PERIMETER SECURITY DETECTION SYSTEM BASED ON PIEZOELECTRIC STRAIN MEASUREMENT

B. Yan, R. Blacow, S.E. Prasad and D. Waechter

Sensor Technology Limited, Collingwood, Ontario, Canada

ABSTRACT

A system is described that uses force-plate-mounted piezoelectric strain measurement to detect and quantify pedestrian traffic. The system uses distributed piezoelectric sensors in a stiff structural platform and is combined with a sensing and counting circuit. The paper describes the application of this technology for monitoring pedestrian traffic on a municipal trail. The application of the same technology in security systems for intruder detection and in static and dynamic posturography for medical research and diagnostics is also discussed.

INTRODUCTION

Systems for detecting and quantifying pedestrian traffic have a wide range of applications from data collection for municipal planning to perimeter security systems for homeland security. Modern surveillance systems often employ multiple modalities including video and infrared surveillance, and acoustical detection. Multiple modalities eliminate gaps in security systems, provide back-up protection and reduce the incidence of false alarms. In public institutions security systems often need to be coupled with traffic counting systems in order to continuously monitor the on-site population and verify complete evacuation after-hours. Pressure and vibration sensing equipment is becoming increasingly important due to its ability to sense disturbances over large areas, operate in the dark and, when combined with suitable analysis software, to distinguish different types of acoustical signatures.

Force-plates that are suitable for traffic monitoring and security detection also have significant applications in other fields such as bio-mechanics research on both human and animal subjects [1] and in medical research and diagnostics. Postural stability studies have been reported for medical conditions that include manganese [2] and lead [3] exposure, parkinsonism [4], spinal mal-alignments [5], HIV [6] and cerebellar ataxia [7], to name a few. These studies usually consider a wide range of measured parameters such as the patient's sway frequency, standard deviations of the coordinates of the centre of pressure, length of sway path and mean velocity of the centre of pressure along the sway path. Such parameters can be readily extracted from distributed force-plate sensors. In Computerized Dynamic Posturography (CDP), they are automatically extracted and analyzed using application-specific software. Data collected from medical and bio-mechanical studies may also prove useful in security and pedestrian counting systems to help distinguish human–induced disturbances from those caused by animals or other sources.

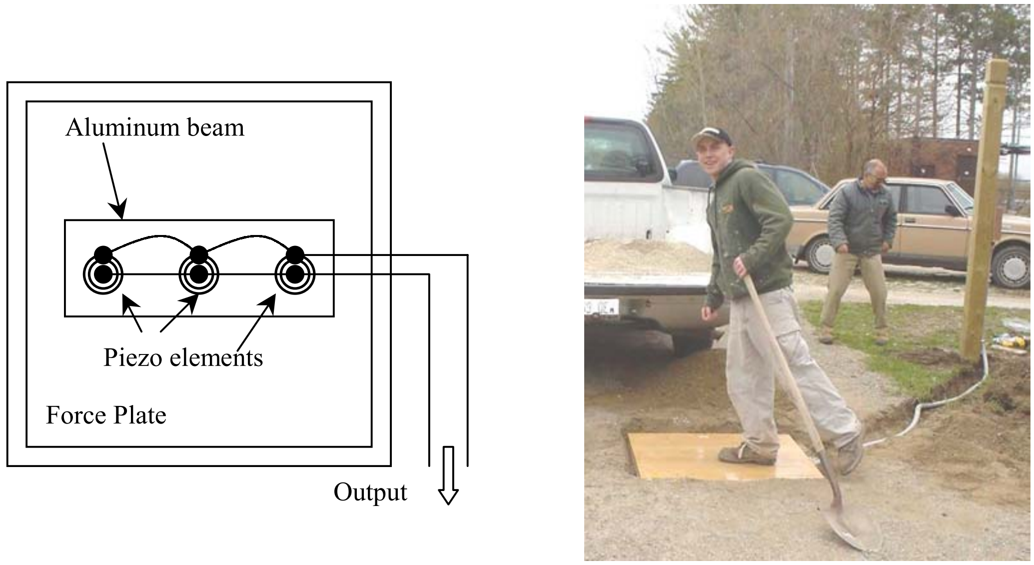
This paper describes an integrated system consisting of a force-plate with distributed piezoelectric sensors, coupled with sensing and counting electronics. The piezoelectric sensor design is discussed and compared to an alternative configuration. The sensing and counting electronics is described and data collected from a system used to monitor pedestrian traffic on a municipal trail is presented. The use of the same technology for perimeter security detection is also discussed.

