HORN-OK-PLEASE

An ***Acoustic*** Sensor Based Road ***Congestion Detection*** technique in ***Developing Regions***

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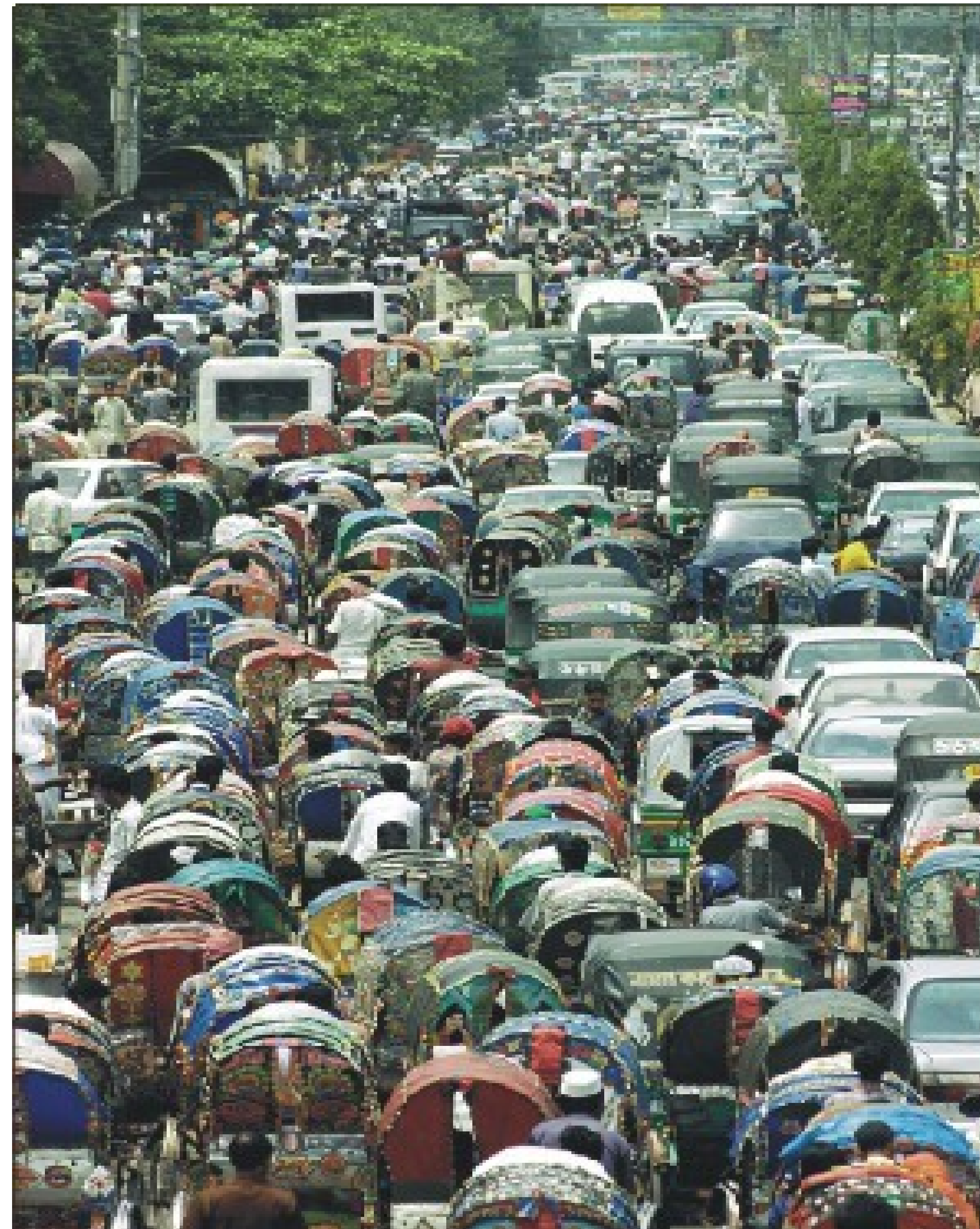
Why is solving this problem important ?

"Congestion in Developing Regions"

