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A Study on the Estimation Models of Road Electric Energy Harvester According to the Traffic Characteristics Using Piezoelectric Effect

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ABSTRACT
In this paper, we introduce the estimation models of road electric energy generation by installing a piezoelectric energy harvester using piezoelectric effect. In addition, we propose an analysis system for piezoelectric energy harvester including the estimation models of road electric power generation according to the traffic characteristics. A piezoelectric energy harvester with 10cm thickness was laid underground down to a depth of about 5cm. In this paper, we focus on developing the estimation models of power generation efficiency variation according to the traffic characteristics using the average power generation of a bulk type's piezoelectric sensor. The traffic patterns are different based on the different places and times on roads. Thus, we developed the estimation models of a piezoelectric energy harvester by analyzing the representative traffic indexes such as flow, speed, and vehicle types. Moreover, the developed estimation models are equipped on our analysis system by which we present specific methods for simple operations.

Keywords: *Piezoelectric power generator, traffic characteristics, power generation, estimation model*

1. INTRODUCTION

Typically, energy industries are considered as a primary political issues in the world. After the industrial era, in recent, many countries have focused on collecting a power from sustainable and renewable energy such as solar, wind, geothermal, and tidal stream. Huge amount of energy can be produced from the natural energy sources mentioned earlier. Many efforts to find unused energy in daily life and natural energy sources have been conducted in various research fields.

The efficiency of power generation using a piezo sensor is very low. Thus, it has not been applied to commercial products. However, it can be employed on tiny electric products that consume electricity in a micro level such as low power motors and actuators. In this paper, we paid attention to the huge amount of pressure energy created by driving vehicles on roads. Many developed countries such as USA, Israel, Japan, and Korea have studied the energy harvesting from the pressure energy generated by road vehicles.

The National Energy Technology Laboratory in USA is operating an analysis system for potential renewable energy, and the Korea Institute of Energy Research in Korea is publishing a renewable energy distribution map. However, the detailed analysis of power generation by traffic flow using a piezo sensor has not been performed.

In Korea, the total length of national and highway roads is about 110,000 km in which only 20% of the roads shows high traffic volume. Some highway corridors show more than 100,000 vehicles. The registered vehicles in Korea are more than 20 million and the number is increasing 3% every year during recent 5 years. The daily traffic flow would be from several thousand to hundred thousand. Thus, huge amount of power will be harvested if we apply a piezoelectric energy harvester on roads.

However, it is difficult to calculate the potential energy according to the traffic patterns because the available power that can be generated from roads was not given. Thus, the estimation models of road electric power generation according to the traffic characteristics and analysis systems should be developed. In this paper, we introduce the analysis models that estimate potential amount of energy from road traffic.

The remainder of this paper is organized as follows. In the next section, we review the literature related to energy harvesting technologies using piezo sensors. In Section 3, we describe our estimation models of road electric power generation based on the traffic characteristics and in Section 4 Our newly designed system procedures are given. Finally, our conclusions and ideas for future work regarding this research are provided in Section 5.

2. RELATED WORK

A piezoelectric energy harvesting is environmentally-friendly energy that transfers mechanical energy (e.g. pressure, impact, and vibration) to electric energy. In particular, it has denser energy distribution than other power generators, and power generation can be performed continuously regardless of weather conditions.

The piezoelectric energy harvesting for road traffic is performed by the piezo sensors installed under the road pavement [1-4].

The Innowattech in Israel has developed the monitoring technology for piezoelectric energy harvesting.

Moreover, they proposed self-generation for the Smart Way system that collects a power from roads,

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railways, and airport runways using IPEG sensors, which is used for traffic lights, railway gates, and road lamps [5].

The POWER leap and Tree volt in USA developed a piezoelectric energy harvester and implemented a monitoring system that shows power generation information in an actual proof corridor [6].

At present piezoelectric sensor does not provide macro-scale power generation, and shows brittleness with external pressure. Moreover, it has a weakness for waterproofing, antifouling, and anti-corrosion. Thus, currently, only a visualization system that presents power generation status has been developed. The visualization technology of piezoelectric energy harvesting has been applied only for monitoring an actual power generation.