HARDWARE DESCRIPTION

A force-plate was fabricated using a square wooden platform underlain with an aluminum beam to obtain the desired stiffness. Three piezoelectric sensor elements were attached to the aluminum beam, electrically insulated from the beam by a thin insulating sheet. The sensors were connected electrically in parallel, as shown in Fig. 1a. A photograph of the force-plate installation in a municipal trail in Collingwood, Ontario is shown in Fig. 1b. The plate was covered by a thin layer of soil and data could be retrieved from the battery-powered electronics box mounted near-by.

The piezoelectric sensors were flexure-mode devices consisting of two 29mm diameter, 0.12mm thick BM532 piezoelectric disks bonded on opposite sides of a 0.1mm thick brass foil having 41mm diameter. Each element had a capacitance of 180nF and a resonance frequency near 1kHz. In this application it was important to choose the stiffness of the crossbar to ensure that the bending deformation induced by the maximum anticipated load is within safety limits for the piezoelectric disks.

An alternative force-plate design having four piezoelectric block elements near the corners is shown in Fig. 2. In this design, signals from the different elements can be measured separately and used to determine the centre of mass of the applied load. Alternatively, they could be wired in parallel to provide a signal that is independent of force location, provided all of the piezo elements have matched sensitivity. The block elements in this configuration respond to the normal compression force with minimal bending deformation and, consequently, a stiffer platform may be used.



a) b)

Figure 1. a) Force-plate schematic showing the under-side piezo mounting and b) photograph of force-plate installation in a municipal trail in Collingwood, Ontario.

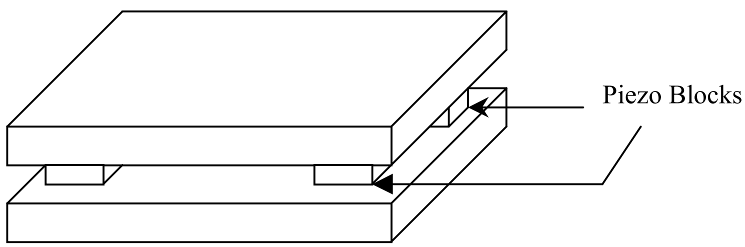


Figure 2. Alternate force-plate configuration having separate piezo block elements mounted near the four corners.

ELECTRONICS DESIGN

A schematic diagram of the sensing electronics used in the trail counter system is shown in Fig. 3. The piezoelectric sensors are shunted by a resistor in order to discharge the sensor within a reasonable time period after excitation. The oppositely oriented series of diodes limit the voltage applied to transistor T_1 to no more than 2V. T_1 is an n-channel MOSFET that will respond only to a positive gate voltage, ignoring any negative excursions caused by a backlash of the force-plate. T_2 is a depletion mode p-channel MOSFET that is normally in the off state when transistor T_1 is off. A positive pressure signal turns T_1 on and causes a rapid discharge of capacitors C_2 and

C_3, thereby turning on T_2. A rising voltage is then presented to the counter as C_4 and C_5 are charged, causing the counter to increment. After the force-plate pressure is released there is a delay in turning off T_2 due to the time constant $\tau = R(C_1+C_2)$, where R can be changed by using the switches JP1-5. The value of τ may be set between 0.3 and 1.5 seconds.

The delay period indicated above prevents a double count for a single walker, which might otherwise occur for one of the following two reasons. The first is that the force-plate size will allow an average walker to make contact with the force-plate either once or twice, depending on the size of their stride and whether the first step is near the centre (one contact case) or front edge of the force-plate (two contacts). The delay ensures that the count will increment only by 1 in either case. The second reason is that even in the single-contact case, the pressure vs. time profile of a walking person has a double peak with a dip in the centre [8]. The magnitude of the dip increases with faster walking speed. This is caused by the centrifugal force associated with the movement of the walker's centre of mass along an arc path. Without the delay period, a double count could occur even when only a single foot lands on the platform.

