An Enhanced Multi-Agent System (MAS) Based Framework for Pipeline Vandalism Monitoring System Niger Delta Region

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***Abstract*—This paper presents a new framework for fast and intelligent diagnosis of pipeline field sensors by Multi-Agent Systems (MAS). The software agents are responsible for efficient operation of the pipeline sensors as well as the detection of anomaly in the pipeline infrastructure such as presence of vandals (whose intention it to steal the crude oil and other petroleum products) around the right of way (ROW) of the pipelines and eventual rupture of the pipelines. This framework allows pipeline plant operator to get fast feedback from the software Agent (Distribution Agent) as either SMS, email or real-time from a web-based interface once there is detection of presence of vandals by the Diagnosis Agent. This paper equally presents a web-based framework using an Agent-based approach to enable monitoring of the status of the pipelines from a friendly Graphical User Interface (GUI) based web-based interface such as http.**

Keywords*—Pipeline leakage, vandalism, Multi-Agent System (MAS), Agent, Niger Delta, Sensor, tuple, semantic, validation, alarm, Microcontroller

I. Introduction

Nigeria is the largest oil producer in Africa and the sixth largest oil exporter in the world [1]. The mainstay of Nigeria's economy is the petroleum sector, contributing about 90% of the nation's foreign exchange earnings and about 25% of the Gross Domestic Products [2]. A significant proportion of the nation's oil is produced onshore, although recently oil production has witnessed increased activities in the off-shores. The crude oil produced from oil fields located at various points in the country including south-south, south-east and south-west are transported by pipelines to four major refineries of Alesa Eleme, Warri, and Kaduna. Out of Nigeria's crude oil reserves of about 16 to 22 billion barrels, the Niger Delta bears most of this reserve according to U.S United states Energy Information Administration (EIA). This region encompasses most of the oil fields. Most of Nigeria's oil fields are small and scattered, and as of 1990, these small unproductive fields accounted for 62.1% of all Nigerian production [3],[4]. This scattered nature of the oil field locations necessitated the establishment of an extensive and well-developed pipeline network to transport the crude. Fig. 1 shows the map of Nigeria containing the oil fields and pipeline network in Niger Delta region.

Over the years, the amount of oil produced and transported between points of production, processing and distribution or export terminals has greatly increased as the demand and dependency on oil increased.

Although this increase in oil production level contributes to the national economic growth, studies have shown that it presents increased potential for environmental pollution and degradation [5, 6]. It has also been observed that thousands

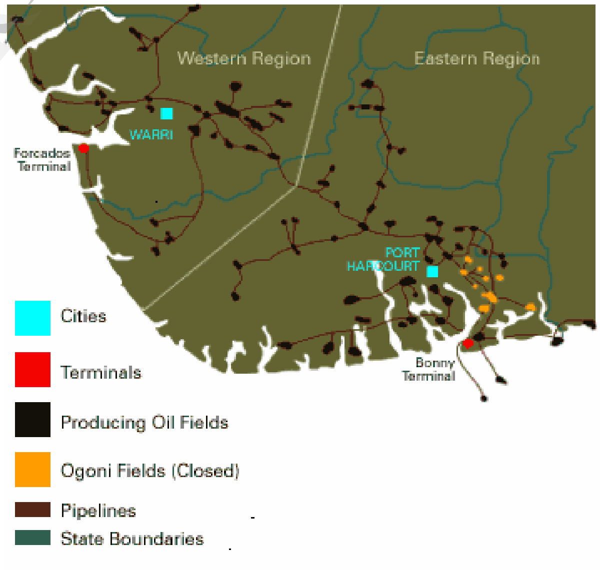


Fig. 1. Map showing Niger Delta Region in Nigeria with oil fields and pipeline architecture [5]

of barrels of oil have been spilled into the environment through oil pipelines and storage facilities' failure in Nigeria [7]. The causes of pipeline damage and leakage vary greatly from material defects, pipe corrosion and contact with ship anchors in the offshore operations to vandalism of pipeline onshore by hoodlums and their collaborators.

