this method is smart pigging. Smart pigging is a technique in which an inspection probe (referred to as the pig) is made to flow through a pipeline while gathering information on pipeline condition (S.N, J.P, E, & A, 1996). In the use of pigging, the pig is equipped with sensors and data loggers to record pipeline parameter readings. This technique is fast, sensitive (about 60%) and has about 60% penetration into the industry as shown in table 1. Up till now, human surveillance remains the most used method in the Nigerian oil and gas industry. Workers and security dogs move round designated pipeline routes to detect possible leaks. The method is difficult to detect hidden leaks. (Batzias F A & M, 2011). Table 1 and Figure 1 show the characteristics of the human surveillance/biological control method.

**Table 1:** Characteristic Comparison of Human surveillance /biological control

Technique	Dogs	Humans	Smart pigging	Helicopters	References
Response time	Very slow	Slow	Fast	Moderate	(Garner, et al., , 2001)
sensitivity	40%	42%	60%	47%	(Murvay & Silea, 2012)



Technique	Dogs	Humans	Smart pigging	Helicopters	References
Operational time	120 mins	180 mins	1176 mins	168 mins	(Garner, et al., , 2001)
Industrial penetration	30%	70%	60%	30%	(M., 2014) (Quarter, 2914)
Maturity	15 years	50 years	30 years	35 years	(Garner, et al., , 2001) (Government, 1990)
Operational Cost	NGN 1 million per annum	NGN 20 million per annum	15 million pe annum	15 million per annum	(M., 2014) (Garner, et al., , 2001) (Quarter, 2914)

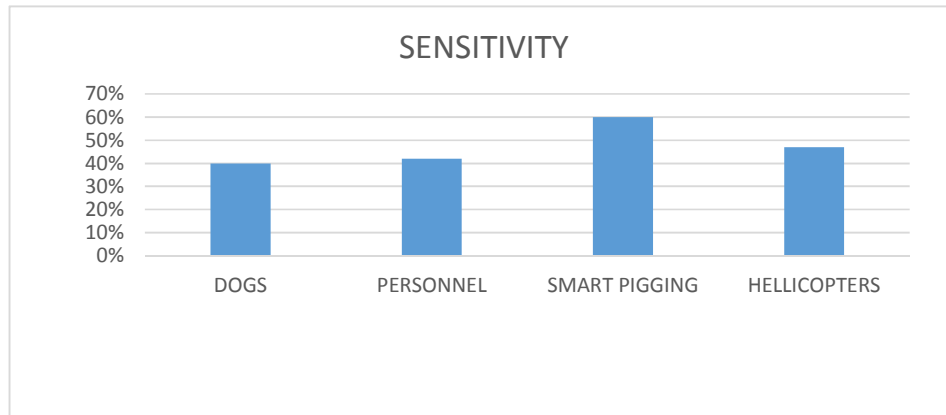


Figure 1a: Sensitivity of Humna/biological technique

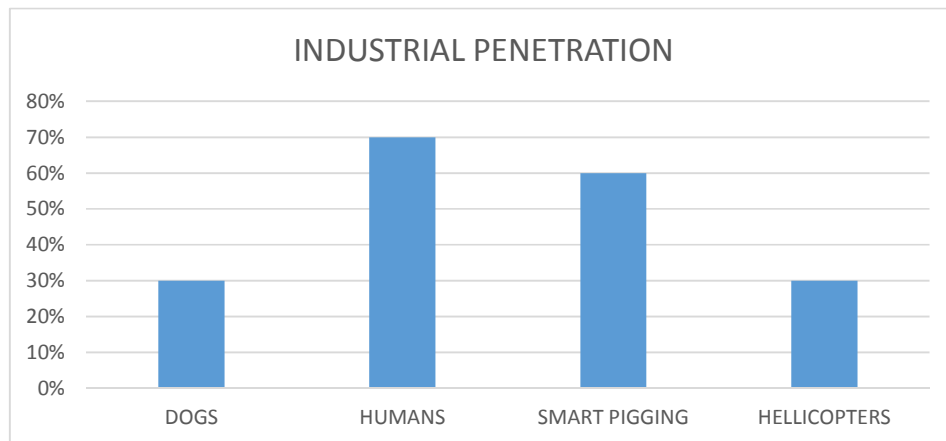


Figure 1b: industrial penetration of human/biological technique

#### Remote Sensing

This method deals with the use of unmanned aerial vehicles (UAV) and satellite in pipeline control systems.

