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Train Arrival Warning System at Railroad Crossing using Accelerometer Sensor and Neural Network

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Abstract. Currently, there are many railroad crossings with no official guards. This will increase the number of traffic accidents. The trains can produce vibrations that travel through the air or rails, so the waves can be used to predict its presence or position. The detection of the sound can be disturbed by many noises. Therefore, this paper has analyzed railroad vibration using microelectromechanical systems-type accelerometer sensor to recognize the existence and to measure the position of the train as a warning system. Fast Fourier Transform algorithm is used to obtain the frequency spectrum feature. A neural network is used to recognize the vibration patterns of both the train and the non-train. The result of this experiment shows that the Neural Network can recognize the vibrations generated by the train to the non-train with a 100% success rate at a distance of 45 meters. The system is expected to be used as a warning system for the arrival of trains by giving alarm to people around the railway junction.

INTRODUCTION

The increasing number of railroad crossings is inevitable due to the development of neighbors around the railroad area, caused by the expansion of house building, market area and the development of local economic activities that manage to build an instance or called illegal railroad crossing. If there is a guard officer at the railroad crossing then there is no need to worry for the people who want to cross the railroad. As a public transportation operator, PT KAI (Kereta Api Indonesia) mentioned that in 2016 the number of accidents that occurred at the intersection of the railroad in North Sumatera region I is 52 cases [1]. Despite this fact, the cost to build a complete railway junction is another constraint for PT KAI and local government.

Trains can produce vibrations in the air or rail, so the wave can be used to predict its presence or position. This sound wave can usually be heard by human ears for several hundred meters. However, this sound detection can be disturbed by a lot of noise around the location. Therefore, in this paper the authors have conducted the analysis of railway vibration by using accelerometer sensor to determine the position of the train so that a train arrival warning system will be obtained.

The accelerometer sensors are commonly used in mechanical vibration studies. The vibration produced by train can be detected using piezoelectric accelerometer [2, 3]. While MEMS (microelectromechanical systems) accelerometer sensors have also been applied to observe the mechanical vibrations [4, 5, 6].

In this study, we used MEMS accelerometer to predict the position of the arriving train and determine its vibration pattern compared to the other vehicles passing on the railroad crossing. To obtain the frequency feature, the signal at the time domain is converted by using a Fast Fourier Transform (FFT) algorithm [7]. The frequency spectrum is used as input to a pattern recognition system. An artificial Neural Network is a type of pattern recognition algorithm that is often used in multiple inputs or sensor array [8, 9]. When this system successfully identifies the train's vibration pattern, it will immediately provide a sound alarm and a light warning to the people around it.

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The Fourier analysis is a mathematical technique based on the decomposition of time domain signals into their constituent sinusoidal signals. The transformation equation is in the frequency domain, expressed by:

$$X(f) = \int_{-\infty}^{\infty} x(t).e^{-j\omega t} dt \tag{1}$$

This continuous transformation is rather difficult to apply in real-life measurements; therefore, a digital approach known as Discrete Fourier Transform (DFT) will be used, expressed as:

$$X(k) \sum_{n=0}^{N-1} x[n].e^{-\frac{j2\pi nk}{N}}, 0 \leq k \leq N-1 \tag{2}$$

The FFT is an algorithm used to calculate DFT with a more efficient calculation process.

The artificial Neural Network, which belongs to an intelligent system, is an algorithm that mimics biological cells based on the principle of the human brain. This method requires a learning phase to update the weights between neurons before the testing phase. The backpropagation using gradient descent algorithm is an optimization method commonly used in the learning phase because it is simple with high accuracy. This learning phase consists of two stages: feedforward and backpropagation. The learning process is repeated until the desired error level is reached. The error function in learning phase can be written as:

$$E_p = \frac{1}{2} \sum_k (t_k - y_k)^2 \tag{3}$$

$$E_{RMS} = \sqrt{\frac{\sum_p E_p}{p}} \tag{4}$$

The feedforward stage will calculate the activation function for each neuron, expressed as:

$$z\_in_j = v_{oj} + \sum_j x_i v_{ij} \tag{5}$$

$$z_j = f\left(z\_in_j\right) \tag{6}$$

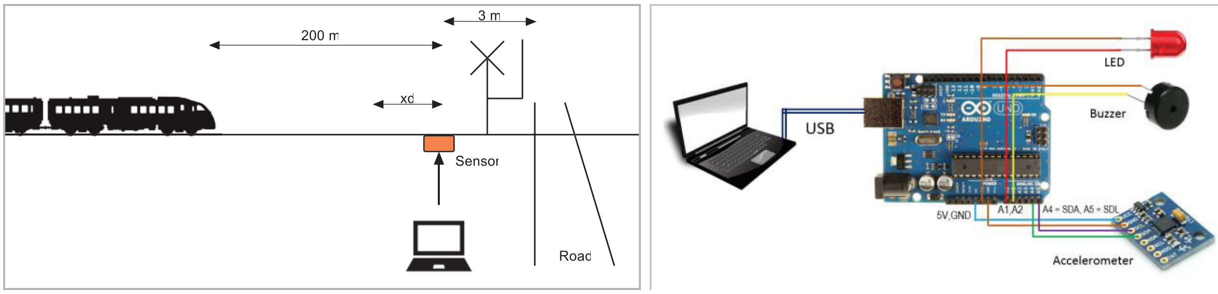
While the backward propagation will calculate the change of weights and update them with the rates of learning and momentum expressed as:

$$\Delta v_{ij}(t) = \eta.\delta_j.\frac{df\left(z_j(t)\right)}{dz_j(t)}.x_i(t) + \mu.\Delta v_{ij}(t-1) \tag{7}$$

$$\Delta v_{ij}(t) = \Delta v_{ij}(t-1) + \Delta v_{ij}(t) \tag{8}$$

MATERIAL AND METHOD

The experiment was located at the crossroads of the railway in Cerme, Gresik regency, East Java, Indonesia. Figure 1 shows the set-up of equipment at the railroad crossing. When the train speed is 60 km/h, then for a distance of 200 meters will take about 16 seconds. This system consists of MPU6050 accelerometer module and Arduino Uno microcontroller to collect vibration data via I2C communication. The baud rate of data transfer from Arduino Uno to the personal computer was set at 115.200 bps via USB. This speed is the maximum rate of the accelerometer module [10], to accommodate 1000 data per second. For the warning signs, the output pins of Arduino Uno will control the buzzer and the LED. The sensor was attached under the tracks with the x-axis accelerometer in the direction of the earth's gravitational acceleration, as shown in Figure 2.



(a) (b)

Figure 1. The design of the train arrival warning system: (a) the location, and (b) the wiring diagram.

(a) (b)

Figure 2. Sensor installation: (a) position on the track, and (b) x-axis accelerometer.

The system developed in this study is to analyze and identify the frequency patterns of vibrations. This system should be able to distinguish between the vibrations generated by the train and other vehicles. If the detected frequency pattern is recognized as the vibration generated by the train then the warning alarm will be ON and vice versa for the motorcycle, car, or truck will be OFF, as shown in Figure 3. Since the sample rate is 1000 samples per second for a duration of 1 second, it will produce 1 Hz of the frequency resolution of the FFT. The resulting frequency spectrum is 501 points ranging from 0 to 500 Hz.

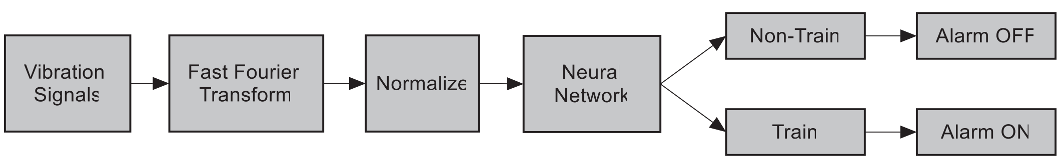


Figure 3. The identification of vibration pattern of the train.

RESULT AND DISCUSSION

Figure 4 shows the vibration signal at the time domain generated by the accelerometer module for several vehicle types. While Figure 5 shows the vibrations in the frequency domain resulted by the FFT. The Neural Network consists of 501 nodes in the input layer, 50 neurons in the hidden layer, and 2 neurons in the output layer. The activation function of each neuron is a binary sigmoid. While the momentum constant is 0.6, the learning rate is 0.6, and the target error is 0.0001. The learning and testing data of vibration patterns for train and non-train are shown in Table 1. The identification result of vibration pattern by Neural Network in the testing phase is shown in Table 2. It shows that the Neural Network can distinguish between the train and the non-train with the rate of 100%. Figure 6 shows the railway vibration in the time domain. The experimental result shows that Neural Network can recognize the vibrations generated by the train with an average distance of 45 meters, as shown in Table 3.