Oil spillage disaster through pipeline vandalism is a phenomenon that has thrived and come to stay especially in the Niger Delta region in Nigeria, where crude oil is produced both on-shored and off-shored. This has resulted to the loss of billions of crude oils and corresponding loss of income every year. An average of 35,000 barrels of crude oil is stolen per day in circumstances that threaten lives and the environment [20]. Also according to NNPC in April 2013, about five (5) billion Naira is lost by Nigeria as a result of pipeline vandalism and crude oil bunkering [7].

Apart from the loss of lives and property through pipeline fire, the run-off from impacted sites usually degrade the quality of the fresh water sources which serves the domestic rural water supply needs of most communities in Nigeria. The enormous oil installations deployed in the Niger Delta region explains their vulnerability to vandalism. Presently, the Niger Delta region plays host to 606 oil fields of which 355 fields are onshore while 251 are offshore with over 3,000 kilometers of pipelines crisscrossing the region and linking some 275 flow stations to various export terminals.

A. Security Challenges in Niger Delta Oil and Gas prospecting

Oil and gas production facilities are critical infrastructures and as such can be targets for sabotage and terrorist attacks [8]. Such is the case in Nigeria Niger Delta Region. There is however, a serious decline in militant activities since the inception and implementation of amnesty programme of the Nigerian Federal Government initiated by then Yar 'Adua regime but cases of oil bunkering and pipeline vandalisation in order to steal crude oil is still on the increase[9].

The dominant security challenges in Niger Delta Region ranges from pipeline vandalisation, illegal oil bunkering, kidnapping of oil and gas workers by militants and criminals, vandalisation and destruction of oil and gas facilities such as oil wells, flow stations, oil rigs and even theft and destruction of oil and gas installed equipment and wireless sensors that are supposed to monitor these facilities. According to [10], vandalisation is the most serious challenge out of these whole lots.

II. REVIEW OF PAST RELATED WORKS

A Multi-Agent System (MAS) based intelligent environmental monitoring system was proposed by Ioannis N. Athanasiadis and Pericles A. Mitkes [11] for continuous surveillance and online decision-making to monitor and access eleven (11) air-qualities attributes of a meteorological station such as SO2 (Sulphur dioxide), O3(Ozone), NO (Nitrogen Oxide), NO2(Nitrogen dioxide), VEL(Wind Velocity), DIR(Wind Direction), TEM(Temperature), HR(Relative Humidity), RAD(Radiation), and PRE(Pressure) coming from eleven installed field sensors. Multi-Agent System (MAS) was used to ensure efficient operation of the sensors, take measurements from the sensors, validates the sensors' data and trigger/send custom and formal alarms (alerts) to appropriate personnel/operators in the meteorological station.

The Multi Agent System (MAS) guaranteed good and fast decision-making which would have been difficult, if not impossible, for human operators to accomplish. Multi Agent Systems can equally be employed to monitor oil pipelines from different installed environmental sensors to detect presence of vandals around pipeline infrastructure and to confirm pipeline leakage and alarm/alert the data to appropriate operator using SCADA web-based interface.

G.N.Ezeh et al. in [12], proposed a microcontroller-based pipeline vandalisation detection system with SMS Alert capability. This system has the capability to trigger alarm or alert (SMS only) and get them delivered to appropriate personnel/operator upon the detection of breakage or intrusion into the pipeline system by the installed field sensors. The system cannot allow real-time monitoring of the pipeline and also cannot enable web-based or online-based monitoring which is an essential requirement for corporate SCADA network. The system has no way of capturing the footage (audio, video or photo) of the vandalisation event.

Authors in [13] proposed a microcontroller-based alarm system for pipeline vandals' detection. The system design was in modular forms - communication (transceiver), microcontroller and power system. The system uses pressure sensor, light sensor and break sensor (PIR sensor) to detect break (vandalisation) of pipeline and alarm is triggered and SMS alert is sent to the operator(s) using installed GSM module. The communication system (transceiver) can be called from the control station by dialing its SIM card number and voices (audio) around the vicinity of the vandalisation scene can be heard. This enables spying functionality to confirm the presence of vandals around the pipeline infrastructure and can be used as prosecution evidence in a law court if the vandals happen to be arrested. This system is an improvement to the proposed system by authors in [12] but the drawbacks of this system is that it cannot allow real-time monitoring of pipelines; also it has no functionality such as a GUI or web-based interface to monitor the pipelines which is an essential requirement for SCADA corporate network. Also this system can only allow audio footage but not video or photographic footage.