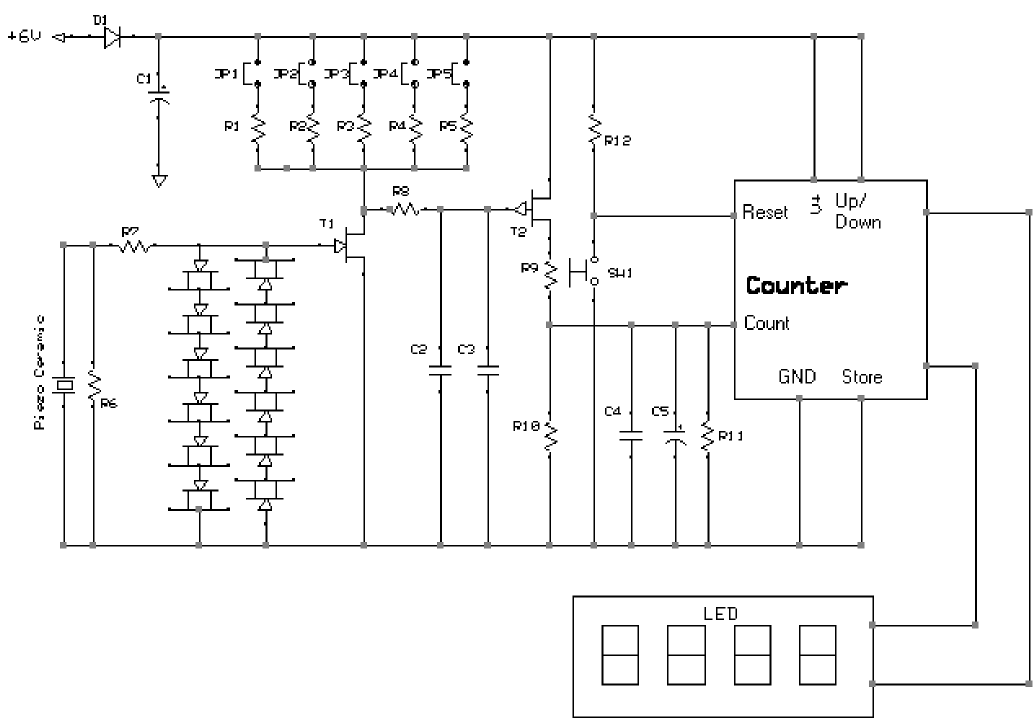


Figure 3. Schematic diagram of trail counter sensing and counting circuit.

SYSTEM PERFORMANCE

In the municipal trail counter application, the objective was to measure pedestrian usage of a trail that is generally not heavily used. The cumulative pedestrian count measured during spring and summer, 2004 is shown in Fig. 4. The trail usage was quite consistent over the period from May 14 to July 5, averaging 38 counts per day. It showed a slight decrease over the period from late July and early to mid August (33 counts/day), and a significant increase during the peak of the summer holiday season in late August and early September (62 counts/day).