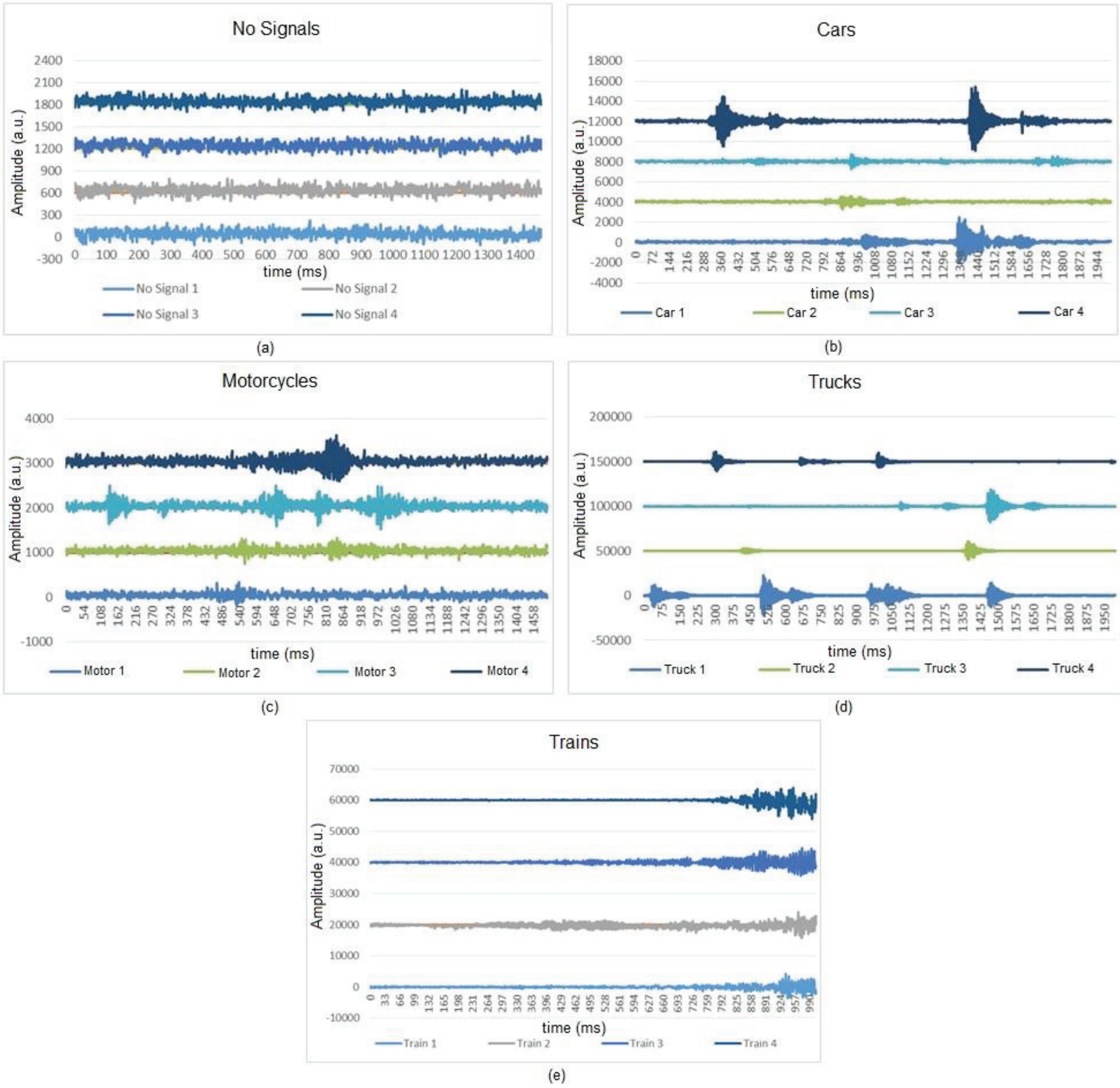


Figure 4. The vibrations in the time domain resulted by the accelerometer module: (a) no-signal, (b) cars, (c) motorcycles, (d) trucks, (e) trains.