#### Unmanned Aerial Vehicles (UAV)

Airborne remote sensing involves using sensors on an airborne platform such as an unmanned aerial vehicle (UAV) to monitor the state of a pipeline and equally detect spills on the





ground or at sea. The sensors attached to the UAV provide the necessary data signal for extensive analysis of the pipeline. Fixed wing UAVs can cover a wide area of pipeline route with respect to its flying speed as well as energy consumption rate. Multi-drone UAVs makes it possible to obtain maximum details for medium and small areas to ensure detailed scanning of subsurface pipelines (Benyeogor, Olatunbosun, & Kumar, 2020). RGB photo and/or video cameras as well as spectral cameras and thermal imaging cameras are installed on the UAVs for analysis of the infrared spectrum band of the pipeline region (Ejofodomi O. , 2020) (Kochetkova, 2018). Mbadiwe et al. (Benyeogor, Olatunbosun, & Kumar, 2020), Ejofodomi and Ofualagba (Ejofodomi O. , 2020) (Kochetkova, 2018) and other indigenous researchers have done extensive research on UAV remote sensing method. They have made attempts to present their research breakthrough to relevant regulatory bodies in the oil and gas sector for possible adoption and industrial application. This technique has a fast response time of about 15 minutes with a sensitivity of about 60% as shown in Table 2 and Figure 2.

#### Satellite Sensing

Satellite remote sensing involves utilizing sensors on a space-based platform.

Satellites orbiting the earth capture images of the surface of the earth. This technique has been employed in recent times for pipeline monitoring especially in the area of pipeline leak detection. The delivery time of satellite images is between 3-5 hours and can pass over a land area once a day. Attempts have been made to replace airborne sensing with space-based sensing, but not many sensors can be used in space. Also satellite remote sensing requires a clear sky and good weather conditions. The frequency and timing of the overpass is also a major challenge with satellite remote sensing. (Ejofodomi O. , 2020)

The detection, mapping and monitoring using the remote sensing method are problematic in regions like the Niger Delta because of canopy cover, cloud cover, inaccessible nature of the ecosystem, and insecurity (Ejofodomi & Ofualagba, 2016). Satellite sensing has a very slow response time of about 300 minutes, maturity of about 10 years and has about 33% sensitivity as shown in Table 2. The industrial penetration of the remote sensing method has less impact in the Nigeria oil and gas sector as none of these existing oil companies (local and international oil companies) has adopted this method for the control and surveillance of pipeline infrastructure.

**Table 2:** Characteristic Comparison of Remote sensing

	UAV	SATELLITE REMOTE SENSING	References
Industrial Penetration	Not in use	Not in use	(Ejofodomi O. , 2020) (Kochetkova, 2018) (Benyeogor, Olatunbosun, & Kumar, 2020)
Response time	15 mins	300 mins	(Benyeogor, Olatunbosun, & Kumar, 2020) (Ejofodomi O. , 2020) (Ejofodomi & Ofualagba, 2016)
Operational cost	NGN 10 million	NGN 700 million	(corporation, 2011) (ACL, n.d.) (GROUP, n.d.)
Maturity	12 years	10 years	(ACL, n.d.) (GROUP, n.d.)
Sensitivity	67%	33%	(Be.Do, n.d.) (corporation, 2011)