In this study, we focus on developing the estimation models of piezoelectric energy harvesting based on the traffic characteristics. In addition, the developed models are applied to the piezoelectric power analysis systems in which users can easily see the entire power generation status on a geographical map.

3. THE ESTIMATION MODELS OF ROAD ELECTRIC POWER GENERATION BASED ON THE TRAFFIC CHARACTERISTICS

3.1 Traffic Parameters for Power Generation

The traffic parameters influencing on the power generation performance are flow, speed, vehicle load, and traffic congestion as follows.

- Flow: it causes the sensor displacement.
- Speed: it causes the variation of the displacement.
- Vehicle load: it causes the variation of the displacement.
- Traffic congestion: it causes the variation of the energy harvesting.

We performed data transformation from time domain to frequency domain using the 4 parameters as shown in Figure 1.

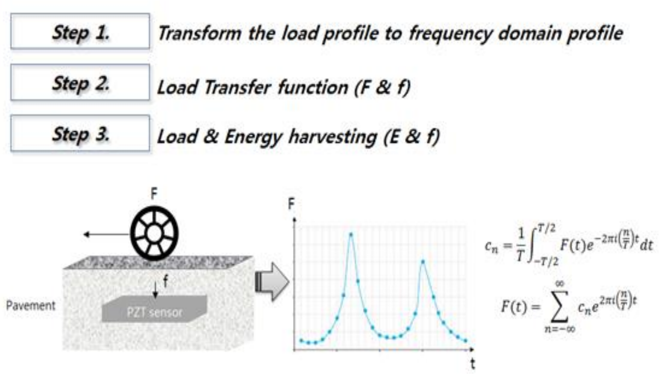

Figure 1: Transformation to frequency domain

a. Flow

We can expect that the amount of power generation is directly proportional to the traffic volume, but the actual values show non-proportional pattern because the power generation is proportional to a vehicle load and frequency. As shown in Figure 2, the traffic flow in free-flow regime can increase to maximum capacity without speed reduction. However, the speed and flow are reduced in congestion regime. We can estimate the load frequency for piezo sensors based on the traffic status and time headway.

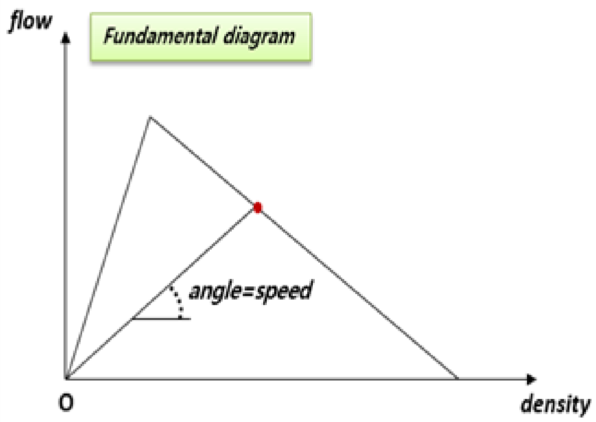

Figure 2: Flow-density curve

As shown in Figure 3, it is difficult to distinguish the actual speed data using density and occupacy during the traffic congestion period. Thus, both the traffic flow and speed should be considered for acurate power generation estimation.

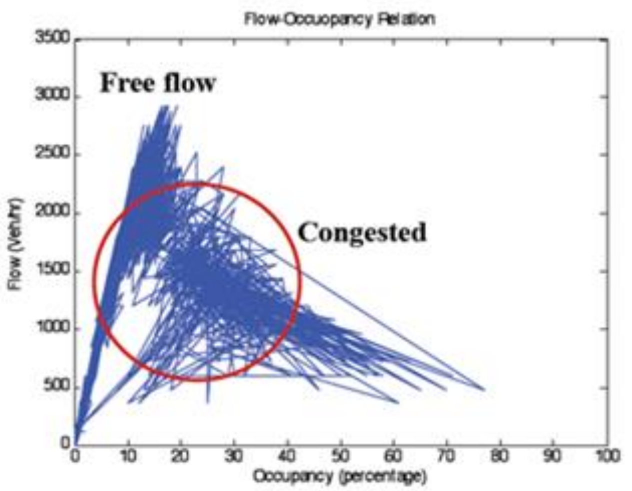

Figure 3: Flow-occupancy curve

The time headway and space headway can be calculated using density and flow data as follows.

$$\widetilde{T_h} = \frac{1}{flow}, \quad \widetilde{T_s} = \frac{1}{density} \qquad (1)$$

where $\widetilde{T_h}$ is time headway and $\widetilde{T_s}$ is space headway.