Jasper Agbakwuru in [14] introduced horizontal directional drilling (HDD) rig technology which is a new method used in laying of underground and underwater pipelines especially oil and gas pipelines. It was reported in [15,16] that the major reason why oil pipelines in Nigeria Niger Delta region were frequently vandalized is because of the way the pipelines were laid. Investigation revealed that vertical drilling by the oil companies facilitated access to their facilities by vandals and oil thieves. The oil pipelines were planted just 1(one) metre below, a development which encouraged the saboteurs/vandals to easily tamper with them. But horizontal direction drilling (HDD) rig technology allows pipes to be buried underground or underwater as far as 50-metre depth, away from the prying eyes of vandals and oil thieves. This technology is already making waves in Nigeria Niger Delta region; major oil companies such as NNPC, Shell and Chevron are already thinking in the direction of HDD rig technology to secure their pipelines against vandalism especially future pipeline projects.

This new technology is the key to solving the rapid rate of pipeline vandalism and oil theft in Nigeria Niger Delta in the future. The drawback of this new technology is that it cannot be used in the already laid pipelines except the old pipelines are completely overhauled and replaced with new ones using this HDD rig technology during their installation. This will bring enormous costs and logistic problems for the IOCs operating in Nigeria because it is impossible for them to replace over 5000 kilometers of pipelines scattered all over the country and install new ones with HDD rig technology.

III. REQUIREMENTS FOR AN IDEAL PIPELINES LEAK/VANDALISM MONITORING SYSTEM

From the research conducted the following requirements are needed for any pipeline monitoring system to work well in Nigeria:

1. The pipeline monitoring system must be wireless (other conventional technologies such as fibre optics were abandoned due to difficult terrain of Niger Delta region and their cost of maintenance),

2. The monitoring system must operate in real-time to help monitor the safety/health status of the pipelines every second in order to detect anomaly or danger to the pipelines on time.

3. The monitoring system components must be cost-effective so as to be economically viable to deploy it to vast area of oil field with several kilometers of pipelines.

4. There is need for the software sub-system to have friendly user interface such as a Graphical User Interface (GUI) designed to fit the web-based nature of SCADA which is the modern architecture used to monitor remote assets from company's corporate intranets.

5. There is need for the system to be able to contribute to prevention of incidences – it should detects intrusion into the pipelines' right-of-way (ROW), i.e. the system should know or detect when there is presence of vandals attempting to break the pipelines before they begin to vandalize the pipelines. Once this is detected the system should be able to alert the authorities or operators of the pipelines.

6. There is need for the system to be able to minimize false positives or false alarms to avoid wastages.

7. There is need for the system to incorporate a method of capturing the footage of vandalism of pipelines when it finally occurs so that the authorities can use this evidence in law court in prosecuting the culprits.

8. The system should be scalable, i.e. installing deploying more number of units of the system to a la pipeline infrastructure should be easy and seamless.

9. The monitoring software sub-system should be fast proactive (intelligent) and should be able to diagnose fa from the installed environmental sensors which monitor pipelines apart from alerting the operators of the pipelin Also the software should be fast in decision-making in orde save time because response time in the system should be v low.

IV. OVERVIEW OF THE ARCHITECTURE OF THE PROPOSED SYSTEM

The block diagram of the proposed multi-agent real-ti anti-vandalism pipeline control and monitoring system shown in Fig.2. Agents are organized in three implementation layers - Contribution, Management Distribution.

Multi Agents System (MAS) is therefore very useful in accomplishing these tasks. This research work therefore focuses on using Multi Agent software Systems to coordinate the tasks and decision-making from the sensors to the web-based SCADA interface at the control station. All the reviewed related works lack this feature except the one proposed by authors in [11]. Our proposed framework/architecture will therefore utilize Multi-Agent System framework used in paper [11].