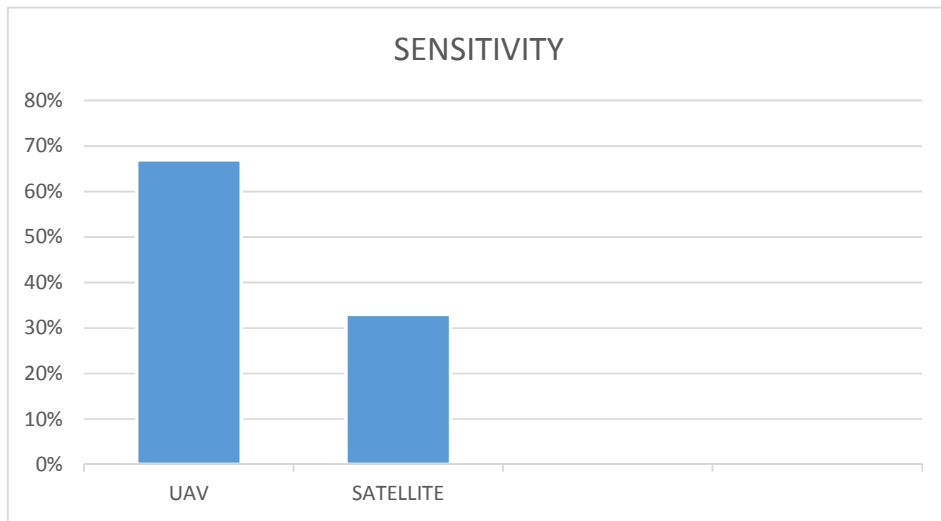


Figure 2a: Maturity of techniques used in remote sensing method

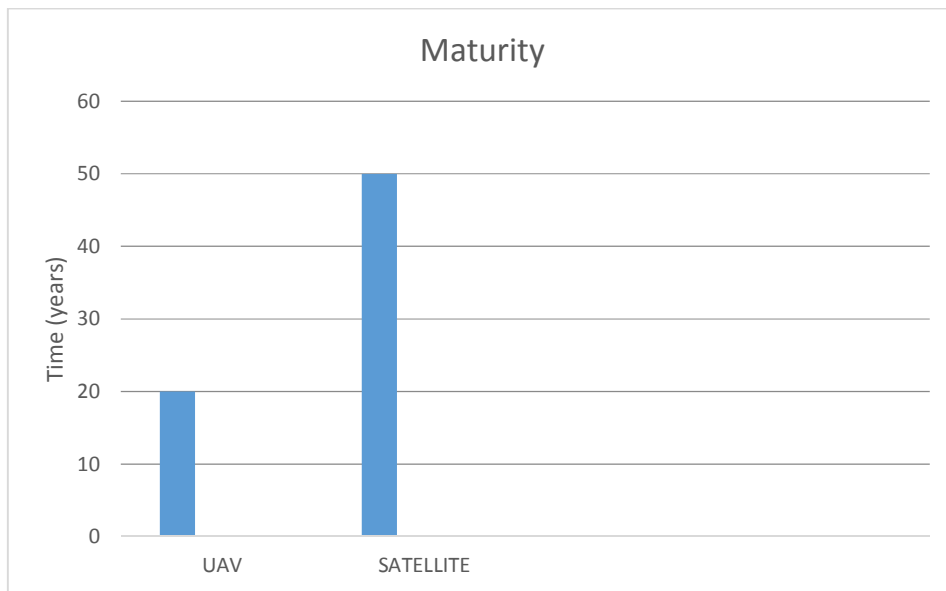


Figure 2b: Sensitivity of techniques used in remote sensing method

#### SUPERVISORY CONTROL

A Supervisory Control system is a system that has the ability and intelligence to perform controls with minimal or no human supervision. Supervisory Control and Data Acquisition (SCADA), Distributed control system (DCS) and Internet of Things (IoT) are supervisory systems employed in pipeline operations.

