Wireless sensor networks for measuring traffic

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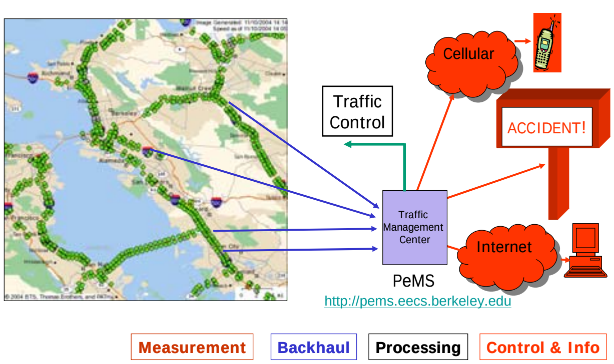
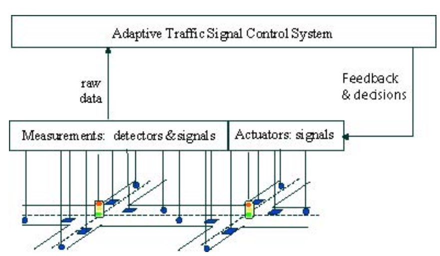
Outline

- Traffic measurement
- Wireless Sensor Networks
- Vehicle Count, Occupancy, Speed
- Vehicle Classification
- Vehicle Re-identification
- Communication protocol
- Future work

Freeway Traffic Management



Adaptive Signal Control



Source: Mirchandani, P. and L. Head, 'Rhodes' Traffic-adaptive control system, TRB 2001

Requirements

- Freeway detectors must report count, occupancy, speed every 30 s
- Intersection detectors must also report presence of vehicle at intersection within 0.1 s

Current Traffic Measurement Technologies

Inductive loop | Video | Microwave radar

- Loop detector is the standard; lasts years; closing lane to cut loops in pavement is disruptive; alternatives are microwave radar, video
- Can wireless sensor networks compete?

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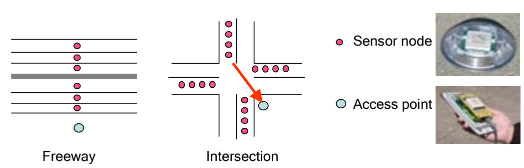
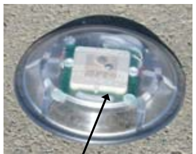
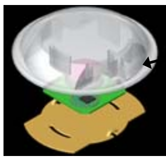
Wireless Sensor Networks



- Sensor nodes
  - Detect vehicles by change in earth’s magnetic field
  - Transmit data to access point via radio
- Access point reports to signal controller or TMC
- Low cost, non-intrusive, flexible, easy to install

Prototype sensor Node

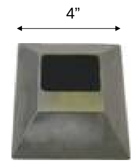




Protective cover can withstand 9000kg

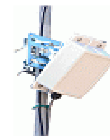
3-axis magnetometer, microprocessor, radio transceiver, antenna, battery

Sensys Vehicle Detector Station



Steel case, glued on pavement, withstands 9000 kg, 7 year battery life

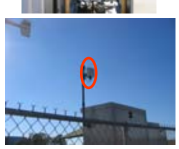
Hardened plastic mounted flush with pavement surface, 10 year battery life



GPS receiver, GPRS/CDMA interface, poE, or power over RS485

Disclosure: Varaiya is a co-founder of Sensys Networks, Inc

Advantages of Wireless Sensing



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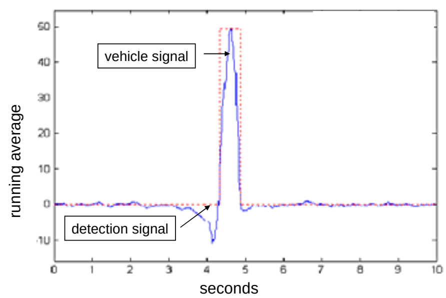
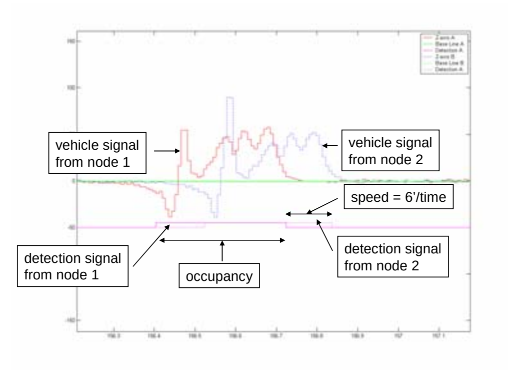
Vehicle Detection (count)

