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Diagnosis of horizontal pipe leaks using neural networks

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Abstract. This document presents an experimental study that supports probabilistic decisions based on neural networks to detect the presence of leaks in pipeline transport systems, since such leaks can cause serious consequences. In addition to the economic losses presented by the lost product, process stoppage and repair of the damage, there can be insurmountable environmental and social losses such as the death of human beings. The probabilistic model correlates measurements of inlet and outlet pressures and flow to the state of leakage. The study and experimentation presented in this work are based on information acquired by simulating the behavior of the fluid in a pilot tube installed in the Fluid Mechanics laboratory of the Universidad Francisco de Paula Santander, Seccional Ocaña. Finally, experimental tests were carried out to obtain the data of the physical variables of the flow sensors at the entrance and exit, with these data a multilayer neural network of perception was trained. The results obtained from the test equipment, with intentionally caused leaks, showed that the structure of the multilayer Perceptron neural network was capable of detecting leaks in the pilot tubes. With the accomplishment of this work it was found that the neural network presents favorable results at the time of detecting the leak compared with other methods of detection since this one presents immunity to the noise, a parallel structure and, consequently, capacities of fast processing and classification.

1. Introduction
The transportation of fuels by pipeline is considered a safe and low operational cost method. However, possible product leaks or spills can cause serious consequences. In addition to the economic losses presented by the lost product, process stoppage and damage repair, insurmountable environmental and social losses can occur, such as the death of human beings, irreparable environmental damage and damage to endemic species, among others [1].

One of the main problems is associated with the operation and safety of pipelines transporting chemicals, petrochemicals, gasoline and gas. In recent years, intensive work has been carried out to increase safety, reliability and availability in the pipeline network, through large investments to prevent pipeline product theft and pipeline leaks.

Over the years, different types of methods have been implemented in the field of pipeline leak detection, external or dependent methods such as visual, acoustic, negative pressure and sampling techniques, which have been used in a qualitative and not very precise way. Internal or non-dependent methods are widely used today as they do not require human intervention such as pressure and flow
changes, mass balances, pressure point analysis, and dynamic modeling, and other technologies have been used for years [2].

Fault detection and diagnosis systems have two fundamental tasks, the first is "fault detection" where the objective is to recognize that there is a fault, and the second is "fault diagnosis" whose task is to isolate the fault and tell us the possible cause, location and number of faults [3].

The different techniques associated with artificial intelligence and expert systems such as fuzzy logic, neural networks, genetic algorithms, and rule-based systems have opened up a new possibility in the implementation of advanced controls and process optimization systems, where experience and knowledge of processes and their behavior are the basis for implementation [4].

In this work, a proposal for a method of detecting leaks in pipes using techniques used in artificial intelligence is presented. The advantage of this approach is that unlike analytical methods, it is not necessary to know the mathematical model that describes the dynamics of fluid transport in the piping. This makes it applicable to any type of fluid or piping as it only requires two flow measurements.

This document is organized as follows: Section 2 presents the methods of pipe fault detection using neural networks; section 3 presents experimental configuration and data collection; section 4 shows the results; section five presents the conclusions.

2. Fault detection using neural networks

Artificial neural networks are specialized computer systems that can be implemented in both hardware and software and are used to represent complex functions in many fields of application. Historically, these systems tried to simulate the processes developed by the brain, which processes information, combines or compares it with stored information and gives adequate answers even to new situations [5].

2.1. Neuronal fault diagnosis system

The main task of a fault diagnosis system is to determine the location and magnitude of a possible fault. Based on the behavior and knowledge of a process, making use of a mathematical model or a qualitative one [6,7]. Figure 1 shows the general structure of a model-based fault diagnosis system [8,9] It can be observed that the fault diagnosis procedure in a dynamic system is divided into two stages: the generation of the residue and the evaluation of the residue. The residual value r is determined as the difference between the measuring process of the Ys signal and the output of the respective model. Models are built for fault-free states for leak-sensitive variables. When a leak occurs, the Ys measurement signal behaves differently than modeling for a flawless state. This results in the generation of the residual value r, which signals a faulty process state.

2.2. Multilayer perceptron

The multi-layer perceptron is a network in which neurons are grouped into layers as shown in Figure 2. This network has an input layer, 1 or more hidden layers, and an output layer. The main task of the input layer is to pre-process the input data and pass it to the elements of the following layers. This pre-processing can be scaling, filtering or data normalization. The fundamental processing of the network is carried out in the hidden layers and in the output. It is necessary to emphasize that the connections
between neurons are designed in such a way that each element of the previous layer is connected to each element of the next layer [10].

![Neural network, perceptron multilayer](image)

**Figure 2.** Neural network, perceptron multilayer [8,9].

2.3. *Methodology to diagnose the leak in the experimental pipe*

The schemes for diagnosing leaks in the experimental piping are shown in Figure 3 and Figure 4, which are divided into two fundamental stages: learning stage and monitoring stage.