#### Supervisory Control and Data Acquisition (SCADA)

Supervisory Control and Data Acquisition (SCADA) is an intelligent system which performs supervisory control and data acquisition on control systems such as pipeline control systems. Pipelines require a control system which is very different from other types of control systems require a low speed, limited bandwidth communications over long



distances; hence SCADA system is employed. In a SCADA system, data is transferred in small packets. Constant data such as controller ID data are stored in the central database, not in the field controller. Operating data is stored in controllers for intermittent polling and communications are minimized by designing controllers to report by exception for a change of status.

Communication links must be verified with each report and the sequence of events is often recorded in the controllers so that history can be re-established if communication links are interrupted. The Data Acquisition part of the SCADA system is responsible for collecting data from the field and storing in a database where it is available to other functions on the system. Each item of data is generally called a tag and SCADA systems can collect data from hundreds of thousands of points many times each day. A standard requirement of pipeline control systems is the collection of large amounts of historical information about each point. The Human Machine Interface (HMI) is responsible for much of the Supervisory Control part of the SCADA system. At this point, an operator can call up graphic displays showing the current values of the point in database and send changes to field devices for appropriate control actions on the pipeline in the field (Browne, 20001) (Subramanian, 2008) (SystemsAcad, n.d.).

Subsidiaries of Nigeria National Petroleum Corporation (NNPC) such as Nigeria Gas Company (NGC), Warri Refining and Petrochemical Company, Port Harcourt Refining and Petrochemical Company and Kaduna Refining and Petrochemical Company all uses SCADA system for oil and gas monitoring (NNPC, n.d.) as well other International oil companies such as TOTAL, Chevron Nigeria Limited (CNL), Shell Petroleum Development Company (SPDC) uses SCADA for pipeline monitoring (SPDC, n.d.) (CNL, n.d.) (NIGERIA, n.d.).

So far, SCADA systems has attained a maturity of about 20 years and has 40% of industrial penetration in the oil and gas industry in Nigeria; with a response time of about 12.5 minutes and about 150million naira as its operational cost but has a security challenge of being subject to hacking by cyber hackers as shown in Table 3.

#### *Distributed control system (DCS)*

A distributed control system (DCS) is a computer-based control system for a process or plant usually with multiple control loops and autonomous controllers distributed without a central supervisory control in a system. (D'Andrea & Raffaello, 2003) (Massiaoni, 2009). DCS are reliable for pipeline monitoring and control because. If any processor fails, it only affects one section of the system and not the entire system. This distribution of computing power ensures fast control processing time by removing possible network delays. DCS is divided into a hierarchical structure which includes the field level, direct control level, plant supervisory level, production level and production scheduling level. DCS performs automatic detection, monitoring and protection on pipeline systems. (Feng, 2017). Only very few international oil companies in Nigeria implements DCS in their facilities; TOTAL in their OML 42 facility (NIGERIA, n.d.) and CNL in their Escravos Gas-To-Liquid Project (EGTL) in Delta state Nigeria uses DCS in full implementation (CNL, n.d.). DCS systems have maturity of about 10 years and have 20% of industrial penetration in the Nigerian petroleum industry; with a response time of about 5-10 minutes and high operational cost as shown in Table 3.

#### *INTERNET OF THINGS (IoT)*

Internet of Things (IoT) as an advanced technology uses internet connectivity to detect, control and monitor pipeline systems in real-time remotely (Ayeni & Ayogu, 2020) (J Ammar & Samer, 2017). Oil and gas companies in recent times are utilizing IoT to ensure pipeline safety in the course of petroleum product transportation. In the use of IoT, sensors are fixed at a regular distance of the pipeline for effective control and transmission of signals from the field to the base station via the internet. (K.Lalitha, V, S, K.M, & V, 2020).

Though not yet adopted by any company at the moment in the petroleum industry in Nigeria, IoT has a maturity of around 5 years in the global industrial arena and has about 0.5% of industrial penetration in the oil and gas industry with a fast response time of about 12.5 minutes as indicated in Table 3. IoT is however, posed with a security challenge of being subject to hacking by cyber hackers.



