Transportation Consortium of South-Central States (Tran-SET)

Development of a Self-Powered Weigh-in-Motion System

Highlight | Dec. 2020

Project No. 19ITSUTSA01

PI: A.T. Papagiannakis (UTSA)

This study involves the development of a novel weigh-in-motion (WIM) system that utilizes piezoelectric elements for sensing load and powering an ultra-low power microcontroller unit (MCU) that serves as its data acquisition system. A system of 4 piezoelectric (PZT) stacks serves as the energy harvester, while load sensing is done via a set of 4 PZT elements connected in parallel. Two alternative MCUs were considered, with various data handling capabilities and power consumption requirements. These MCUs have very short "wake-up" times allowing vehicle sensing without the need for inductive loops commonly used in conventional WIM systems. Special electric circuits were developed for maximizing the power output and for conditioning/sensing the voltage output. Electromechanical models were fitted to describe the relationship between voltage output, load and loading frequency/vehicle speed. Software were developed implementing the electromechanical model selected for estimating vehicle speed, axle load, number of axles and their spacing as well as vehicle classification. The software was first implemented in Matlab® and then converted to C prior to loading on the MCU memory. The system was tested in the laboratory by applying loads through a UTM servo-hydraulic loading system. Accuracies in measuring load, speed and class were successfully compared to the tolerances prescribed by the ASTM standard E1318.

Background

Traffic data collection is an essential input to roadway infrastructure design and management. It encompasses the collection of a multitude of data elements ranging from simple traffic volume counts to vehicle classification and axle weighing. Automated axle load weighing systems measure individual axle loads and classify vehicles without stopping them. These systems are called weigh-in-motion (WIM) systems. They are better suited for traffic data collection than the static weigh scales used for load enforcement, since the latter are by their function biased towards the heavier loaded vehicles. WIM data are widely used in pavement design, bridge design and traffic analysis, as well as in screening overloaded trucks for law enforcement purposes. Roadway agencies in the United States spend millions annually for purchasing/maintaining WIM systems and processing their output. Despite that, there is seldom a sufficient amount of traffic load data, mainly because there is a limited number of permanent WIM stations available.

Considering the shortage of permanent WIMs, it is necessary to assemble this traffic input by combining limited site-specific traffic information with representative regional or national traffic data obtained from other permamnelty installed WIM systems. This introduces a high uncertainty in the traffic load input, which could result in significant underestimation of the required structural thicknesses needed to accommodate the actual traffic loads. Clearly, more accurate site specific WIM data and larger number of WIM stations can improve traffic load estimation and reduce design uncertainties.

As a result, there is a need for a less expensive WIM system that is affordable enough to install in many more locations throughout a roadway network. Furthermore, it would be advantageous to operate such systems independently of the electrical power grid.

Project Objectives

The main objective of this study is to develop an inexpensive and self-powered WIM system equipped and driven by piezoelectricity. The piezoelectric materials are crystalline materials found in nature or synthetically produced. Piezoelectric materials exhibit electric polarization when they are mechanically strained (Figure 1). Their electric polarization is proportional to the applied strain. The particular objectives of the project are to:

Figure 1: Piezoelectric stack

- Characterize the electro-mechanical behavior of piezoelectric elements,
- Develop electronics to condition and maximize the power output under the loading conditions anticipated under in-service roadway traffic,
- Develop algorithms and software for conditioning the load sensing signal and processing it into the output produced by

conventional WIM systems, yielding axle loads, vehicle speed and vehicle classification for each passing vehicle and,

- Integrate these elements into a prototype system that can be installed on the roadway surface.

Project Outcomes

The main outcome of this study was the development of a cost effective self powered WIM system that makes such systems more accessible for transportation agencies. The developed WIM consist of a steel box enclosure that has a simple "shoe-box" design, with each corner of its upper plate supported by one of the PZT stacks/sensor combinations (Figure 2). The box was sized to capture loads on one wheel path. Electromechanical models were fitted to describe the relationship between voltage output, load and loading frequency/vehicle speed. The model for the four PZT sensing elements was used to translate voltage output to load for sensing purposes, while the model for the four PZT stacks connected in parallel was used for simulating the energy harvesting potential of the system. Software was developed implementing the electromechanical model fitted for sensing. It outputs vehicle speed, axle load, number of axles and their spacing as well as vehicle classification according to the FWHA 13 vehicle scheme. The data is output for each individual vehicle using the W-record format specified in the 2016 Traffic Monitoring Guide. The software was first implemented in Matlab® and then converted to C language prior to loading onto the memory of an ultra-low power microcontroller unit (MCU). Two MCUs were considered, with varying data handling capabilities and power consumption requirements. These MCUs have very short "wake-up" times allowing vehicle sensing without the need for inductive loops commonly used by commercially available WIM systems. Special electric circuits were developed for conditioning/sensing the voltage output and for maximizing the power output. Simulations of the latter indicate that under heavy truck traffic the harvester should generate sufficient power to maintain the operation of the MCU and recharging a backup battery. The system was tested in the laboratory by applying loading sequences simulating various vehicle classes moving at various speeds. The results suggest that vehicle speed and classification predictions were accurate, axle load predictions were precise and in general within the tolerance limits prescribed by the ASTM standard E1318. Additional work is needed to implement the faster MCU which will shorten the time need to process a vehicle and test the WIM system in and field. This study reinforces the potential of having a network of off-grid self-powered pavement monitoring systems which is becoming increasingly attractive to transportation agencies. This work is also appealing to agencies and researchers in the area of sustainable development, green energy resources, energy management and sustainable infrastructures.

Publications

Earlier findings of the project have been published in the journal of "Applied Energy":

- Khalili, Mohamadreza, et al. "Electro-mechanical characterization of a piezoelectric energy harvester." *Applied Energy* 253 (2019): 113585.

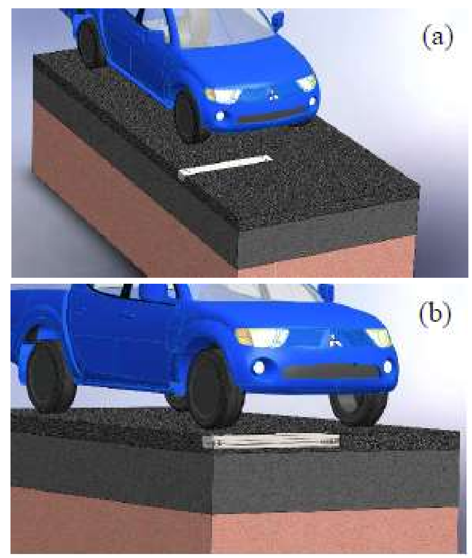

Figure 2: WIM box installed in the road schematic (a) top view (b) section view

Tran-SET

Tran-SET is Region 6's University Transportation Center. It is a collaborative partnership between 11 institutions (see below) across 5 states (AR, LA, NM, OK, and TX). Tran-SET is led by Louisiana State University. It was established in late November 2016 "to address the accelerated deterioration of transportation infrastructure through the development, evaluation, and implementation of cutting-edge technologies, novel materials, and innovative construction management processes".

Learn More

For more information about Tran-SET, please visit our website, LinkedIn, Twitter, Facebook, and YouTube pages. Also, please feel free to contact Dr. Momen Mousa (Tran-SET Program Manager) directly at transet@lsu.edu.