9th International Symposium on Lowland Technology
September 29-October 1, 2014 in Saga, Japan

APPLICATION OF ASTAR AND RBF-NN TO PREDICT LOCATION AND MAGNITUDE OF PIPE LEAK ON WATER DISTRIBUTION NETWORK

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ABSTRACT: In this research, the system of plumbing leak detection will be done by a computerized technique by using analysis of pressure monitoring as a determinant of presence of pipeline leaks in the water distribution network. The pressure data obtained from EPANET, namely a modeling system in a hydraulic system. This study uses two methods, namely Adaptive Spline Threshold Autoregression (ASTAR) and Radial Basis Function (RBF) methods which the results can be compared in order to predict the magnitude and location of leakage.

Overall both of these methods can be used to predict the magnitude and location of leakage. The accuracy of predictions for the magnitude and location of leakage of these methods are based on the value of RSME. In this case the results obtained by using the method of RBF is more accurate namely 0.000049 compared than the method of ASTAR i.e. 0.005 of the entire pipeline systems.

Keywords: Plumbing leak , ASTAR, RBF-NN, EPANET

INTRODUCTION

The leak of water in distribution pipes is a very important issue that often occurs in almost all countries in the world where it is causing large losses. Thus, this study aims to predict the magnitude and location of leakage in the water distribution network. The development of computerized technology allows the detection of water leaks are no longer using the search manually by using tools, but the detection can be performed by using a computer.

There have been many studies were done regarding to this matter namely, (Caputo and Pelaggage 2003) using neural networks in predicting oil pipeline leak from the pressure sensor data. (Yang et al. 2009) using RBF-NN with differential pressure to detect air leakage, (Van Zyl 2007) stated the relationship between the amount of leakage with pressure by comparing some leakage exponents. (Mashford et all. 2009) using the EPANET in modeling the water pipe leaks and the method of SVM to predict the magnitude and location of leakage up to 90 lt/hour and the distance of prediction is 100 to 500 m. (Jalalkamali and Jalalkamali 2011) using Hiybrid Neural Network and Radial Basis Function in determining large of water leak in the distribution network. (De Silva et al 2011) is a continuation of previous studies by adding sensor instrument which have a sensitiveness toward the small leaks.

Therefore, in order to complete the previous studies, this research is done to compare Adaptive Spline Threshold Autoregression (ASTAR) and Radial Basis Function Neural Network (RBF-NN) methods to determine the location and also major of pipeline leak in the water distribution system.

RESEARCH METHOD

Radial Basis Function

The model of artificial neural network of Radial Basis Function is one form of a multilayer perceptron that fixing the weight values, the median value, and the distance among data in order to reduce the errors that occur on the network output. In this model, Neural Networks using basis activation function in the hidden layer.

Before the Radial Basis Function Neural Network doing prediction process of location and leak large at the junction and drain pipes, it is previously performed the training process. The training process of method including three phases, namely the entry input data variable during the training process, setting the value of

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the spread and neuron/epoch and calculation of error value. The process of setting the value of the spread and epoch aims to minimize the value of the error that occurred.

The steps were done in the process of Radial Basis Function Neural Network are as follows:

1. To load the input data in the form of pressure changes data at junction/intersections of pipes or pipelines;
2. Making the process of data normalization to obtain the data interval from 0 to 1;
3. Creating the network initialization will be trained to predict the future data with functions in Matlab, NEWRB;
4. The Process of network training by using the train functions in Matlab applications. The training process is done so that the system can learn the patterns of input data until to get performance and percentage of target achievement the best value of magnitude and location of leakage.

In the network structure of Radial Basis Function Neural Network, this study using three layers namely input layer, hidden layer and output layer with 2 neurons. Determination of the number of neurons in the hidden layer is done by trial and error, until to get the small error value and fast training time. The number of hidden layer neuron is equal to the value of the training epoch. The maximum number of neuron is equal to the number of junctions in the pipeline.