z axis measurement as vehicle goes over node

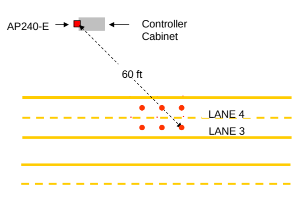


- Note sharp, localized threshold crossing

Occupancy and speed by Node Pair



Texas Transportation Institute test



- 15-minute counts and speeds within 1.5% of calibrated loops

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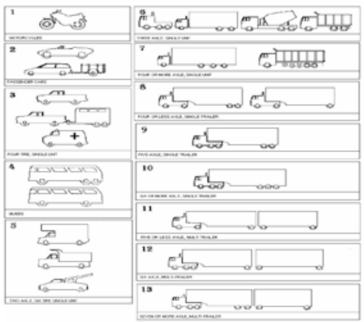
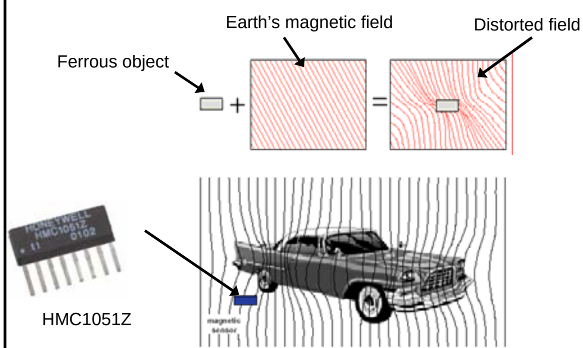
FHWA Classes



- Classify detected vehicle from signal

Magnetometer: Basic principle



Classification approach

- Collect labeled samples, $(x_1,y_1), \ldots, (x_N,y_N)$, $x_i \in R^{n(i)}$, class of $x_i = y_i \in \{1, \ldots, 13\}$
- Design good classifier, $f: x_i \to y_i$
- Classify new sample x as f(x)

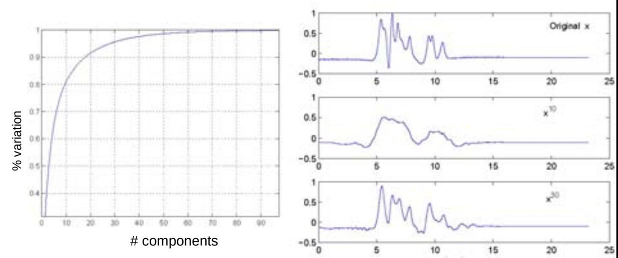
Difficulties

- Large and unequal sample vector size:
  – Vehicle length 5-20 m, speed 2-25 m/s, so duration is 0.2-10s, f_s = 128/256 Hz, so size n(i) is 75-7680 samples; inter-vehicle spacing 2-4 s
- Approach: Convert to fixed vector size n
  – Preprocessing: $x_i \in R^{n(i)} \to R^n$ all i
  – Extract features (compress): $f: R^n \to R^k$, k << n
- Find classifier: $g: R^k \to \{1, \ldots, 13\}$

Preprocessing + compression A

1. Normalize sample vector to zero mean, [-1,1] and fixed sample size n: if n(i) > n downsample; if n(i) < n upsample
2. Extract features by principal components: If X is $N \times n$ matrix of N test sample vectors with SVD $X = USV^T$, $X^TX = VS^2V$. Project x_i components onto subspace of k eigenvectors with 90-99% of variation
3. Step 1 is expensive

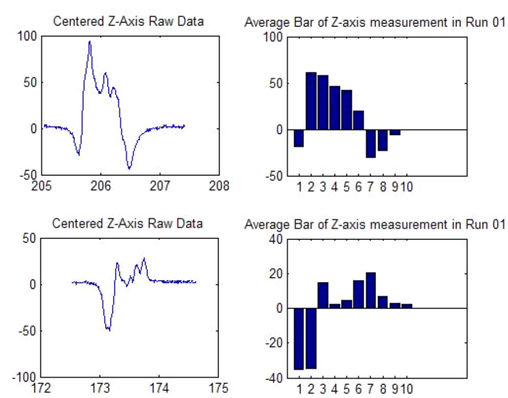
Example A (n=2971)



