Poster Abstract: A Wireless Magneto-resistive Sensor Network for Real-Time Vehicle Detection

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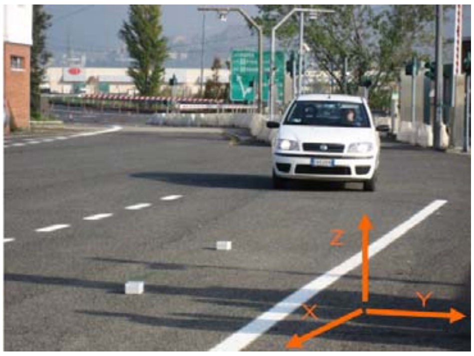

Fig. 1. Two wireless sensor nodes deployed on the road

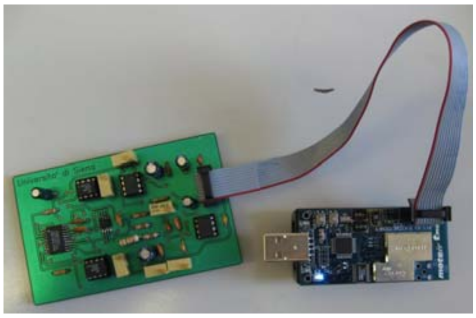

Fig. 2. Magneto-resistive wireless sensor node

***Abstract*— This works describes a prototype wireless sensor network for vehicle detection developed at the University of Siena in collaboration with the Italian highways society Autostrade S.p.A. Each wireless sensor node is composed by an in-house designed electronic board driving a 2-axis Honeywell HMC1002 magneto-resistive sensor interfaced to a Telos rev.b (Moteiv Corporation) mote, and by a Matlab/Simulink interface for collecting and processing sensor data in (soft) real-time.**

I. Magneto-Resistive Wireless Sensor

Wireless magneto-resistive sensor networks are a cheap, easily deployable, and non-invasive alternative to inductive loops and cameras for real-time count, speed measurement, and occupancy of vehicles on roads, and, indirectly, of traffic parameters like density and flows [1], [2].

In our setup each wireless node provides samples of two components of the Earth magnetic field, perturbed by the vehicle, in a rather reliable way, thanks to a set-reset control circuit on the magneto-resistive sensor's board. The board is physically connected on the ADC expansion pins of the Telos mote (see Figure 2). Though specially tailored NesC components for TinyOS, the mote samples the amplified analog signal from the sensor's Wheatstone bridge at 64Hz and transmits the digital samples to the remote station located along the road at a distance of about 10m. The sampling frequency is high enough to recognize vehicle magnetic "signatures" on a wide spectrum of vehicle speeds (see Section 3). Two sensor nodes are employed for robustified vehicle detection and speed measurements.

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II. Magnetic Signature

Every vehicle leaves its own characteristic magnetic signature when passing in the proximity of the sensor. For example two different vehicles provide a different perturbation of the Earth's magnetic field because their ferrous parts (engine, chassis and body) have different dimensions and are placed in a different way. The passage of the same vehicle can be therefore identified by its signature. The shape of the magnetic signature is almost insensitive to vehicle speed, modulo deformations along the time axis due to non-uniform speed (that is, the magnetic signature signal $m(t) = m(s(t))$, where $s(t)$ is the vehicle position at time t). Figure 3 shows the same signature identified at 30 and 80 km/h. In terms of number of samples of the signature, at the given sampling frequency 64 Hz around 50 samples are collected at 40 km/h, 32 samples at 70 km/h. Different vehicle signatures were observed by changing the orientation of the sensor, a very promising result pointing towards the possibility of reliable vehicle classification.

III. Detection algorithm

Several detection algorithms running at the base station for noise filtering (like integrals, autoconvolutions, FFT, etc.) were tested. A very efficient solution in terms of both numerical burden, accuracy of detection, and robustness, is an algorithm that integrates the raw magnetic signal $x(t)$ ($y(t)$ or $z(t)$) on a moving window of M (typically $M = 32$) samples depurated by the average of the samples, and then compares the resulting signal with a given threshold $\pm L$, therefore obtaining a $\{-1, 0, 1\}$ signal $a_x(t)$ ($a_y(t)$ or $a_z(t)$). The logical "and" $|a_x(t)| \wedge |a_y(t)|$ (or $|a_x(t)| \wedge |a_z(t)|$) provides a binary signal $b(t)$ that flags the passage of a vehicle.

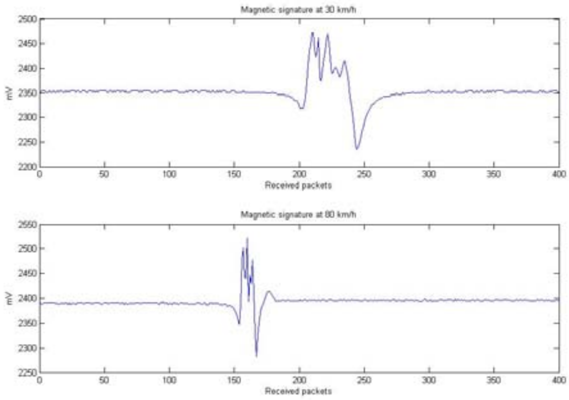

Fig. 3. Magnetic signature of the same vehicle detected on x axis (along the motion direction) at the speed of 30 and 80 km/h.