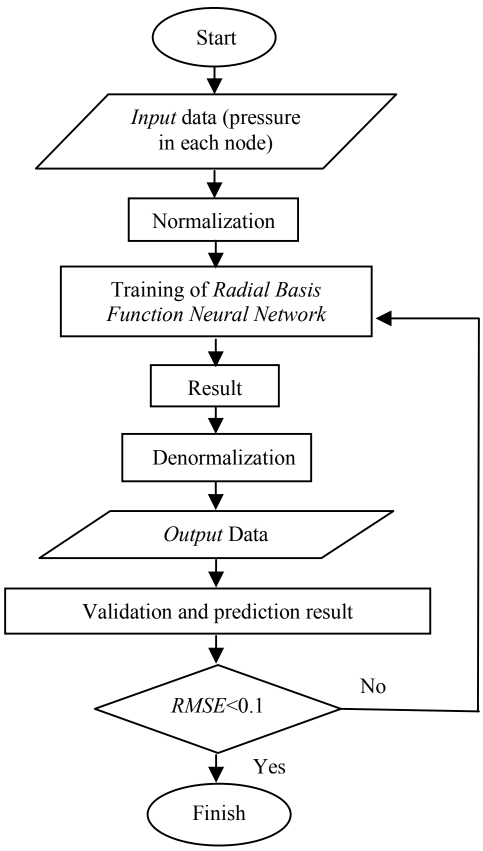

Fig 1. Flowchart of System Planning of *Radial Basis Function Neural Network*

Adaptive Spline Threshold Autoregression (ASTAR).

ASTAR method is non-linear time series analysis is based on algorithm of Multiple Adaptive Regression Spline or more known as Multivariate Adaptive Regression Splines (MARS).

ASTAR model is the development of MARS with $\mathbf{Z_t}$ as response variable and $\mathbf{Z_{t-j}}$ as predictor variables, so that ASTAR model can be written as follows:

$$Z_t = a_t + \sum_{m=1}^{N} a_m \prod_{k=1}^{K_m} \left[s_{km} \cdot \left(Z_{(t-j)l(km)} - t_{km} \right) \right]_+ \quad (1)$$

The forming of knot in the ASTAR is similar with the formation of knot in MARS. Point of knot in ASTAR is usually called threshold. Selection of forward starting with the basic functions of the constant $B_0(x)$ =1. At every step forward stepwise, the selection of the number and location of knot automatically based on the minimum value of ASR (Average Sum of Square Residual). In furthermore, (Andriani 2009) stated that backward algorithm to eliminate some of the base functions of (M - S) basis function where 1 ≤ S ≤ M was done, so that it is founded a model that minimizes the GCV.

In this research, the data used is the pressure at the junction leakage current occurs with large leakage ranged from 0.01-0.6 L/s and ASTAR model linking the response and predictor variables. The response variable in the modeling of emitter coefficients is big with the emitter coefficients (0.005 - 0.3), meanwhile the predictor variable is the pressure at each junction with the total variable are 44. Based on the theory proposed by (Friedman 1991) amount of basic function (BF) has value 2 to 4 times from the predictor variables and maximum interactions (MI) has value 1, 2, or 3 with the assumption that the interaction is more than 3 will result in a model that increasingly complex. Based on trial and error toward the combination of BF and MI in order to obtain minimum GCV value, the obtained amount of BF = 88 and MI = 3. The combination resulted best ASTAR model to predict big emitters' coefficient.

For example, a large predicted pipe leak that occurred in the connecting junction 13 and 2.

The model is formed as follows:

Ye = 0:12 +18 * -18.7 * BF1 BF2 (2)

where:

BF1 = max (0, x1 -3.86)

BF2 = max (0, 3.86-x1)