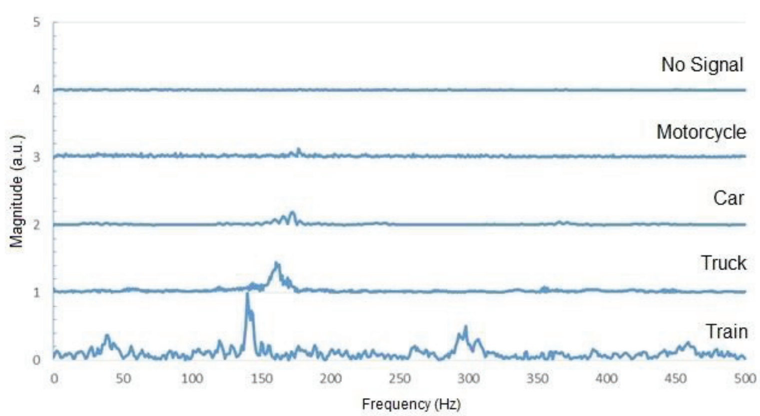


Figure 5. The vibrations in the frequency domain resulted by the FFT.

Table 1. The number of learning and testing data for the Neural Network.

Condition	Data Learning	Data Testing
Non-train	16	4
Train	4	4
Total Data	**20**	**8**

Table 2. The identification resulted by the Neural Network.

Condition	Testing	MSE		
		0.01	**0.001**	**0.0001**
Non-train	1	Non-train	Non-train	Non-train
	2	Non-train	Non-train	Non-train
	3	Non-train	Non-train	Non-train
	4	Non-train	Non-train	Non-train
Train	1	Train	Train	Train
	2	Train	Train	Train
	3	Train	Train	Train
	4	Train	Train	Train
Percentage		**100%**	**100%**	**100%**

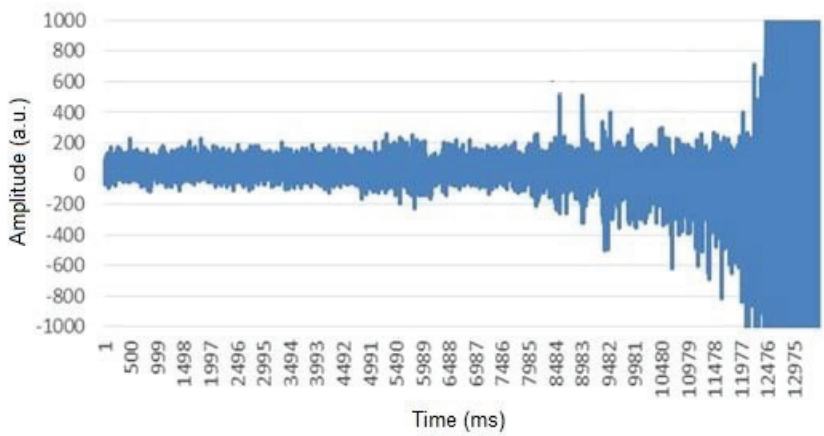


Figure 6. The vibration of the railway in the time domain.

Table 3. The distance of the train recognized by the Neural Network.

Train Number	Speed (m/s)	Time Arrival (s)	Time Appear (s)	Distance Detection (m)
1	14.8	13.5	8.5	74
2	13.3	15	13	19.95
3	16.7	12	8.7	55
4	16	12.5	10.5	32
5	14.8	13.5	9.2	63.64
Average				45

CONCLUSION

In this study has been designed and constructed a warning system of train arrival. The microelectromechanical systems-type accelerometer sensor is used to recognize the existence and to measure the position of the train. The Fast Fourier Transform algorithm is used to obtain the 501 points ranging from 0 to 500 Hz of frequency spectrum of the vibrations. A 3-layer Neural Network is used to recognize vibration patterns of both train and no-train. The result of this experiment shows that the Neural Network can recognize the vibrations generated by the train to the non-train with a 100% success rate at a distance of 45 meters.

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