The inherent advantages of using this framework are enormous – Speed; multi-agent system approach allows monitoring, diagnostic and decision tasks to be done in parallel by assigned different agents thereby increasing speed system's processing. Multi-Agent systems enhance codes reusability, scalability and intelligence of the overall system, etc.

Information flows from pipeline leakage/vandalism detection sensors (on the left in Figure 1) to the users (on the right) through the three agent layers. Pipeline safety (leakage/vandalism) measurements arrive into the system from the sensors- pressure, acoustic, PIR and hotspot.

Diagnosis Agents are task agents; they capture measurements from pipeline sensors and determine whether a formal or custom alarm must be issued about the safety status of the pipelines. The validated measurements are stored into the database for future use by the *Database Agent*.

Possible alarms or alerts are stored and forwarded by the *Alarm Agent* to the *Distribution Agent*, which delivers them in the appropriate format to the corresponding end users or plant control operators in the control station about possible status of pipeline- whether leakage has occurred as a result of vandalisation or that Right-Of-Way (ROW) or perimeter of the pipeline infrastructure has been breached by pipeline vandals who want to steal crude oil or petroleum products.

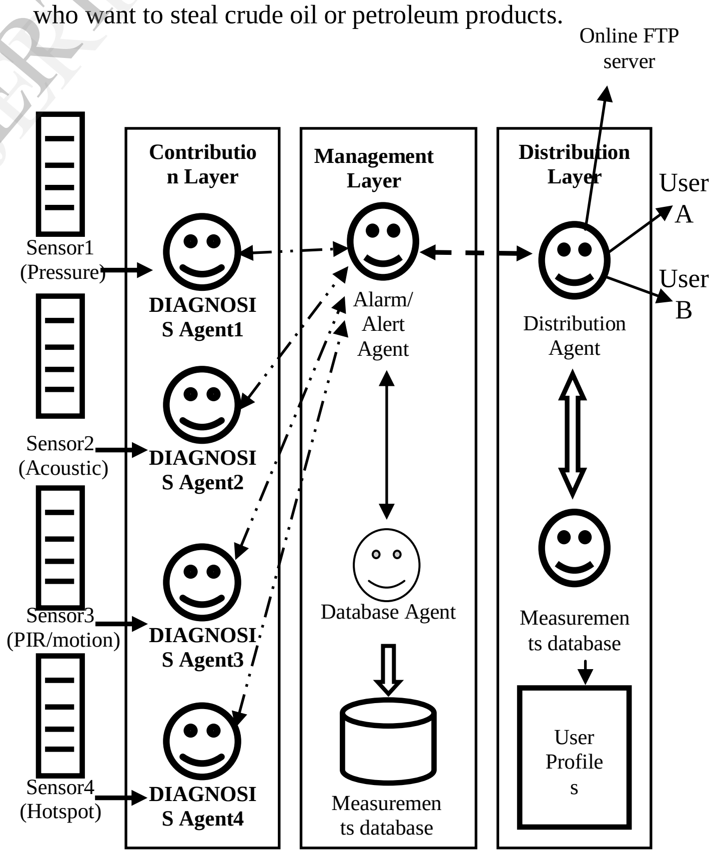


Fig. 2. A 3-layered Multi-Agent system architecture for the proposed system

A. DIAGNOSIS AGENT TYPE

Diagnosis Agents or task Agents are in charge of monitoring various pipeline safety attributes including – pressure level, hotspot level, motion/presence availability of animals/humans, acoustic/ultrasonic (noise) level around the pipeline. The respective Diagnostic Agent checks what is happening to the pipeline field from its corresponding sensor. For instance, to detect whether a vandal is within the Right-Of-Way (ROW) of the pipeline infrastructure, it takes the combination of inputs from Diagnosis Agents 3 and 4 to confirm that. To confirm that the pipelines have been punctured and vandalized, the Diagnosis Agents 1 and 2 must obtain inputs from their corresponding sensors 1 and 2. Once there is a puncture of any segment of the pipeline carrying liquid or petroleum products, the pressure level will drop or reduce with respect to the threshold or normal value or level.

Diagnosis Agents are also responsible for ensuring the efficient operation of sensors. In case of a sensor breakdown, diagnosis agents are in charge of estimating the missing values.