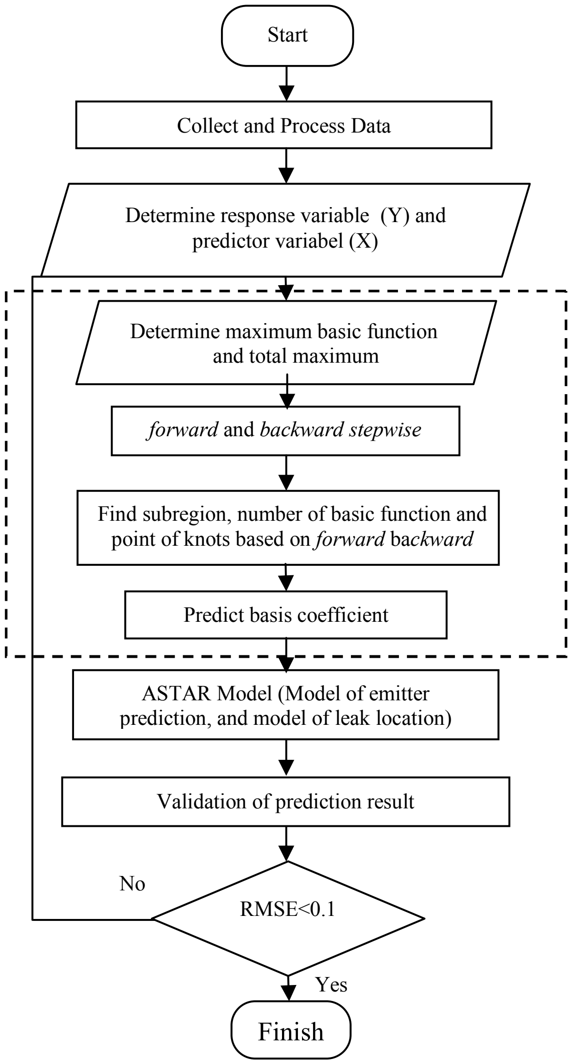

Fig 2. Flowchart of forming ASTAR Model

METHODOLOGY

The data used in this study is pressure data in each junction/intersection of pipe obtained from Regional Water Supply Company for region Taman Khayangan Makassar Resident, Indonesia can seen in figure 3. The data is taken from the pressure data when a leak was happened, either at junction/intersection point or the leak that occurred in a pipeline.

To obtain a model with the accurate prediction results, hundreds or even thousands of training data set are needed. It is therefore not possible to use data of the actual pipe leak occurs in the field as a data training. So, the pressure data used are the data obtained from the simulation results by using the software EPANET 2.0. created by (Rossman 2000). Software EPANET 2.0 is software for the hydraulic system has been used by Regional Water Supply Company to monitor pipelines.

Before doing simulation of leaks, first the development of piping network system using Epanet 2.0. was done. System of piping network constructed by inserting the data in the form of a large flow of water flowing from the reservoir, the length and diameter of the pipe, the level of roughness of each pipe, as well as great of elevation and demand of average water needs in each junction. The data are obtained from the piping network system in Taman Khayangan Makassar Resident. In the figure 4 can seen the position of pipelines.

In general, although EPANET is used for modeling the system of piping network and water quality, but the properties of the emitters on the EPANET designed for modeling fire hydrants/sprinklers can be used to model the leakage.

Once the system piping network has been completed, then the leakage simulation using EPANET 2.0 software. Simulation carried out by changing the emitter coefficient at junction that will serve as the point of leakage. According to (Mashford et all. 2009) that Emitters are equipment related to the junction which is a model of the flow through the nozzle or orifice that is released into the atmosphere. Function emitters in EPANET are as follows:

$$EC = Q / P^{P\ exp} \quad (3)$$

Where EC is the emitter coefficient, Q is the water discharge, P is the fluid pressure, P exp is pressure exponent. So, coefficient emitter is discharge per unit of pressure with units of liters per second per meter of pressure (Ls^{-1}/m^{-1}). For head nozzle and sprinkler heads P exp is equal with 0.5 for circular apertures.

The emitter's coefficient that is used for simulation of leakage is 0.005 to 0.3 with an interval of 0.005. Large of average pressure on the pipeline is 3.739158 m. So for 0.005 yield leakage of 0.01 L/s. Large of leakage simulated achieving between 0.01 to 0.6 L/s.

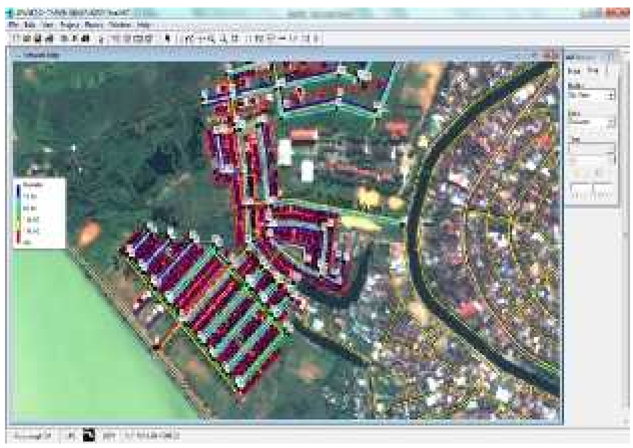

Fig 3. Pipeline System of Taman Khayangan Makassar Resident by using EPANET 2.0 software