**WIRELESS SENSOR NETWORK (WSN)**

Wireless sensor network (WSN) is a group of sensors spatially dispersed for monitoring and recording purposes of the physical conditions of the environment and coordinating the collected data to a control station simultaneously. Over the years many researchers have explored the use of wireless sensor network for pipeline monitoring and inspection ranging from different sensing techniques, mathematical formulation, data acquisition methods, and data processing algorithms in developed countries as well as in Nigeria. Stoianov et al. proposed wireless sensor network with fixed nodes to collect acoustic vibrations in detecting pipeline vandalism as well as the location it is taking place (Stoianov, Nachman, Madden, & Tokmouline) (IJES, n.d.). Jin and Eydgahi also developed a WSN using acoustics sensing devices in which signals generated by the acoustic sensors propagate along the pipeline and is used locate defects such as corrosion.

When signals generated differ greatly from reference signals stored then a leak is recorded (Jin & Eydgahi., 2008). Imad I. et al. (Imad, Nader, & Khaled, 2007) carried research on Pipeline Infrastructure Monitoring Using Wireless Sensor Networks and covered the areas of network deployment, data collection and communication structure. Research on Fault Tolerant Wired and Wireless Sensor Network Nader, M., & Imad, J. (Imad, Nader, & Khaled, 2007), in their research work on WSN was able to look at the capability and reliability of using both wired and wireless for pipeline monitoring. The security of the system was not guaranteed in the work. Fawaz, A. worked on the use of WSN for oil pipeline surveillance but the security of the communication link was not put into consideration. (Fawaz, 2011). WSN systems have just about 7% of industrial penetration in the oil and gas industry on the global index; with a response time of about 20 minutes as indicated in Table 3.0 and Figure 3.

**Table 3.0:** Characteristic Comparison of supervisory control systems

	SCADA	DCS	WSN	IoT	References
Industrial Penetration	40%	20%	7%	0.5%	(CNL, n.d.) (NIGERIA, n.d.) (K.Lalitha, V, S, K.M, & V, 2020)
Response time	20 mins	7.5 mins	7.5 mins	2.5 mins	(D'Andrea & Raffaello, 2003) (Massiaoni, 2009)
Operational cost	NGN 150 Million	NGN 500 Million	NGN 5 Million	NGN 2 Million	(D'Andrea & Raffaello, 2003) (Massiaoni, 2009)
Maturity factor	20 years	10 years	6 years	5 years	(Erickson, Miller, Stanek, & Dunn-Norman, 2000) (Jin & Eydgahi., 2008)
Safety factor	Prone to hacking	Safe	safe	Prone to hacking	(D'Andrea & Raffaello, 2003) (Massiaoni, 2009)