Fig. 3 depicts the internal structure of the Diagnosis Agent type. When a message is received by a Diagnosis Agent, it is checked. If it is a measurement request by another agent, the diagnosis Agent will respond by sending the value of its current measurement. If a new measurement has arrived, it is checked for its validity.

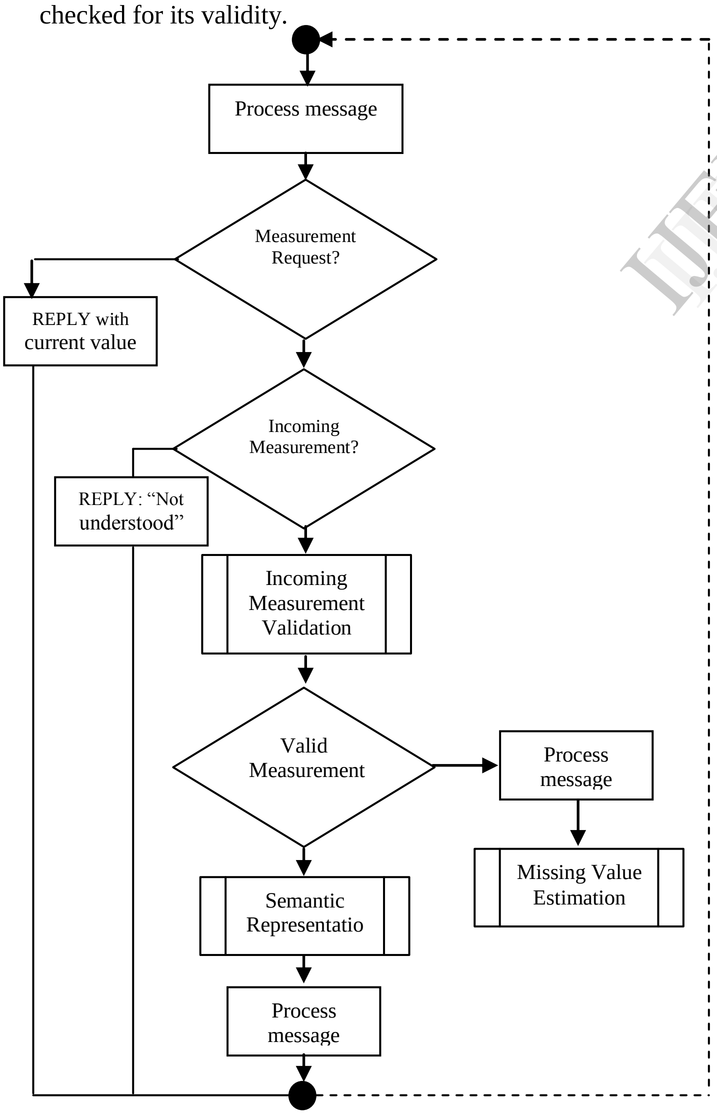


Fig. 3. The internal structure of each Diagnosis Agent for the pipeline vandalism sensor

In other case, the incoming message is not understood and the Agent responds with an appropriate message.

B. ALARM AGENT TYPE

Alarm or alert Agents are Manager Agents and are responsible for triggering formal alarms and custom alarms or alerts. Formal alarms are the ones imposed by law or rule, indicating dangerous situations in the pipeline network or infrastructure exceeding set thresholds. These alerts warn plant operators that pipeline carrying petroleum products are in danger of being vandalized or already vandalized. Custom alarms are alerts for the system users about situations of their concern such as the pipeline's current pressure levels or concerned environmental variable. The measurement tuple or record is equally sent to the Database Agent for onward storage in the database. Fig. 4 depicts the internal structure of the Alarm Agent