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The frequency of vehicle load is inversely proportional to the average time headway as shown in Figure 4.

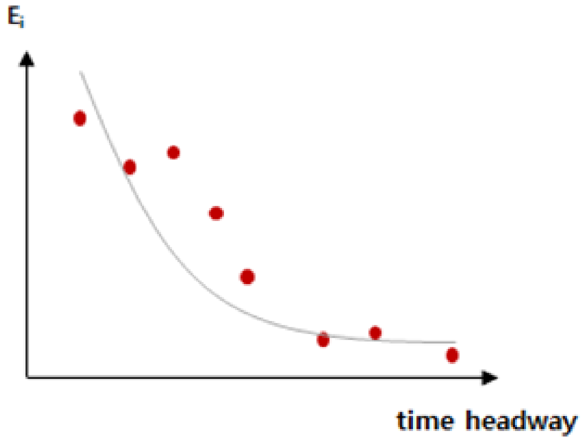

Figure 4: Estimated energy by time headway

b. Speed

We can expect that the amount of power generation is directly proportional to the traffic speed. The time variation of piezoelectric sensors will increase if that of vehicle speed increases.

The amount of power generation will be different with the traffic conditions such as free flow and congested flow even though the total traffic flow is the same. As shown in Figure 5, the estimated energy can be presented by different speed.

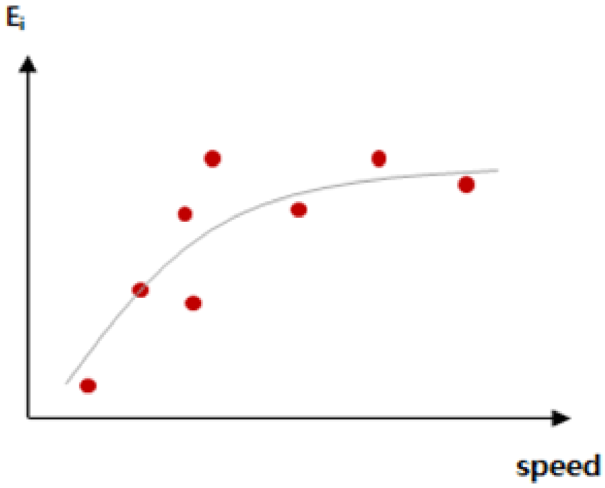

Figure 5: Estimated energy by speed

c. Vehicle load

As the same with the vehicle speed, the amount of piezoelectric energy harvesting is directly proportional to vehicle load, but each vehicle has different weight on roads. To consider the factors, we applied the research results of road pavement lifetime conducted by USA.

In addition, equivalent axle load factor (EALF) and pavement information are provided in USA, which present the impact of road pavement by the proportional values to 1-axis vehicle types. Thus, the amount of piezoelectric energy harvesting can be calculated by multiplying the EALF values.

Table1: Truck classes of FHWA and EALFs

Class	Type	EALF
1	• Motorcycles	Negligible
2	• Passenger Cars	Negligible
3	• Other Two-Axle, Four-Tire Single Unit Vehicles	Negligible
4	• Buses	0.57
5	• Two-Axle, Six-Tire, Single Unit Trucks	0.26
6	• Three-Axle Single Unit Trucks	0.42
7	• Four or More Axle Single Unit Trucks	0.42
8	• Four or Less Axle Single Trailer Trucks	0.30
9	• Five-Axle Single Trailer Trucks	1.20
10	• Six or More Axle Single Trailer Trucks	0.93
11	• Five or Less Axle Multi-Trailer Trucks	0.82
12	• Six-Axle Multi-Trailer Trucks	1.06
13	• Seven or More Axle Multi-Trailer Trucks	1.39

