
Jemal H. Abawajy  
Faculty of Science, Engineering and Built Environment, Deakin University, Australia

Tai-hoon Kim  
School of Computing and Information Systems, University of Tasmania, Australia

R. S. Sudhakar,  
Chief Executive Officer, Techno Forum Business Process Centre, Wolfsburg, Germany

K.KokulaKrishna Hari,  
Country Head, Techno Forum Group, India.

Abstract - Installation of a system to monitor and measure sand production from an oil well especially in a petroleum industry would be valuable to assist. Sand production is considered one of the major Problems facing the petroleum industry since a small amount of sand in the produced fluid can result in significant erosion in a very short time period. In this paper, we present a framework for sand detection and sand production rate measurement. The framework combines Two modules: 1) a wireless sensor data acquisition (WSDA) module and 2) a central data fusion (CDF) module. The framework is designed to collect data from oil pipeline using acoustic sensors (SENACO AS100), flow analyzer (MC-II), and differential pressure transmitter (EJA110A) in real time. A test bed is established from ten acoustic sensors mounted on a closed-loop pipeline. The flow rate and the differential pressure are monitored as well. The sand is injected in the test bed with a constant flow and pressure. The output of the acoustic sensor is analyzed in order to calculate the sand production rate. The sand rate, flow rate, and pressure are digitized for wireless transmission using the WSDA module. The data are collected in the gateway, i.e., a laptop in our case. The CDF module is implemented in the gateway. The purpose of data fusion is to improve the system performance. Three different fusion methods, fuzzy art, maximum-likelihood estimator, and moving average filter are evaluated throughout the simulation and experimental results. The proposed framework is successfully tested and evaluated.

Keywords — Data fusion, sand production, wireless sensor network (WSN).

I. INTRODUCTION

SAND production is considered one of the major problems facing the petroleum industry. In the oil and gas industry, the sand production from wells may use considerable erosion damage in the pipes, fittings, separators, valves, and other equipment [1]. It can cause poor performance in injection wells and can lead to lost production. It arises in the case of failure of sand control measures. Produced sand can also result in serious damage to the reservoir, where, in some cases, the reservoir collapses as a result of the sand production. It can cause poor performance in injection wells and can lead to lost production. It arises in the case of failure of sand control measures. Sand screening is a critical part of the mining process. The most common practice for controlling sand erosion in gas- and oil-producing wells is simply to limit the production [2].

The trend in oil companies nowadays is to integrate the entire well sensors (modern and legacy sensors) with a wireless sensor network (WSN). The main contribution of this paper is that we introduced a new framework from such sensors using a heterogeneous network of sensors taking into consideration the WSN’s constraints.

![Fig. 1. (a) Intrusive device. (b) Nonintrusive devices.](image)

II. SAND MONITORING

Some sand monitoring devices are located down hole on the production tube. More commonly, monitoring is undertaken on the Topsides pipe work. Two generic types of devices are used to monitor sand production: 1) intrusive devices and 2) nonintrusive devices.

A. Intrusive Devices

The intrusive devices can be intrusive sensors, tuning forks, or erodible resistance probes, as shown in Fig. 1(a). These are probes inserted through the pipe wall into the flow path. Erodible resistance probes is the most commonly used today among the intrusive types. This type uses the Whetstone Bridge as a principle for measurement techniques and is a well-proven and working principle. However, all the intrusive systems have some disadvantages due to their intrusiveness, i.e., it is not real-time measurement device, as they are not able to give the user a quick respond. Moreover, sand and particles in the flow cause erosion on the probe, and it has to be replaced.

B. Nonintrusive Devices
The nonintrusive devices clamped onto the pipe wall, as shown in Fig. 1(b). They are acoustic devices that detect the sound of particles impacting the pipe wall. However, careful positioning of the devices is essential; usually, they are installed after a bend. When the flow is passing the bend, particles will be forced out and hit the inside of the pipe wall and generate an ultrasonic pulse. The ultrasonic signal is transmitted through the pipe wall and picked up by the acoustic sensor itself.