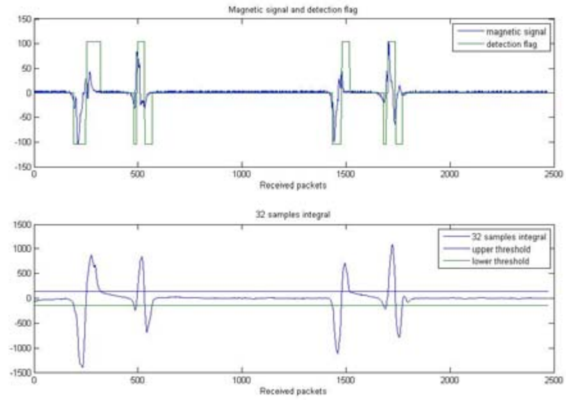

Fig. 5. Data processing based on integrals on moving windows (x-axis): $x(t)$ and $I_x(t)$ (top), integral signal and thresholds (bottom)

Such a simple detection algorithm is described in more detail below:

1. Initialization: $m_x(0) = \sum_{i=0}^{M-1} x(-i)$, $m_y(0) = \sum_{i=0}^{M-1} y(-i)$;
2. At time t:
   a. collect last M samples $x(t)$, $x(t-1)$, $\ldots$, $x(t-M+1)$ and $y(t)$, $y(t-1)$, $\ldots$, $y(t-M+1)$;
   b. $m_x(t) = (1-\lambda)m_x(t-1) + \lambda x(t)$ (λ is a given fading factor), $m_y(t) = (1-\lambda)m_y(t-1) + \lambda y(t)$;
   c. $I_x(t) = \sum_{i=0}^{M-1}(x(t-i) - m_x(t))$, $I_y(t) = \sum_{i=0}^{M-1}(y(t-i) - m_y(t))$;
   d. If $I_x(t) > L$ then $a_x(t) = 1$, else if $I_x(t) < -L$ then $a_x(t) = -1$, else $a_x(t) = 0$ ($a_y(t)$ is defined similarly);
   e. $b(t) = |a_x(t)| \wedge |a_y(t)|$.

Results of the algorithm on experimental signals are shown in Figure 5.

Fig. 4. Wireless sensor node embedded in road pavement

IV. Implementation and Experiments

On the base station data are collected by special methods and conversion routines designed around a Matlab Java object. In addition, a Simulink S-function based on the Java object is used for real-time data processing and visualization.
Several experiments have been carried out in collaboration with the Italian highways society Autostrade S.p.A at their test site in Florence, Italy. The wireless network was first placed on the road surface and tested (as in Figure 1), then buried under the pavement at about 10cm and covered by asphalt (Figure 4). In the latter case we experienced almost no loss in radio transmission and only a very mild reduction of intensity of the sensed magnetic field, that does not jeopardize the correct functioning of the overall measurement and detection system. When the nodes are placed aside rather than under the vehicle, the signal-to-noise ratio remains acceptable up to a distance of about 70cm between vehicle and sensor.

On the base station we have implemented a Simulink diagram for soft real-time data processing and visualization. A Simulink block is devoted to listen to all the packets of the network and to take out and convert the data of interest about the magnetic field. Other blocks are used to implement the algorithm described in Section III based on the integral of a mobile window of 32 samples and they create a detection flag comparing the processed signal with two specular thresholds L and $-L$, where $|L| = 150$. Others blocks are used to count the number of vehicles passing over the sensors using the information of the detection flag. The same Simulink diagram can be also easily adapted to measure the speed of vehicles.

V. Conclusions

Our wireless magneto-resistive sensing system proved to be a quite viable and reliable scheme for real-time vehicle detection on roads, such as at highway toll stations, and it can replace the large and invasive inductive loops. Several issues remain to be explored. Adaptive transmission schemes improving on battery life by local processing data on the Telos node should be investigated, as well as the possibility to move the detection algorithm from the base station to the motes. To prevent the congestion of the network it may be useful to synchronize the nodes or to use a different transmission protocol, like TDMA, instead of the CSMA. For using this kind of wireless sensor network for vehicle classification, it is necessary to collect a large number of magnetic signatures and create a database.

References

[1] S.Y. Cheung, S. Coleri, B. Dundar, S. Ganesh, C.-W. Tan, and P. Varaiya. Traffic measurement and vehicle classification with a single magnetic sensor. Technical report, Institute of Transportation Studies, University of California at Berkeley, 2004.

[2] Vehicle detection using amr sensors. `http://www.magneticsensors.com`, August 2005.