Table2: Simplified system of TDOT and EALFs

Class	Type	EALF		FHWA Class
		Flexible	Rigid	
1	Cars & Motorcycles	0.001	0.001	1,2
2	Pickups, Panel Vans	0.004	0.005	3
3	Buses	0.300	0.300	4
4	2-axle, 6-tire Singles	0.170	0.170	5
5	3-axle or more Singles	0.700	1.000	6,7
6	4-axle Combos	0.700	0.780	8
7	5-axle or more Combos	1.100	1.780	9-11

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Table3: Simplified system of WSDOT and EALFs

Class	Type	EALF	FHWA class
1	Single Units	0.40	4-7
2	Double Units	1.00	8-10
3	Trains	1.75	11-13

In order to analyze the data of traffic and vehicle types, we studied the vehicle classification of Korea Expressway Corporation, and we re-classified the vehicles as shown in Table 4.

Table 4: Re-classified vehicles

<table>
<tr><th colspan="2">STATISTICAL YEAR BOOK OF MOLIT (12 Class)</th><th colspan="2">Korea Highway Capacity Manual (6 Class)</th><th colspan="2">Korea Pavement Design Guide (10 Class)</th><th colspan="2">Tunnel ventilation design (8 Class)</th></tr>
<tr><td rowspan="3">1</td><td rowspan="3">Cars & minibus</td><td rowspan="2">1</td><td rowspan="2">Cars</td><td rowspan="2">1</td><td rowspan="2">Cars</td><td>1</td><td>Cars (gasoline)</td></tr>
<tr><td>2</td><td>Cars (Diesel)</td></tr>
<tr><td>2</td><td>minibus</td><td>2</td><td>minibus</td><td>3종</td><td>minibus</td></tr>
<tr><td>2</td><td>buses</td><td>3</td><td>Medium bus</td><td>3</td><td>Medium bus</td><td>4</td><td>King size bus</td></tr>
<tr><td>3</td><td>Light Truck (A)</td><td>4</td><td>Light Truck</td><td>4</td><td>Light Truck</td><td>5</td><td>Light Truck</td></tr>
<tr><td>4</td><td>Light Truck (B)</td><td rowspan="4">5</td><td rowspan="4">Medium Truck</td><td>5</td><td>Medium Truck</td><td>6</td><td>Medium Truck</td></tr>
<tr><td>5</td><td>Medium Truck (A)</td><td rowspan="3">6</td><td rowspan="3">Heavy Truck</td><td rowspan="3">7</td><td rowspan="3">Heavy Truck</td></tr>
<tr><td>6</td><td>Medium Truck (B)</td></tr>
<tr><td>7</td><td>Medium Truck (C)</td></tr>
<tr><td>8</td><td>Heavy Truck(A)</td><td rowspan="5">6</td><td rowspan="5">Special Truck</td><td>7</td><td>Semi trailer (4A↓)</td><td rowspan="5">8</td><td rowspan="5">Special truck</td></tr>
<tr><td>9</td><td>Heavy Truck(B)</td><td>9</td><td>Full trailer (5A↓)</td></tr>
<tr><td>10</td><td>Heavy Truck(C)</td><td>8</td><td>Semi trailer (5A)</td></tr>
<tr><td>11</td><td>Heavy Truck(D)</td><td>9</td><td>Full trailer (5A↓)</td></tr>
<tr><td>12</td><td>Heavy Truck(E)</td><td>10</td><td>Semi trailer (6A↑)</td></tr>
</table>

3.2 The Estimation Model Design of Road Electric Power Generation Based on the Traffic Characteristics

The piezoelectric energy harvesting can be calculated using the traffic characteristics multiplying the conversion data by EALF as follows.

$$Total\ energy = \Sigma(EALF_i \times E_i) \qquad (2)$$

$EALF_i$: Equivalent axle load factor
E_i: Piezoelectric energy (re-classified vehicle)

In this study, we calculated the frequency of the load forced to the piezoelectric element on the basis of traffic data.