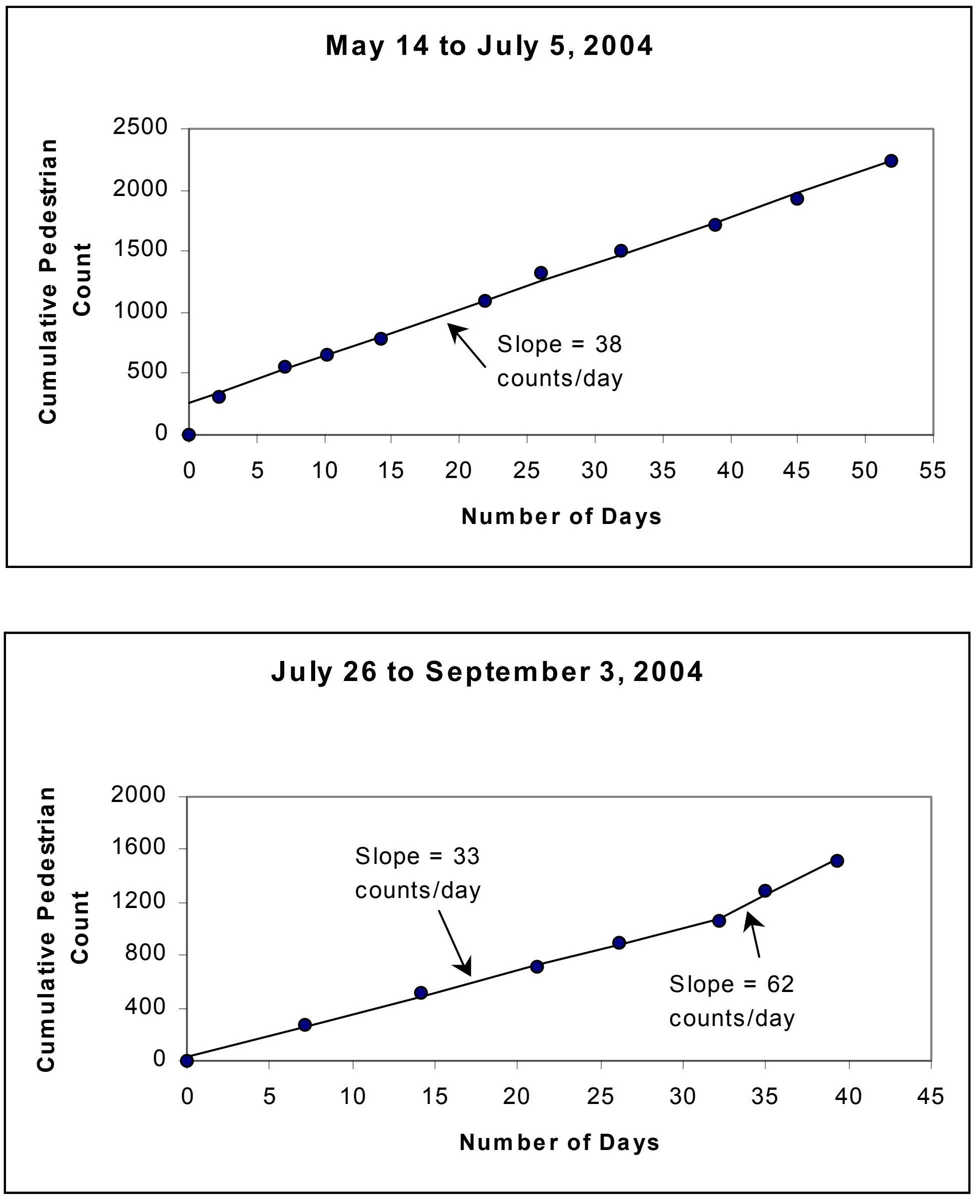


Figure 4. Cumulative pedestrian count measured using trail counter during spring and summer of 2004.

The absence of anomalies and the consistency of the slope over the nearly two month period in the top graph of Fig 4, suggests that the counting technique is a reliable and repeatable means of quantifying pedestrian traffic in this application. Count inaccuracies caused by unusual circumstances such as a large group passing simultaneously appear not to be a significant problem. The increased trail usage during late August and early September is not unexpected given that this corresponds to the height of the tourist season in the area.

In an application involving heavier traffic or requiring a near-zero incidence of false counts for security monitoring, a computerized data acquisition system with intelligent software and multiple sensor inputs would be required to reduce or eliminate counting errors. Such a system could include digital cameras that would capture and store images at each count increment, allowing later review by security personnel. The counting system described in this paper contains relatively inexpensive components, can be easily camouflaged and can be readily integrated into a multi-input security system.

CONCLUSIONS

Force-plate technology using piezoelectric sensor elements coupled to sensing and counting electronics has been described. The technology has been successfully used for monitoring pedestrian traffic on a municipal trail. The same technology can adapted to a wide range of additional applications including security systems, medical diagnostics and bio-mechanical studies.

ACKNOWLEDGEMENTS

We wish to thank the Collingwood Trails Committee of Leisure Services, Town of Collingwood, for providing the trail usage data.

REFERENCES

1. M.J. Adrian and J.M. Cooper, "*Biomechanics of Human Movement*", 2nd ed., Brown and Benchmark, Madison, Wisconsin (1995).
2. S.E. Chia, S.L. Gan, L.H. Chua, S.C. Foo and J. Jeyaratnam, "*Postural stability among manganese exposed workers*", Neurotoxicology, 16, (1995) pp. 519-26.
3. S.E. Chia, L.H. Chua, T.P. Ng, S.C. Foo and J. Jeyaratnam, "*Postural stability of workers exposed to lead*", Occup Environ Med., 51, (1994) pp. 768-71.
4. C. Trenkwalder, W. Paulus, S. Krafczyk, M. Hawken, W.H. Oertel, and T. Brandt, "*Postural stability differentiates "lower body" from idiopathic parkinsonism*", Acta Neurol Scand., 91, (1995) pp. 444-52.
5. D. DeCamillis and R. Carr, "*The reliability and potential value of a specific 'centre of pressure locator' in chiropractic practice",* J. Can. Chiropr. Assoc., 44, (2000) pp. 209-22.

6. C. Trenkwalder, A. Straube, W. Paulus, S. Krafczyk, E. Schielke, and K.M. Einhaupl, "*Postural imbalance: an early sign in HIV-1 infected patients"*, Eur. Arch. Psychiatry Clin. Neurosci.., 241, (1992) pp. 267-72.
7. K.H. Mauritz, J. Dichgans and A. Hufschmidt, "*Quantitative analysis of stance in late cortical cerebellar atrophy of the anterior lobe and other forms of cerebellar ataxia",* Brain, 102, (1979) pp. 461-82.
8. R. Cross, "Standing, walking, running and jumping on a force plate", Am. J. Phys. 67 (1999) pp.304-9.