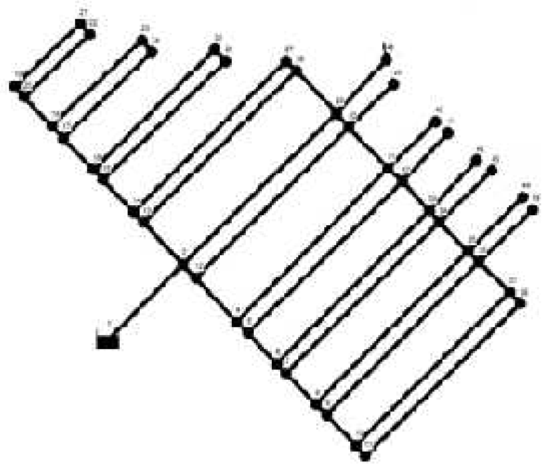

Fig 4. The position of pipe and junction in water distribution network in Taman Khayangan Makassar Resident.

The simulation of leak done as many as 44 sets of case at junction and 623 set of leakage case in the pipeline with each leak point within 4 meters and emitter coefficient of 0.005 - 0.3. So, overall there are 40020 of leak data for various large and position of leaks. Data layout is used as much as 70 % of data training and 30 % as test data in two models, namely ASTAR and RBF-NN. In order to find out the comparison of performance accuracy level of method prediction of Radial Basis Function Neural Network can be seen from the value of Root Mean Square Error (RMSE). The calculation using the following formula:

$$RMSE = \frac{\sqrt{\frac{1}{N}\sum_{i=1}^{n}(P-a)^2}}{Pmax - Pmin} \quad (4)$$

Where :

- N : Number of input data
- P : Actual value
- a : Value of prediction result
- P*max* : Maximum value of actual data
- P*min* : Minimum value of actual data

The accuracy of prediction of the location of the leak can also be expressed by the formula percentage of accuracy as follows:

$$A = \frac{N_p}{N_t} \; x \; 100\,\% \quad (5)$$

Where Np is the amount of success prediction and Nt is the total number of observation.

RESULTS AND DISCUSSION

After doing the training data on the RBF-NN and ASTAR models, it was obtained test results for the entire pipeline on each model. The result of prediction of leakage great and location of each model are shown respectively in Figure 5 to 8.