A single load frequency applied to the piezoelectric element according to the average speed is as follows.

$$freq_q = \frac{1}{T_h} = \frac{1}{\frac{3600}{q_{1hr}}} = \frac{q_{5min}\ \mathrm{X}\ 12}{3600} = \frac{q_{5min}}{300}$$

$$freq_q = \frac{1}{\Delta T} = \frac{1}{\frac{s}{v}} = \frac{v}{s} \qquad (3)$$

s : The length of a piezo sensor
v : Vehicle speed
ΔT : Vehicle passing time

The piezoelectric energy can be calculated separately the vehicle driving speed and the traffic characteristics as follows.

$$\mathrm{Energy} = \mathrm{C\ X}\ [(\frac{freq_c}{freq_q}) + (\frac{freq_c}{freq_q})] \qquad (4)$$

C: Piezoelectric energy
$freq_c$: Load frequency

3.3 Experimental Procedure

The piezoelectric energy harvesting with 10cm thickness was laid underground down to a depth of about 5cm. In this paper, we focus on developing the estimation models of power generation efficiency variation according to the traffic characteristics using the average energy harvesters of a bulk type's piezoelectric sensor.

The piezoelectric energy generation is calculated using the traffic characteristics and traffic flow (Jan. 2014, Gyeonggi-do, Yong-In) as show in Figure 6 and 7.