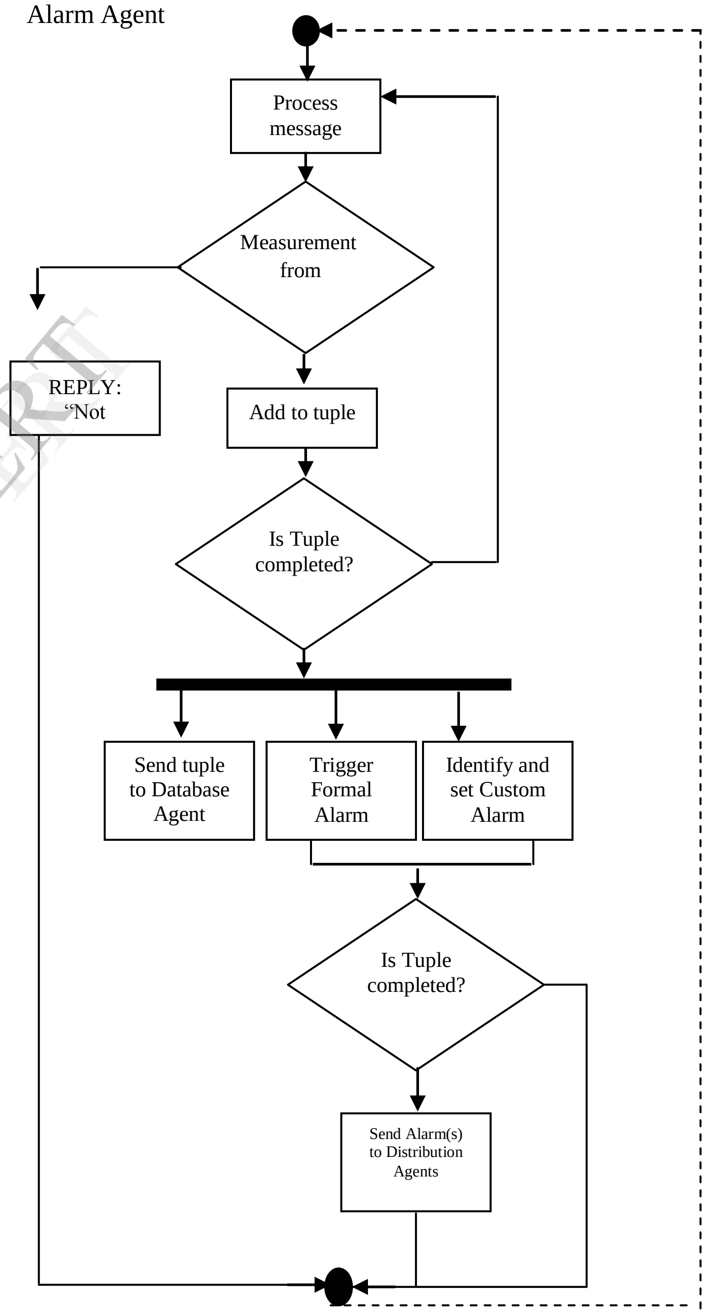


Fig. 4. The internal structure of Alarm Agent

C. DATABASE AGENT TYPE

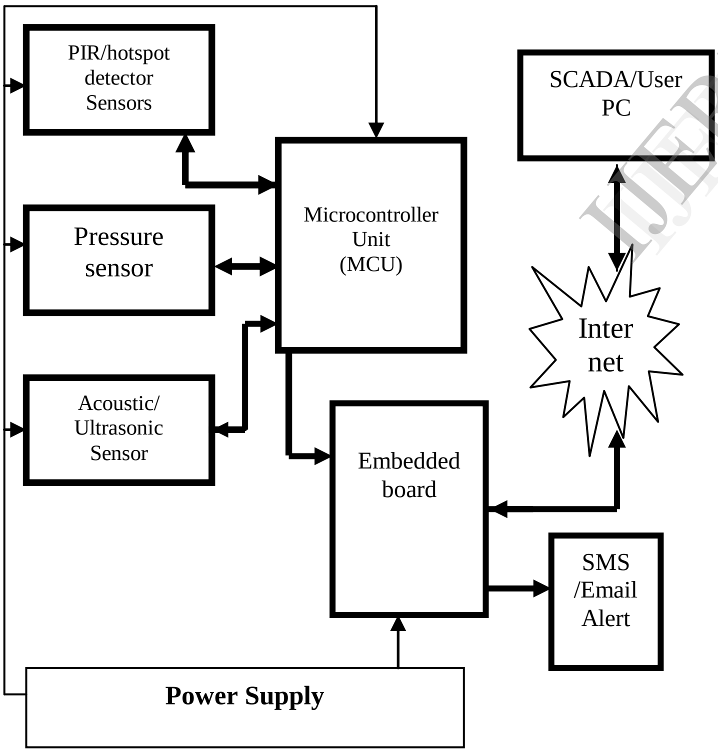
The Database Agent is responsible for updating environmental databases with data from pipeline field sensors. The task is vital for the system performance, as it relives humans from manipulating all this large amount information.

