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Comparisons of energy sources for autonomous in-car wireless tags for asset tracking and parking applications

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Abstract

This study compares the energy available on the car dashboard for powering in-car wireless tags for asset tracking and parking applications. Three energy sources available on the dashboard of a vehicle were investigated, i.e. vibration energy, thermal energy and light energy. The area available for the energy harvester is the same as a credit card (85×54mm^2). Simulations were carried out to estimate the potential electrical power that can be generated from the three energy sources. It was found that a vibration harvester can generate tens of μW under all weather conditions. The other two types of energy harvesters can generate tens of mW on a sunny day. However, the output power of a thermogenerator drops to 0 while the power density of a solar cell drops by up to 40% on an overcast or rainy day.

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Keywords: autonomous system, energy harvesting, GNSS geo-positioning

1. Introduction

Long range asset tracking is currently based on GSM/GPRS network to transmit the position of the items being monitored between servers and end-users. These communication channels normally require expensive subscriptions with telecommunication operators. This limits the applications of existing long range asset tracking systems. In fact, many more 'tracking' applications could be realised if the long range communication cost could be decreased.

The EU FP7 project CEWITT [1] aims at developing a wireless tag with GNSS geo-positioning capabilities to

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ensure the integrity and cost effectiveness for parking applications such as Pay per Use parking and identification of free parking slots in urban areas. Battery, as the primary power supply for wireless devices, has a limited lifetime. Energy harvesting is an enabling technology for the wireless tag to be “fit-and-forget”.

In order to access the satellite signal, the tag has to be placed on the dashboard of the car. In this study, energy available on the car dashboard will be investigated to find out the most suitable energy source for powering in-car wireless tags for GNSS geo-positioning based asset tracking and parking applications where targeted average power consumption is around 200 mW and the normal usage of the system is twice a day for approximately 5 minutes each time.

2. Comparisons of energy sources

Three kinds of energy are widely on the car dashboard, i.e. vibration, thermal and solar energy. In order to identify the most suitable energy harvesting strategy for the tag, the ambient energy levels in the target applications were measured and the results were used to quantify the electrical energy available from different harvesting technologies, i.e. vibration energy harvesters, thermogenerators and solar cells.

2.1. Vibration energy

Vibration data were collected on the dashboard in a 2006 Renault Clio 1.5L diesel car. Three sets of data were acquired simultaneously in each test, i.e. three axis vibration accelerations, car engine performance (engine load and Revolutions per minute) and GPS data. Acquired vibration data were recorded using quickDAQ version 1.5.0.6. In vibration measurement, the x-axis directs to the side of the vehicle, the y-axis directs to the front of the vehicle and the z-axis is vertical to the dashboard. The sample rate was 1024Hz. Car engine performance and GPS data were recorded using a tablet to track engine status and speed of the vehicle.

Tests were done on urban, country roads and a motorway to investigate vibrations on a vehicle on different road conditions. Vibrations, engine performance and output power generated on different vibration energy harvesters on these three types of roads are shown in Fig. 1. Simulations were carried out to estimate the output power of three types of Vibration Energy Harvesters (VEH), i.e. linear, Duffing’s nonlinear and bistable harvesters, under the measured vibrations. Details of the model used in the simulation can be found in [2].

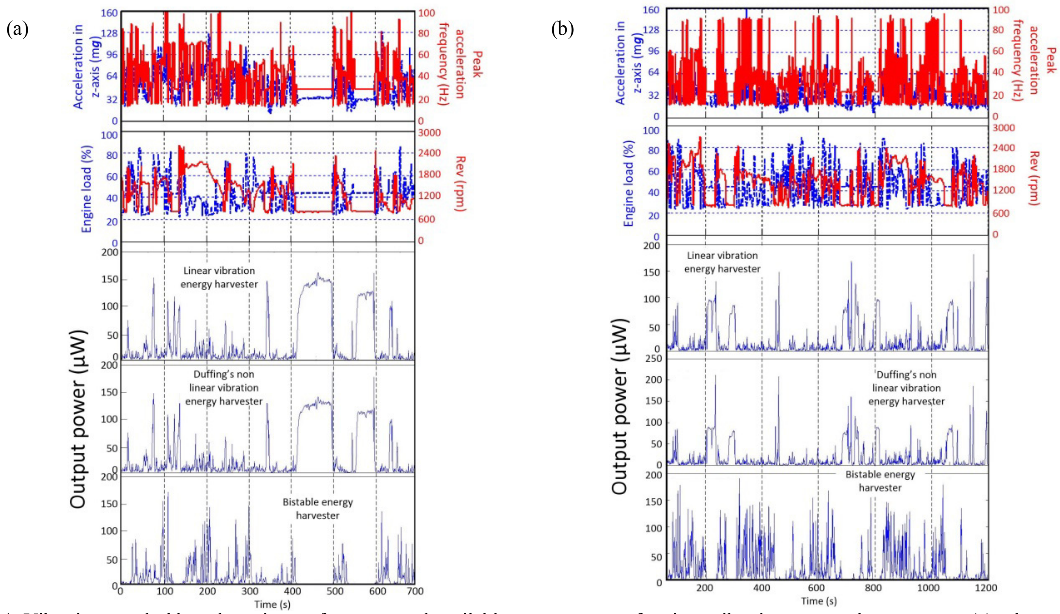

Fig. 1. Vibrations on dashboard, engine performance and available output power of various vibrations energy harvesters on (a) urban road; (b) country road; (c) motorway (to be continued).