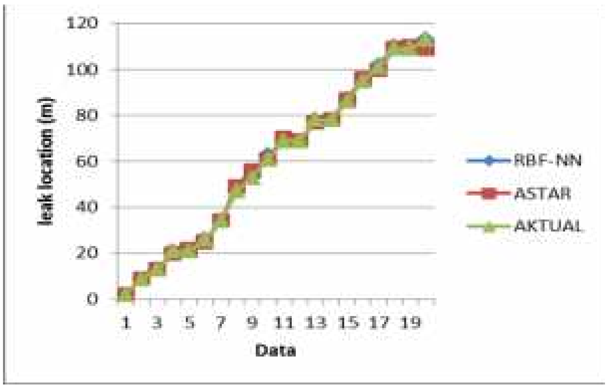

Fig 5. Prediction of leak location at pipe 1328

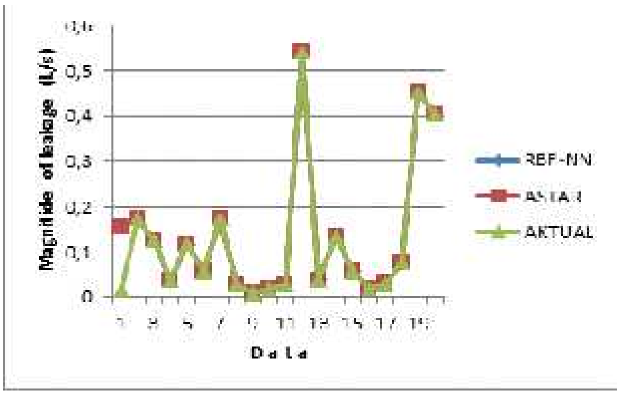

Fig 6 Prediction of leak magnitude in pipe 1328

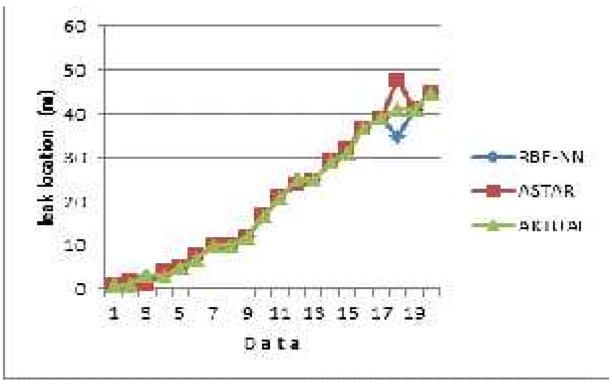

Fig 7 Prediction of Leakage location at 1921 pipe

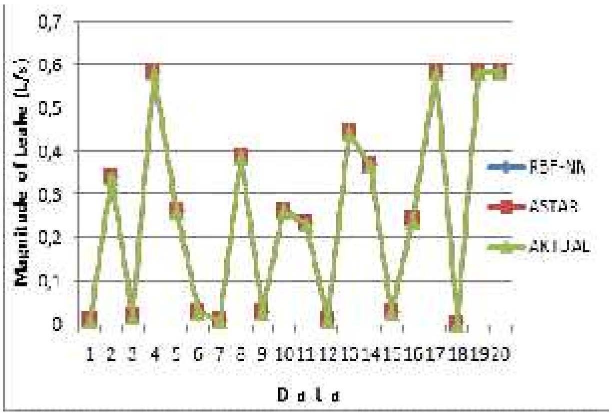

Fig 8. Prediction of Leakage great in pipe 1921

Figure 5 to 8 respectively show the trend of both methods follow the actual data that nearly coincides with the line. It indicates both methods can be used to predict the location of leaks and magnitude of leaks in pipes.

Table 1. The result of RBF-NN and ASTAR predictions based on RSME value

Method of Prediction	RSME value			
	Pipe 1328		Pipe 1921	
	Leak position	Leak Magnitude	Leak position	Leak Magnitude
RBF-NN	0,0000337	0,0000318	0,000039	0,0000318
ASTAR	0,0044135	0,0917459	0,021640	0,0011661

Table 1 shows that the comparison of the two methods used was indicates with ASTAR method produces RSME values smaller than ASTAR method for predicting the location of pipe leak and magnitude of water leaks.

Table 2. The result of location of leakage using RBF-NN and ASTAR methods

Method of Prediction	Akurasi value (%)	
	Leak Position Pipe 1328	Leak Position Pipe 1921
RBF-NN	98	95,94
ASTAR	87	87,83

The result are shown in table 2, which confirm that the RBF-NN achieves high accuracy than ASTAR. By using interface GUI, user will be easier to use ASTAR or RBF-NN methods in order to detect the leaks. By using the button on the GUI , the user will easily to enter pressure data that will be detected and to find out the result immediately in the form of a large leak in L/s and the location of the leak is depicted on the map location.

The results of making interface of pipe leak detection system by using MATLAB R2010a GUIDE, can see in figure 9.

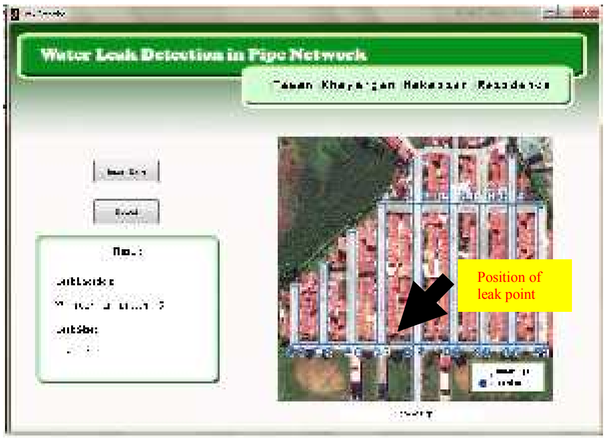

Fig 9.Layout of GUI Leak Detection System by using GUIDE MATLAB

There are two buttons, the "Input Data " is used to enter pressure data in each junction to be detected and the "Detection " to see the prediction results of the leakage magnitude and location. Field "Description" will show the prediction results and then on the location map will appear the marker in the form of a flashing red dot at the point of leakage.

CONCLUSION

This research compare two methods namely ASTAR and RBF-NN in processing the pressure value obtained at a number of junctions in water distribution networks . Training data obtained from the EPANET hydraulic system modeling program. Overall both of these methods can be used to predict the location and magnitude of leakage. From ASTAR was obtained with accuracy 87% and 96% for the RBF-NN for the average predict location of the leakage from the whole pipeline. Based on the RMSE values was obtained 0.005 for ASTAR and 0.000049 for RBF-NN for the average predict location and magnitude of leakage from the whole pipeline. It indicates RBF-NN predict more accurately than ASTAR.

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