The Database Agent receives a message or signal from the Alarm Agent, containing the measurement tuple. It establishes a connection to the related databases and stores all information in the appropriate format to the corresponding tables.

D. DISTRIBUTION AGENT TYPE

The Distribution Agent pushes the alarms or alerts raised by the Alarm Agent to the appropriate user(s) or to an Internet (Web) server. As an alarm/alert message is received, the Distribution Agent queries user profiles, for selecting target users interested in the alarm, and selects the appropriate medium of notification (i.e. email or SMS or FTP). As the set of recipients and mediums has been pre-specified, the alarm is transformed properly into an alert and finally transmitted to the end users.

The schematic diagram of the hardware sub-system of the proposed pipeline vandalism monitoring system is depicted in Fig. 5.



The Microcontroller Unit (MCU) receives environmental or field signals from the pipeline field sensors such as PIR, hotspot, pressure and acoustic sensors and based on the control algorithm from the MAS sends an alarm message to an embedded board and forwards the message to intended users using either SMS alert, email or real-time message to a web server.

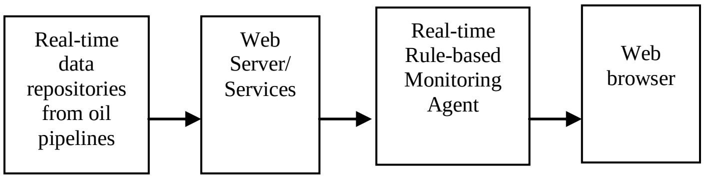


Fig. 6. The proposed Web-based Monitoring model

As shown in Fig. 5, the Agent reads regularly the necessary information from web server using HTTP protocol

The Agent then sort, Infer, and finally display the monitored data according to the web browser.

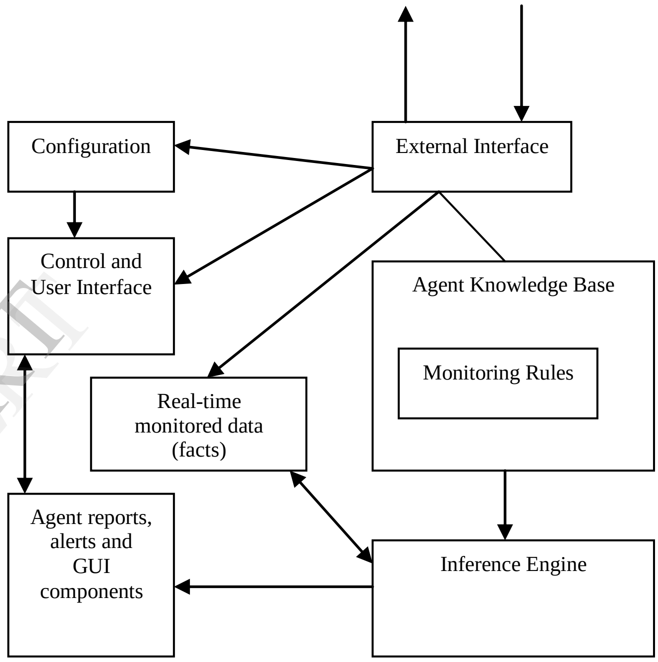


Fig. 7. The schematic diagram showing the Agent data representation of the proposed framework

Fig.7 shows the schematic diagram of the Agent data representation paradigm to be used in this project.

V. FURTHER WORKS

Future works on this research will be to design and implement this framework on existing pipelines in the Niger Delta region.