Preprocessing + compression B

1. Replace sample vector x_i with size n(i) by vector of fixed size k with components = average value of x_i in bins of size n(i)/k
2. Extract principal components if necessary

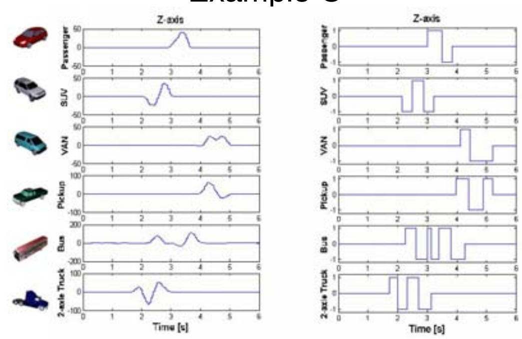
Example B (k=10)



Preprocessing + compression C

1. Extract (-1,0,1) 'hill pattern'
2. Add zero padding to obtain (-1,0,1) vector of fixed size k

Example C



- Very high compression

Classification Schemes

1. Support vector machines (SVM) using radial basis function kernel

   $k(u,v) = \exp(-\gamma\, |u-v|^2)$
2. K-Nearest-Neighbor (KNN) scheme

KNN results (1/2)

- 839 vehicles

Class	2	5	6	8	9	11
#	85	359	45	83	194	73

- 50% from each class are randomly selected for training; 50% left for testing
- Correct rate is average from 10 trials
- Length information is not used

KNN results (1/2)

Passenger vehicles vs Trucks: FHWA 2 vs (5,6,8,9,11)

	Classification rate (%) Test	Training
Hill pattern	91.2	91.4
Ave. bars	97.9	97.6

2-axle vs 3+ axle trucks FHWA 5 vs (6,8,9,11)

	Classification rate (%) Test	Training
Hill pattern	78.9	82
Ave. bars	81.3	87.1

FHWA 9 vs (6,8,11)

	Classification rate (%) Test	Training
Hill pattern	61.2	72.8
Ave. bars	71.2	80.8

- using length would improve accuracy

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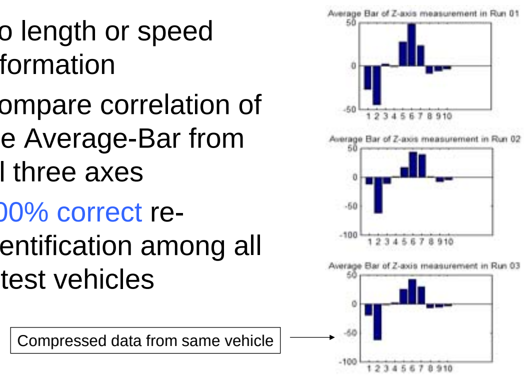
Vehicle re-identification

- Use an array of nodes to compensate for offset
- Experiment conducted with 7 test vehicles
  - Buick Le Sabre 97 (x 2)
  - Toyota Corolla 89
  - LandRover Range Rover 96
  - Ford Taurus 96
  - Ford Taurus 2000
  - Ford WindStar (Van)
- Each vehicle driven over SN array 5 times: Note 2 vehicles are the same model

Compress with 10 ave bar

- No length or speed information
- Compare correlation of the Average-Bar from all three axes
- 100% correct re-identification among all 7 test vehicles



Summary

- It appears that wireless magnetic sensor network has better detection properties than alternatives
- What about lifetime?
- Depends on energy consumption

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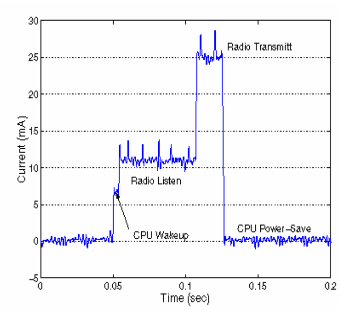
Energy Calculations

- Focus on radio energy
- Suppose battery rating is 2000 mAh @ 3V
- In 1 year = 8700 hours, average power budget is
  - 230 µA for 1 year lifetime
  - 23 µA for 10 year lifetime
- What kind of protocol and load can be supported with this power budget?