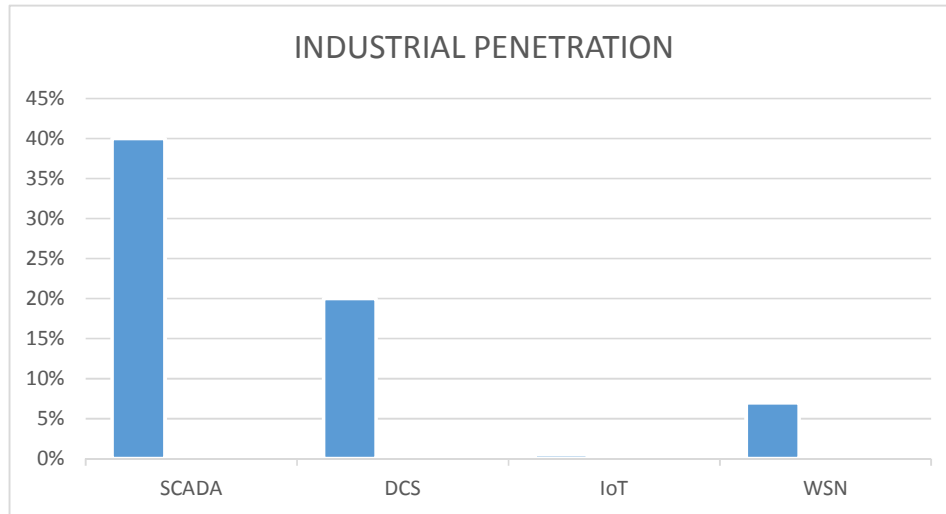


Figure 3a: Industrial penetration of supervisory control

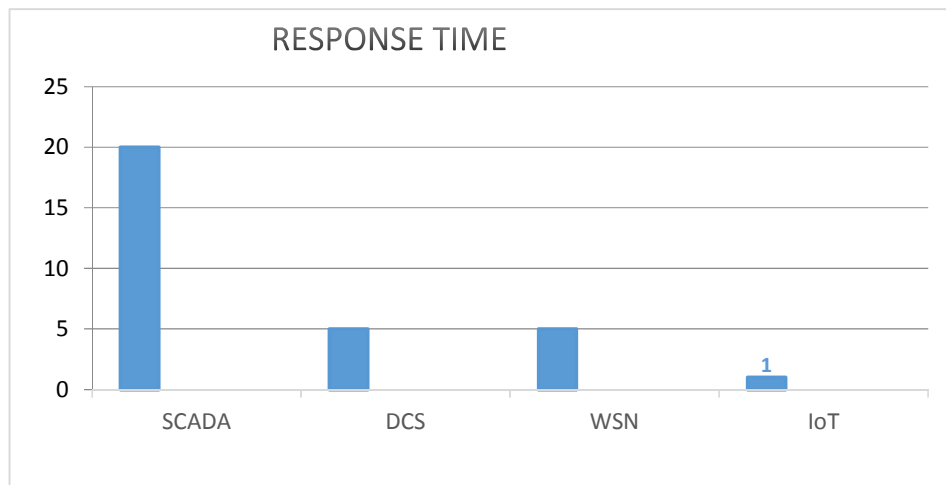


Figure 3b: Response of supervisory control

#### ROBOTIC AND ARTIFICIAL INTELLIGENCE (AI) SYSTEMS

The use of Robotics and AI for pipeline control is relatively a new area and has not gotten any industrial acceptance. Researchers in this region have been employing robotics to provide automatic surveillance and crude oil spill detection from crude oil pipelines. This is a relatively new technique and spills as little as 1L have been detected using this method (Ejofodomi O. , 2020). Robotic systems for pipeline control and monitoring comprises of crawl robots for in-pipe monitoring (Chen, Gao, Zhang, & Deng, 2006),

automated drone robots etc. The automated drone may be the future platform for remote oil spill sensing. This method is still virgin to the petroleum industry in Nigeria and is much available for researchers to explore.

#### EVALUATION OF PIPELINE CONTROL/SURVEILLANCE METHODS

Haven reviewed the various methods that exist in pipeline control and surveillance, it is clear that the biological method has an average of 47.5% industrial penetration in the Nigerian oil and gas industry with an average maturity of 32 years as indicated in Table 4. The

supervisory method with average maturity of 10.25 years has 16.9% industrial penetration as it has the second highest penetration into the industry. Most IOCs operating in Nigeria and the NNPC have since switched to supervisory method. Remote sensing, robotic and AI has not

yielded much result as these are still methods open to serious research and wide acceptance in the Nigerian oil and gas industry. Table 4 and Figure 8 show a summary of the performance characteristics evaluation of these methods.