![Fig. 2. Proposed platform.](image)

III. PROPOSED SAND MONITORING SYSTEM

We propose a remote monitoring system for sand in pipelines. Our goal is to introduce a reliable, accurate, and low-cost sand monitoring system. Fig. 2 shows the proposed system. The framework combines two modules: a WSDA module and a CDF module. Each of the two modules has a wireless Receiving and Transmission (ReT) module for communication between each other. The framework is designed to collect data from oil pipeline using acoustic sensors (SENACO AS100), a flow analyzer (MC-II), and a differential pressure transmitter (EJA110A) in real time. The data are collected in the gateway, i.e., the laptop in our case. The CDF module is implemented in the gateway using three fusion methods: 1) fuzzy art (FA); 2) maximum-likelihood estimator (MLE); and 3) moving average filter (MAF).

IV. SENSORS USED IN THE PROPOSED SYSTEM

A. AS100 Acoustic Sensor

The Senaco AS100 sensor monitors the high-frequency acoustic emissions. Acoustic emissions travel readily through solid materials such as metal but are strongly attenuated when traveling through air. As such, the sensor is immune to airborne interferences and provides a non-invasive method of monitoring process activities. The Senaco AS100 sensor provides an analog output. It is primarily used for liquid flow detection. However, this device can be used in pump cavitations and fluid leak detection. Fig. 3 shows the AS100 acoustic sensor.

B. MC-II Flow Analyzer Specifications

The NuFlo Measurement System’s Model MC-II flow analyzer receives an electronic pulse stream from a turbine flow meter and provides a registration of the totalized flow and an indication of flow rate by utilizing its microprocessor-based circuitry. Fig. 4 shows the MC-II flow analyzer.

![Fig. 3. Senaco AS100 sensor](image)

![Fig. 4. MC-II flow analyzer](image)

![Fig. 5. EJA110A differential pressure](image)

C. EJA110A Differential Pressure Transmitter

Yokogawa Electric Cooperation Model EJA110A differential pressure features high performance, durability, and reliability. The pressure detector, which is the core of the transmitter, uses a silicon resonant sensor that has proven to be highly reliable in the field and offers a complete product lineup. It is a revolutionary technology for configuring instrumentation control systems and a promising successor to the standard 4–20-mA analog communications used in most field instruments today. Fig. 5 shows the EJA110A differential pressure transmitter.
The proposed WSDA framework includes a signal Conditioning and Digitizing (CoD) module, a wireless Receiving and Transmission (ReT) module, and a Management and Control (MaC) module. This paper discusses an implementation of the ReT module based on TinyOS and Crossbow MICA2 motes, whereas different implementations of the ReT module are possible. The CoD module has been implemented to work with three legacy sensors: 1) acoustic sensor; 2) flow meter; and 3) differential pressure transmitter. These devices produce different types of analog signals: the acoustic sensor and the flow meter generate dc voltages, whereas the differential pressure generates dc current outputs proportional to the measured differential pressure. Fig. 6 shows the proposed WSDA. The CoD module permits the following: 1) different legacy sensors to provide their data readings in a unified way to the ReT module for transmission and 2) received data/control signals to be converted back to their respective analog signal forms. Then, it interfaces with the CoD module, which converts the received values before forwarding to corresponding legacy sensors. Moreover, it conditions and digitizes the analogous sensor readings to the given resolution for transmission. The MaC module serves to control the sensor network formed and the sensor data acquisition rates. The proposed WSDA framework is readily applicable to various engineering applications where legacy and modern sensors exist.

The ReT module may be implemented in different fashions. The CoD module provides a connection between legacy sensors and the ReT module. CoD does not need to be aware of the details of the radio transmission but needs only to know how to pass the data to/from ReT on transmission. In the same way, ReT knows nothing about the details of the analog-to-digital (A/D) conversion process or the signal value ranges. It only needs to know that a CoD has registered with it and to provide the data in a normalized format. The proposed WSDA framework includes a MaC module to facilitate sensor data readings to be logged and displayed in a uniform fashion, no matter whether they are from legacy sensors or modern ones. The MaC module also enables quick additions and modifications for data collection types and amounts when involved sensors and devices change. The WSDA framework allows a level of interchangeability between components. The hardware circuits used to condition and normalize a 4–20-mA signal can be reused with different ReTs that use entirely different communication protocols. Thus, CoDs that operate with ReTs that use the default TinyOS protocols can be used with other ReTs that implement standard Zigbee application protocols. While certain modern sensors incorporate the functionality of CoD, this framework integrates data acquisition over those modern sensors, together with their legacy counterparts through ReT with acquired data managed and controlled MaC. As can be seen in Fig. 6, the proposed framework is suitable for any engineering application where various types of sensors exist because its ReT interfaces seamlessly with legacy sensors via CoD and with modern sensors directly.