Mica2 CSMA protocol

- Mica2 CSMA protocol requires 'listen' before 'transmit' and constant 'listen' at 7mA current
- Gives lifetime < 120 days with no transmission



Source: Shnayder, V et al. SenSys 2004

A simple calculation

- Suppose Rx, Tx current is 20 mA @ 250 Kbps; sleep current is 0.5 μA (Chipcon CC2500)
- 23 μA power budget (for 10 year lifetime) gives 250 bps or 900 bytes/30 sec, which is adequate for traffic
- Duty cycle of 0.1%
- Sleep when no Rx, Tx
- Requires TDMA

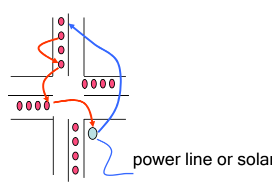
Two TDMA protocols

- Sensor nodes (SN) periodically generate data and transfer to access point (AP)
- SN are power limited, AP is not
- Two protocols
  - PEDAMACS
  - Sensys

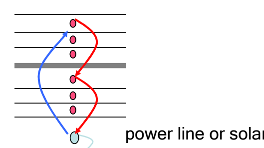
Pedamacs (Power efficient, Delay Aware, MAC protocol)

Transmission AP $\rightarrow$ SN is one-hop
Transmission SN $\rightarrow$ AP is multi-hop

Example

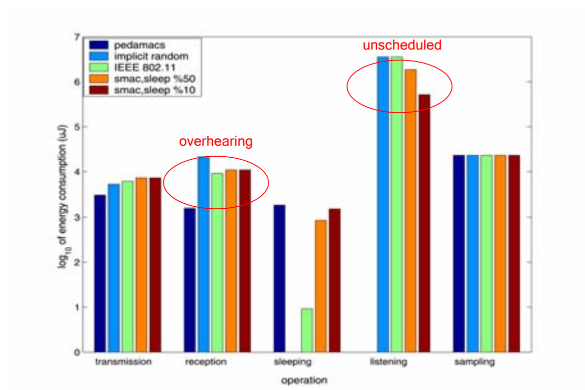


Intersection

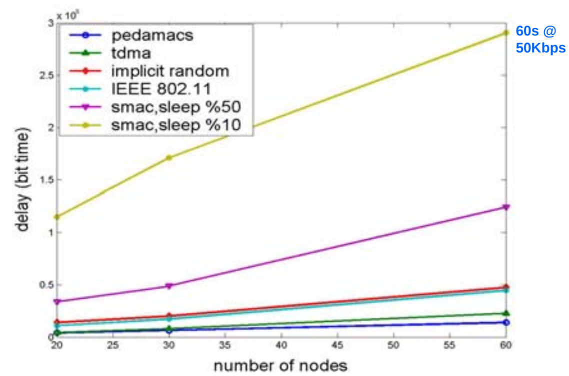


Freeway

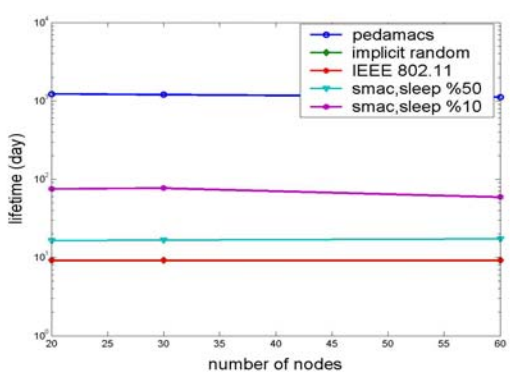
Power consumption



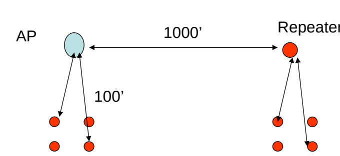
Delay



Lifetime with 2 AA batteries



Sensys



- All links are one-hop

Conclusion

Wireless sensor networks for traffic measurement appear promising and require solving interesting problems of

- Signal processing
- Power consumption
- Engineering design

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