![Learning stage](image)

![Monitoring stage](image)

**Figure 3.** Learning stage.  **Figure 4.** Monitoring stage.

In the learning stage, the objective of this stage is to characterize the leakage or non-leakage changes as a function of the input flow and output flow. The implemented neural network is of the multilayer perceptron type (MLP). The network has 4 input and 2 output variables. This network estimates whether or not there is leakage under different conditions of the piping system. The number of neurons in the hidden layer is estimated by trial and error until the best network configuration is obtained.

In the monitoring stage, flows and pressures are recorded both at the inlet and outlet of the piping system, and the neural network is evaluated. It is then calculated and compared with the alertness level. If it is found to be higher than the alertness level, it can be stated with some level of confidence that there is a leak in the system; otherwise, the data records are recorded again, and this indicator is constantly evaluated.

3. *Experimental configuration and data collection*

3.1. *Pilot tube*

The work is based on experimental data, the first step was to build an experimental pipe, which consists of two water tanks with two pumps for water recirculation, on one of the pipes were located two flow sensors, between which is the leak as shown in Figure 5. This experiment was carried out in the Fluid Mechanics laboratory of the “Universidad Francisco de Paula Santander, Seccional Ocaña (UFPSO)”.
The data recording system is designed and implemented based on National Instrument technology, by means of a virtual instrument and a NI cDAQ-9178 chassis with a NI 9203 module to capture the values of the variables to be studied and transmit them to a database accessible on a PC. The components used are described in Table 1 [11].

![Figure 5. Schematic diagram of the experimental piping configuration in SolidWorks.](image)

Table 1. Main Components used in the experiment.

| Instrument                  | Type             | Parameters                  | Measurement range |
|-----------------------------|------------------|-----------------------------|-------------------|
| Flow meter                  | SBG434           | Inlet and outlet flow.      | 0 to 35 L/min     |
| Pressure gauge              | PG2454           | Inlet and outlet pressure   | 0 to 60 psi       |
| Data acquisition card       | NI cDAQ-9178     | Data acquisition system    | N/A               |
|                            | and NI 9203 card |                             |                   |
| Pump                        | Water pump QB - 60Pumping system | 3450 rpm | Voltage: 120 v |

3.2. Data acquisition system

For the data acquisition system, the NI cDAQ-9178 chassis and NI 9203 card from National Instruments were used. For the development of the research, a user interface was created, which provides the operator with flow and pressure data, graphs and controls for the correct visualization and automation of the leak detection system.

![Figure 6. Leak detection VI graphical interface (instant in which the leak is detected).](image)
This screen shows a virtual instrument that allows visualizing the graphs of the inlet flow, the outlet flow, the inlet pressure, the outlet pressure; it is possible to visualize independently how each signal behaves and the data recorded from the system is visualized in a table (Figure 6). In this same screen, when the differences in flow rates and pressure are lower than the lower limit established in the leak detection algorithm, a message is displayed saying "a leak has been detected", the data is saved in an excel file and then processed [12].

4. Results
The data collected are used in the development of the leak detection system based on the multilayer perceptron neural network. In general, the neural networks have to perform classification tasks, i.e. they classify the incoming flow data of input and output flow in a state of leakage or without leakage. Therefore, data for network training is developed with four input values corresponding to inlet pressure, outlet pressure, and inlet and outlet flow. In addition, they have two output neurons; namely, leaks and no leaks neurons.

For the development of the neural network the Matlab nntool was used, to which were entered the data of the subtraction of the input flow minus the output flow as input data, and a vector of zeros and some as objective data (target data). A feed-forward back propagations neural network was created with 10 neurons, trained, resulting in 10 iterations.

Figure 7 traces the training, validation and test performances given the TR training record returned by the function-train.

![Figure 7. Best validation performance.](image)

Figure 8 shows the response of the neural network to a leak in a given instant of time. It can be seen that in the instant that there is a change in the flow of outputs (320 s) the neural network sends a one to the output, generating a leak detection alert. This leak detection system has advantages over the acoustic methods found in the literature, since they present immunity to noise due to the ability of the network to recognize patterns and respond accordingly, additionally fewer sensors are needed to detect the leak [13,14]. A Matlab simulink block was developed with the neural network, and then fed with inlet and outlet flows.

![Figure 8. Neural network response to a leak.](image)
5. Conclusion
The multilayer perceptron neural network has noise immunity characteristics, as it is able to identify patterns in the training dataset.

The multilayer perceptron neuronal network shows a correspondingly fast processing and sorting capability that provides good performance in leak detection. Data analysis performed by the multilayered perceptron neural network can replace the human operator in the task of monitoring trends in flow signals to warn personnel by presenting the diagnosis of the leak. This methodology could be applied to monitor potentially hazardous fluid distribution networks to provide safe operation and avoid serious injury to human health.

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