**Table 4:** Pipeline control system methods performance characteristics

	BIOLOGICAL METHOD	REMOTE SENSING	SUPERVISORY METHOD	ROBOTIC AND AI
Industrial Penetration	47.5%	0%	16.9%	0%
Response time	180 mins	157.5 mins	9.4 mins	3.5 mins
Operational cost	NGN 12.6 million	NGN 355 Million	NGN 164.3 million	NGN 20 million
Maturity	32.5 years	11 years	10.25 years	3 years

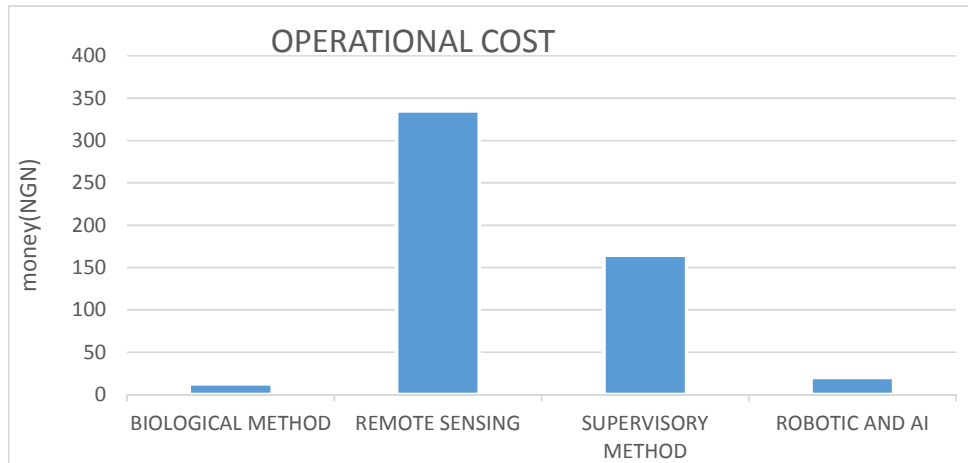


Figure 4a: Average operational cost

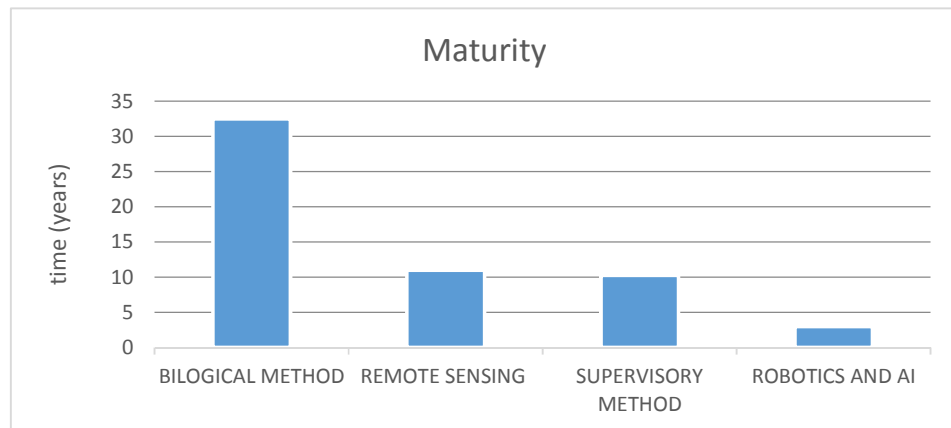


Figure 4b: Average maturity

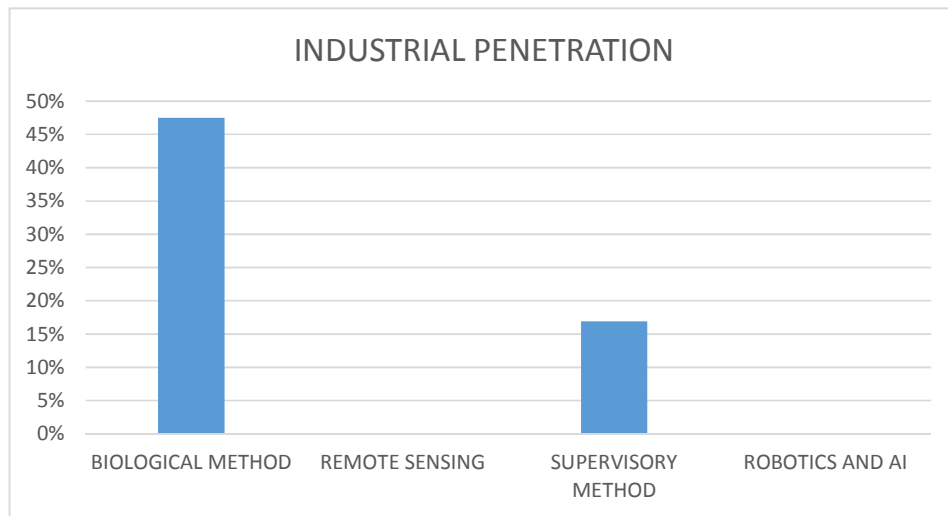


Figure 4c: Average industrial penetration

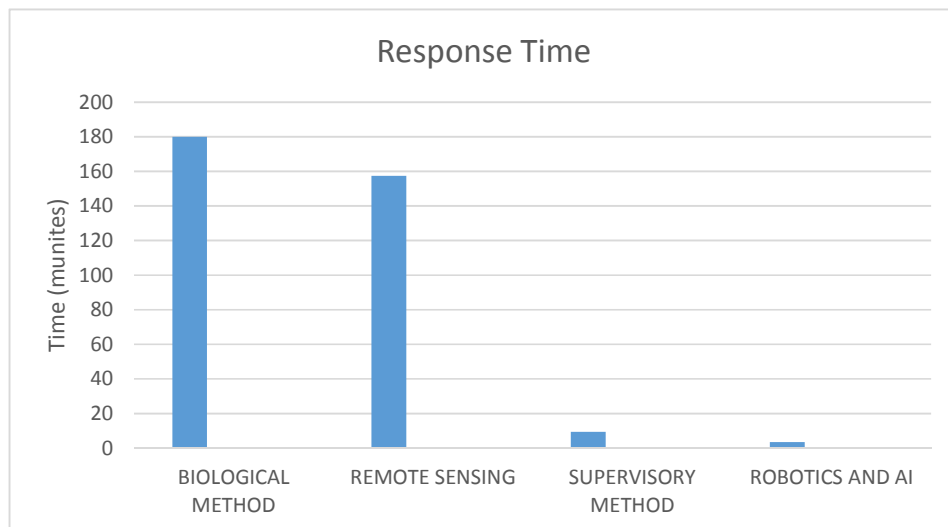


Figure 4d: Average response time

### CONCLUSION

This paper has set out to review the various techniques in use for pipeline control systems in the oil and gas industry in recent times and outlined these techniques and their characteristics in detail. This work is intended to broaden the knowledge of industry players on the most commonly used methods for pipeline surveillance and inspection in the Nigerian oil and gas industry; Also, to help in decision making on the appropriate method to apply in pipeline control projects. From Table 4, it is seen that the biological method so far has the highest industrial

penetration but has a very slow response as well as poor sensitivity, hence making it unfit to meet up with the recent challenges in pipeline surveillance and control. The remote sensing method has 0% industrial penetration as it has no acceptance yet in the petroleum industry in Nigeria basically due to its ineffectiveness in poor weather conditions and also due to the natural mangrove architecture of the Niger Delta environment, it is challenging to carry out proper pipeline monitoring in these areas that has natural cover which obstruct proper signal transmission. The supervisory method, with 16.9% industrial





penetration currently seem to be the most implemented method in recent times in the industry despite its security challenge of being subject to hacking but has a swift response time of about 9.4 minutes as seen in Table 4 and Figure 4. Robotics and AI, which is a recent method with 0% industrial penetration, will definitely be the future of pipeline surveillance and control. No known oil and gas company in Nigeria is implementing this method but serious research and awareness is still ongoing for wider acceptance especially due to its unique characteristics of very fast response and low operational cost. Robotics and AI is the future of pipeline surveillance and control.

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