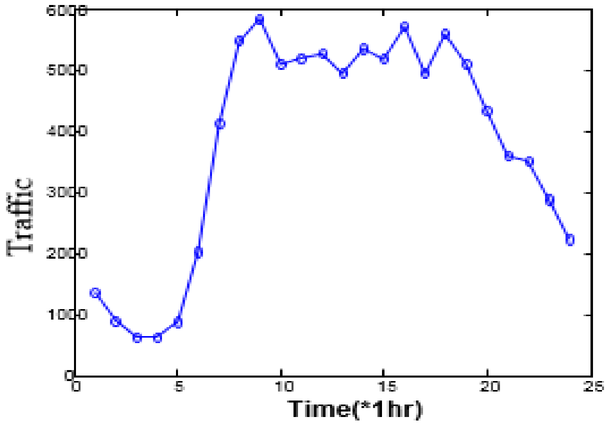

Figure 6: Flow data by different time

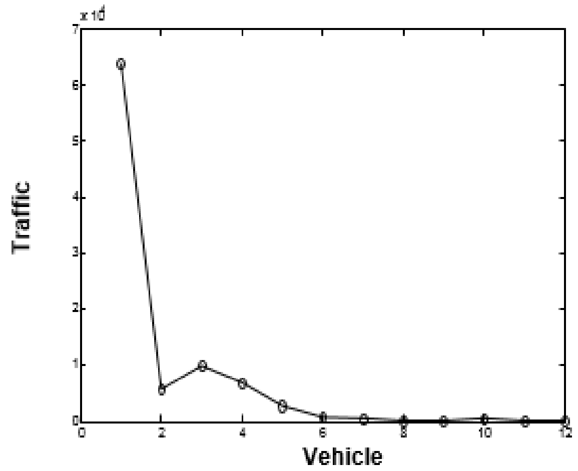

Figure 7: Flow data by different vehicle types

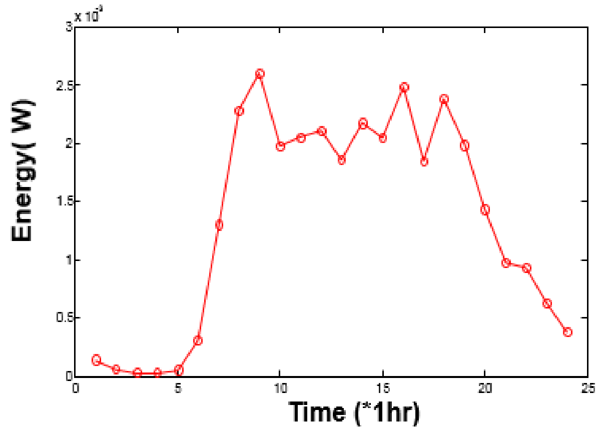

Figure 8: Estimated energy

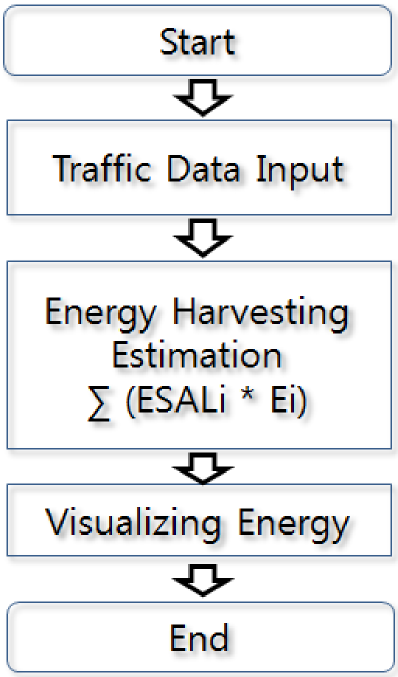

Figure 9: The procedure of energy estimation

We showed the measured results of estimated energy in Figure 8. As shown in this figure,the energy also increased with increasing traffic characteristics and flow.

4. SYSTEM PROCEDURES

In this study, we designed the visualization tools using our estimation algorithm. Our visualization tools can be classified into 2 regions; GIS(Geographic Information System) map control layer and power generation visualization layer. As depicted in Figure 9, the information of traffic and piezoelectric energy harvesters are provided as an input data, and then the visualization system of piezoelectric energy harvesters estimates the amount of power generation using the two input data. The estimated power for each corridor is displayed on the GIS map layer.

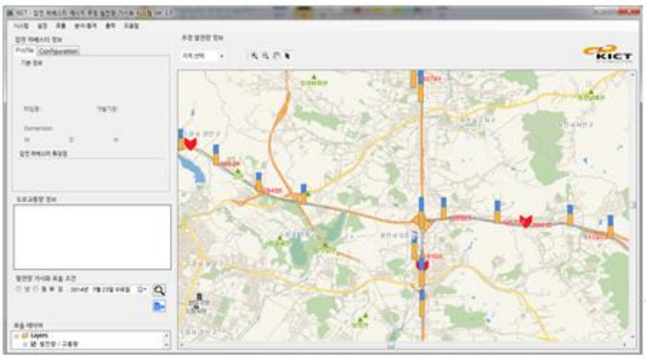

Figure 10: Visualizing software for the piezoelectric energy harvesting

Figure 10 depicts avisualizing piezoelectric energy harvesting software. we can easily see the estimated power generation of the the piezoelectric energy.

5. CONCLUSIONS

In this paper, we estimated the power generation of piezoelectric energy harvesters according to the traffic characteristics using our estimation models. We expect that our models can be applied to the decision procedures for determining construction priority of piezoelectric energy harvesters. In addition, an accurate power estimation technology based on the traffic conditions can provide the rational budget use of road infrastructures.

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REFERENCES

[1] "Using Energy Harvesting System for Road Traffic Control Facility" Korea Agency for Infrastructure Technology Advancement final Report, 2012.

[2] Sodano, H. A., Inman, D. J., and Park, G. (2004). "A Review of Power Harvesting from Vibration using Piezoelectric Materials." The Shock and Vibration Digest., 36(3), 197 – 205.

[3] A. Erturk and D. J. Inman, Piezoelectric Energy Harvesting, Wiley, New York, 2012.

[4] Hossein Roshani, Samer Dessouky, "Feasibility Study to Harvest Electric Power from Highway Pavements using Laboratory Investigation", Department of Civil and Environmental Engineering University of Texas at San Antonio, 2015,

[5] Edery, L. A. "Innowattech: Harvesting Energy and Data; A Standalone Technology." Israel National Roads Company, Ltd. First International Symposium. The Highway to Innovation, Tel Aviv, Israel, 64-81, 2010.

[6] Jaehwan Kim, "Recent Advancement of Piezoelectric Energy Harvesting", Department of Mechanical Engineering, Inha University, Volume 16, No. 4, 2013.

[7] Edie,L.C. "Discussion of Traffic Stream Measurements and Definitions". Proc., 2nd International Symposium on the Theory of Traffic Flow (J. Almond, ed.), Organization for Economic Co-operation and Development, 1965, pp. 139–154

[8] Guler, I. , and Madanat, S. "Axle load power for pavement fatigue cracking: Empirical estimation and policy implications". Transp. Res. Rec. , 2225 , 21–24. 2011.

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