(c)

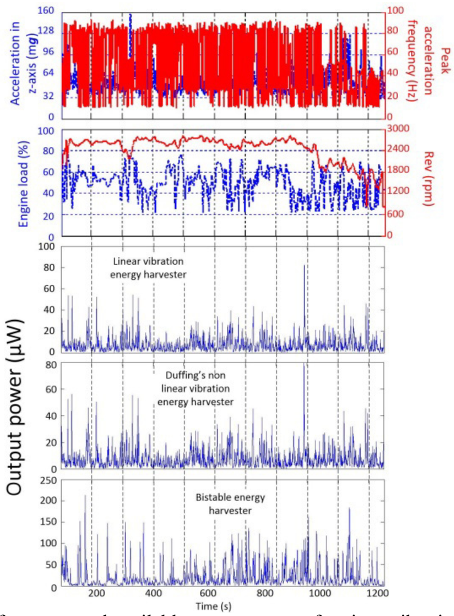

Fig. 1. Vibrations on dashboard, engine performance and available output power of various vibrations energy harvesters on (a) urban road; (b) country road; (c) motorway (continued).

Table 1 summarises the average output power of linear, nonlinear and bistable vibration energy harvesters mounted on the dashboard on different roads when the vehicle travels on various roads. The inertial masses in all three types of energy harvesters were assumed as 5 grams. This is a fair assumption considering that the tag is a planar credit card sized structure such as the vibration energy harvesters presented in [3].

Table 1. Summary of average output power of various VEH on the dashboard.

	Average output power (μW)		
	Urban areas	Country roads	Motorway
Linear VEH	24.4	18.1	7.9
Nonlinear VEH	22.7	17.6	7.9
Bistable VEH	13	22.5	20.2

The output power of the linear and nonlinear VEH depends on the vibration frequency and its amplitude. When the vehicle stops and the engine is idle, the engine has fixed revolutions per minute (rev) of around 750 rpm. There is a dominant peak with a fixed frequency of 30 Hz and an amplitude of around 30 m***g*** (0.29 $m \cdot s^{-2}$). In the simulation, the resonant frequency of the linear energy harvester was set to 30 Hz to match this peak and it had a Q-factor of 50. It was also defined that the maximum power of the nonlinear harvester was generated at 30 Hz. Therefore, most power generated by the linear and nonlinear VEH is produced when the engine is idle. As a result, more output power can be generated from these two VEH when the vehicle travels in the urban areas where traffic lights and the traffic cause vehicle to stop frequently.

For the bistable VEH, its output power is independent of the vibration frequency and only related to the vibration amplitude. Therefore, it generates more power when the vehicle travels at higher speed, i.e. on country roads and motorways. In such circumstances, vibration frequencies change rapidly and amplitudes are higher. In the simulation, it was defined that the bistable operation could happen when the vibration amplitude was over 30 m***g***.

2.2. Thermal energy

Table 2 lists temperatures measured on the dashboard on a sunny day and an overcast day in the summer and their difference to the air temperature in the vehicle. Available thermal power from a 4.248 mm × 3.364 mm × 1.09

mm Micropelt thermogenerator [4] was estimated based on the temperature difference. On a sunny day an output power of 0.25mW is available from one of Micropelt thermoelectric device and a total of approximately 320 such generators can be mounted within the area of a credit card. Therefore, a maximum total electrical power of 80mW can be harvested. However, a very small temperature difference was measured on an overcast day and thus, no power can be harvested. It is worth mentioning that the size of the heat sink is not considered in the simulation. Otherwise, fewer thormogenerators can be assembled.

Table 2. Available thermal power in a vehicle.

	T_{Air} (°C)	T_{Object} (°C)	ΔT (K)	Power from one thermal generator(mW)	Total Power (mW)
Sunny day	33.6	40.8	7.2	0.25	80
overcast day	21.4	21.3	0.1	~0	~0

2.3. Solar energy

Table 3 lists the light level, power density and total power available within a credit card sized area on the dashboard in the vehicle under various weather conditions. It is found that a large amount of power can be generated during daytime under any weather conditions but, as expected, negligible power is available in the night.

Table 3. Available solar power on the dashboard in the vehicle.

	Sunny day		Overcast day	Rainy day	Street lighting
	Direct sunlight	Shadow			
Light level (Lux)	41k	23k	13k	7k	6
Power density (mW/cm^2)	2.8[1]	2.5[1]	2.1[1]	1.7[1]	0
Power within a credit card sized area (46.75 cm^2) (mW)	130.9	116.9	98.2	79.5	0

[1] Projected from datasheet [5] and measured values

3. Conclusions

It is found that in a sunny day, the output powers from the thermogenerators and solar cells are much higher than that from the vibration energy harvesters. However, for thermogenerators, multiple generators have to be used to provide a great amount of energy. This significantly increases the overall cost of the tag. Furthermore, their output power reduces significantly in an overcast or rainy day. For the solar energy harvester, the power that can be generated is extremely low in the night. Therefore, energy storage is necessary if the CEWITT tag needs to be powered in these circumstances. In conclusion, the best solution to powering a CEWITT tag is to use solar cells with the energy storage to extract and store energy from the ambient light. It is worth mentioning that although vibration energy harvesters generate only tens of µW of power and are unable to power the CEWITT system, the amount of power is still sufficient to power some wireless sensor systems for other applications.

Acknowledgements

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