VI. FUSION METHODS

In our proposed platform, we have ten acoustic sensors distributed on the pipeline. Each sensor has a sand rate interface to calculate the sand production rate; the flow rate and differential pressure are monitored as well. At the gateway, we are receiving ten different values from each sensor. In order to increase the associated confidence, we need to fuse all the data coming from the sensors. In our test bed, we used a computer as a gateway, but, for real applications, this gateway will be one of the nodes in the WSN since WSN has energy and computation constraints. In other words, most sensor nodes do not have the energy and computational resources to complete complex tasks repeatedly for long time. In order to meet with these constraints, we used three classic fusion algorithms. CDF module is implemented using three fusion methods: FA, MLE, and MAF.

A. FA

The FuzzyART data fusion technique employs FuzzyART neural network modules to fuse measurements into a coherent estimate. Neural network modules fit in typical sensor network systems since it shares similar characteristics such as distributed processing and data storage, adaption to changes in environment, and resilience to noise and corrupted data. After the input
vector is presented to the FuzzyART fusion center, it will cluster the information into categories. The weight vector of the trained network has a geometric meaning where each category is bounded by a rectangle that contains all the inputs that are close to each other. FuzzyART fuses measurements by assigning a probabilistic weight according to two metrics, i.e., spatial correlation and consensus vote. The measurements that are geometrically close to each other should be given high probabilistic weight, and the more estimates we have in a group, the more confident we are with this group. Furthermore, FuzzyART detect erroneous measurements and assign them a zero weight to prohibit them from contaminating the estimation process. To automate this process, probabilistic weight is assigned according to a decision tree shown in Fig. 7.

1) If all measurements reside in a single category, then a fixed probabilistic of 1 will be assigned to this category, which is divided evenly among the candidates of this category.

2) If measurements are divided into two categories where one category contains two measurements and the other contains only one measurement, then we cannot rule the fact that the category with one measurement contains an erroneous measurement. In this case, the category with two measurements is assigned a weight of 0.75, which is divided evenly between the two measurements. The category with one estimate is assigned a weight of 0.25.

B. MLE

MLE is a method for choosing an estimator of parameters that avoids using prior distributions and loss functions. It is also a statistical estimator that can be used to estimate a model’s unknown parameter values from data.

C. MAF

The MAF is broadly implemented in fusion. It is optimal for reducing random white noise at the same time as retaining a sharp step response. This filter computes the arithmetic mean of a number of input measurements to produce each point of the output signal. A slight improvement in computational efficiency can be achieved if we perform the calculation of the mean in a recursive fashion. A recursive solution is one that depends on a previously calculated value.

VII. SIMULATION RESULTS

In this section, we provide the output performance of the proposed platform. A test bed is established using ten acoustic sensors to collect the data from the same pipe. Fig. 8 shows the test bed platform. In order to get the accurate sand production rate, the global flow rate and the global differential pressure should be monitored as well. The global flow rate is measured using one MC-II flow analyzer sensor, and the global differential pressure is measured using one differential pressure sensor. Both sensors are mounted on the test bed. In the experimental tests, the sand is injected in the test bed by a certain rate using an injector with a known flow rate and pressure. Each sand rate module calculates the sand rate. The sand rates, the global flow rate, and the global pressure are digitized for wireless transmission using the WSDA module. The data are collected in the gateway, i.e., the laptop in our case. The CDF module at the gateway is used to fuse all the ten sand rates in order to improve the system output. The proposed system has been validated experimentally using different sand rate, flow rate, and pressure values.

VIII. CONCLUSION

A framework for sand detection and sand production rate measurement has been presented. The framework combined two modules: a WSDA module and a CDF module. A test bed has been established from ten acoustic sensors mounted on a closed-loop pipe. The flow rate and the differential pressure have been monitored as well. The CDF module was implemented in the gateway using three fusion methods; FA, MLE, and MAF. The purpose of data fusion has been to improve the system performance. The experimental results show that the MAF fusion method is outperforming the other methods. To conclude, we would like to emphasize the simplicity and novelty of this scheme in the use of petroleum applications.

REFERENCES


Fig. 8. Test bed platform.