VI. SUMMARY AND CONCLUSION

Pipeline infrastructures are critical national resources that must be protected from criminal activities of vandals and crude oil thieves. Several works have proposed several methodologies to solve the problem of pipeline leakage and vandalisation in the Niger Delta Region. This paper presented a holistic software implementation framework using a popular software engineering paradigm known as Multi-Agent Systems (MAS). MAS were used in this paper to liaise with installed environmental pipeline sensors in order to detect the activities of pipeline vandals. The paper was able to show how MAS can be used to effect interactions between the pipelines sensors in order to send appropriate alarm messages to the oil pipeline control station so that activities of the vandals can be nipped on the bud in order to curtail loss as a result of product loss and environmental degradation.

The paper also showed that it is possible to use an agent-based to implement web-based monitoring platform so that from corporate SCADA network, the personnel of the of companies can see what happens at the remote locations where the pipelines are deployed.

REFERENCES

[1] Daily Times, "Nigeria ranked second most corrupt Nation",http:/www.dailytimesofnigeria.com/DailyTimes/2003/October/8 /Nigeriaranked.asp/

[2] L.P. Eyo-Essien, "Oil spill management in Nigeria: challenges of pipeline vandalism in the Niger Delta region of Nigeria" unpublished.

[3] G.O. Odularu, " Crude oil and the Nigerian Economic performance", Oil and Gas Business, 2008. Accessed online @ http://www.ogbus.ru/eng/ on 14 December 2014.

[4] E.F. Idachaba, " Remote Operation of Oil and Gas production installations in the Niger Delta", Asian Transactions on Engineering (ATE ISSN: 2221-4267), Volume 01 Issue 03, 2011,pp.55.

[5] Niger Delta Environmental Survey (NDES), "Environmental and Socioeconomic chacrcteristics, 1997. "Unpublished.

[6] P.C. Nwilo, K.O. Peters, and O.T. Bodeji, "Sustainable Management of Ol spill incidents along the Nigerian Coastal areas, 2000.". Unpublished.

[7] B. Ojediran, and J. Ndibe, "Oil Spill Management: SPDC and the Environment, 2005." Unpublished.

[8] E.F. Idachaba, "Remote Operation of Oil and Gas production installations in the Niger Delta", Asian Transactions on Engineering (ATE ISSN: 2221-4267) Volume 01 Issue 03, 2011, pp. 54.

[9] T.John, "TUC backs NUPENG on alleged JTF's connivance with bunkerers", Daily Sun, Thursday, 16, August, 2012, pp.10.

[10] E.F. Idachaba, "Remote Operation of Oil and Gas production installations in the Niger Delta", Asian Transactions on Engineering (ATE ISSN: 2221-4267) Volume 01 Issue 03, 2011, pp. 58.

[11] I.N.Athanasiadis and P.A. Mitkas, "An Agent-based intelligent environmental monitoring system', Management of Environmental Quality Journal, Vol.15, No.3, pp.238-249. Emerald Publishers.

[12] G.N.Ezeh, N.Chukwuchekwa, J.C.Ojiaku and E. Ekeanyanwu, "Pipeline Vandalisation Detection with SMS", International Journal of Engineering Research and Applications (IJERA), Vol.4, Issue 4(Version 9), April 2014, pp.21-25.

[13] O.Shoewu, L.A.Akinyemi, K.A.Ayanlowo, S.O.Olatinwo, N.T.Makanjuola, "Development of a Microcontroller based Alarm System for Pipeline Vandals Detection", Journal of Science and Engineering, Vol.1(2), 2013, pp.133-142.

[14] J. Agbakwuru, " Pipeline Potential Leak Detection Technologies: Assessment and Persepectives in the Nigeria Niger Delta Region", Journal of Environmental Protection, 2011,2, pp.1055-1061.

[15] D.K. Olofin, "Gulf Oil Co., Western Geophysoical Co., and R.A.Will, "Acqusition and Processing of Shallow Water 3-D Seismic Surveys over Producing Fields in the Northwest Niger Delta offshore", "Technology Conference, Houston, 6-7 November 1989.

[16] S.Adebayo, " HDD technology Takes Pipeline Across 1.7km Escravos River", Fortune Business, 2010.