Armenia

Bangladesh : Dhaka

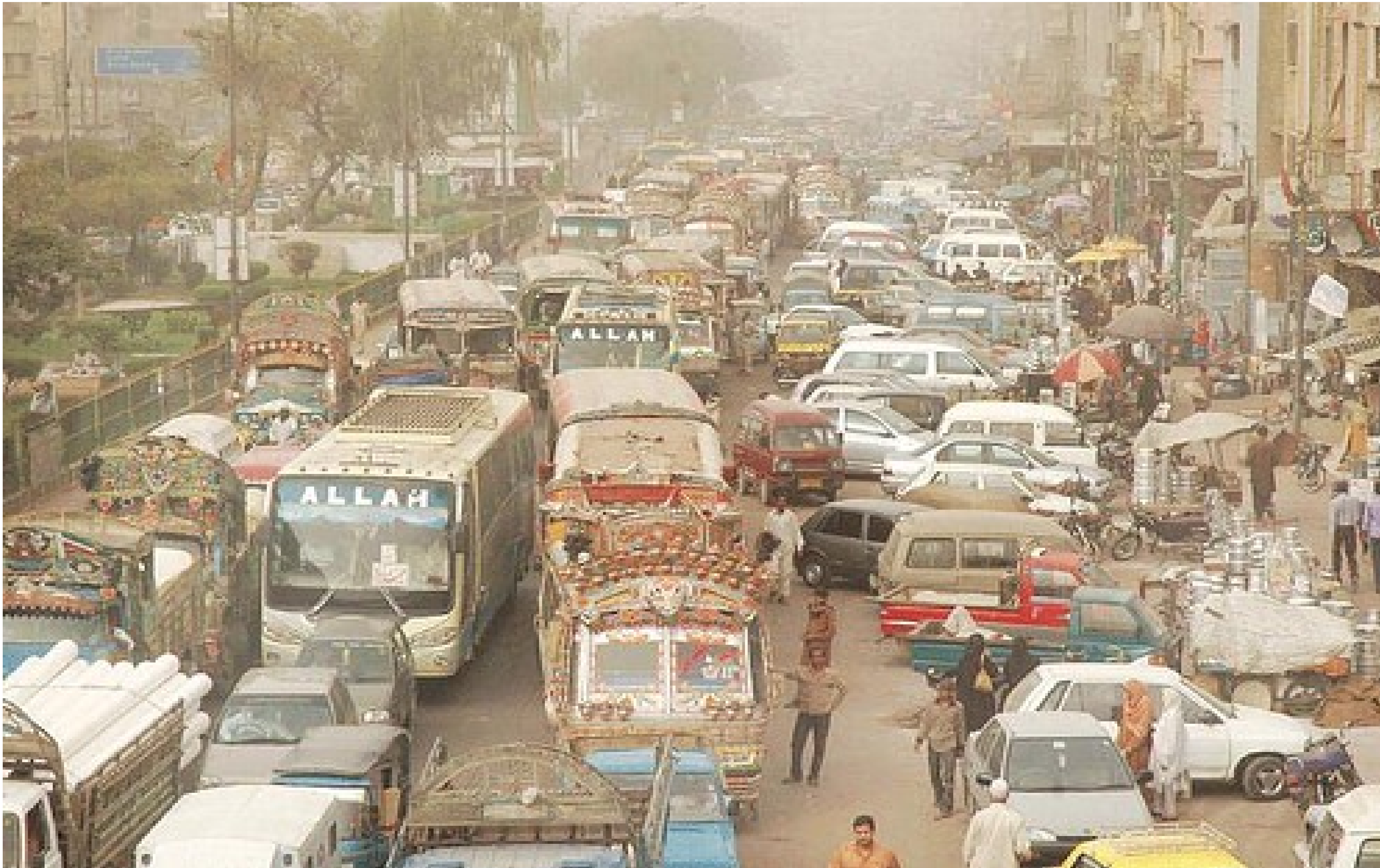


Brazil : Sao Paolo

China

Egypt : Cairo

Pakistan : Karachi



Mexico

Nepal : Kathmandu

Sri Lanka : Candy

India : Delhi

India : Mumbai

India : Chennai

India : Bangalore

India : Hyderabad

Image Sources:

- http://www.2spare.com/item_92761.aspx
- http://freshclick.wordpress.com/2009/04/10/traffic-jam-in-dhaka-bangladesh/
- http://www.thedailystar.net/story.php?nid=111122
- http://www.chinadaily.com.cn/english/doc/2005-12/09/content_502114.htm
- http://nerdnirvana.org/tag/traffic-jam/
- http://visionsfortomorrow.net/2008/10/not-everyone-can-have-a-car-if.php
- http://evworld.com/press/trafficjam_cairo_egypt.jpg
- http://blackberrytravelog.blogspot.com/2009/11/san-luis-potosi-to-lake-chapala-end-of.html
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- http://www.flickr.com/photos/73047728@N00/65928682
- http://www.team-bhp.com/forum/international-automotive-scene/35403-awful-traffic-jams-around-world.html

Why is solving this problem interesting ?

“Issues with Existing Solutions”

Intelligent Transport Systems (ITS)

- **Infrastructure growth slow due to lack of funds & space, bureaucracy**
- **ITS uses *technology* to alleviate problems**

State of the art in ITS

Fixed sensor based
Sensors placed on or under road

Eg. - Dual loop detector, Image sensor, Magenetic sensor

Mobile sensor based
Sensors placed in probe vehicles

Eg. - GPS receiver, smartphone's accelerometer & microphone

Challenges in developing regions

- ✘ High installation and maintainance *costs*
- ✘ Assumption of *lane based system*
- ✘ Assumption of *low variability in vehicle speed*

- ✘ *Low proliferation* of GPS and smartphones
- ✘ *Lack of incentive* in participatory sensing
- ✘ *Power drainage* issue of phones
- ✘ *Privacy* issues

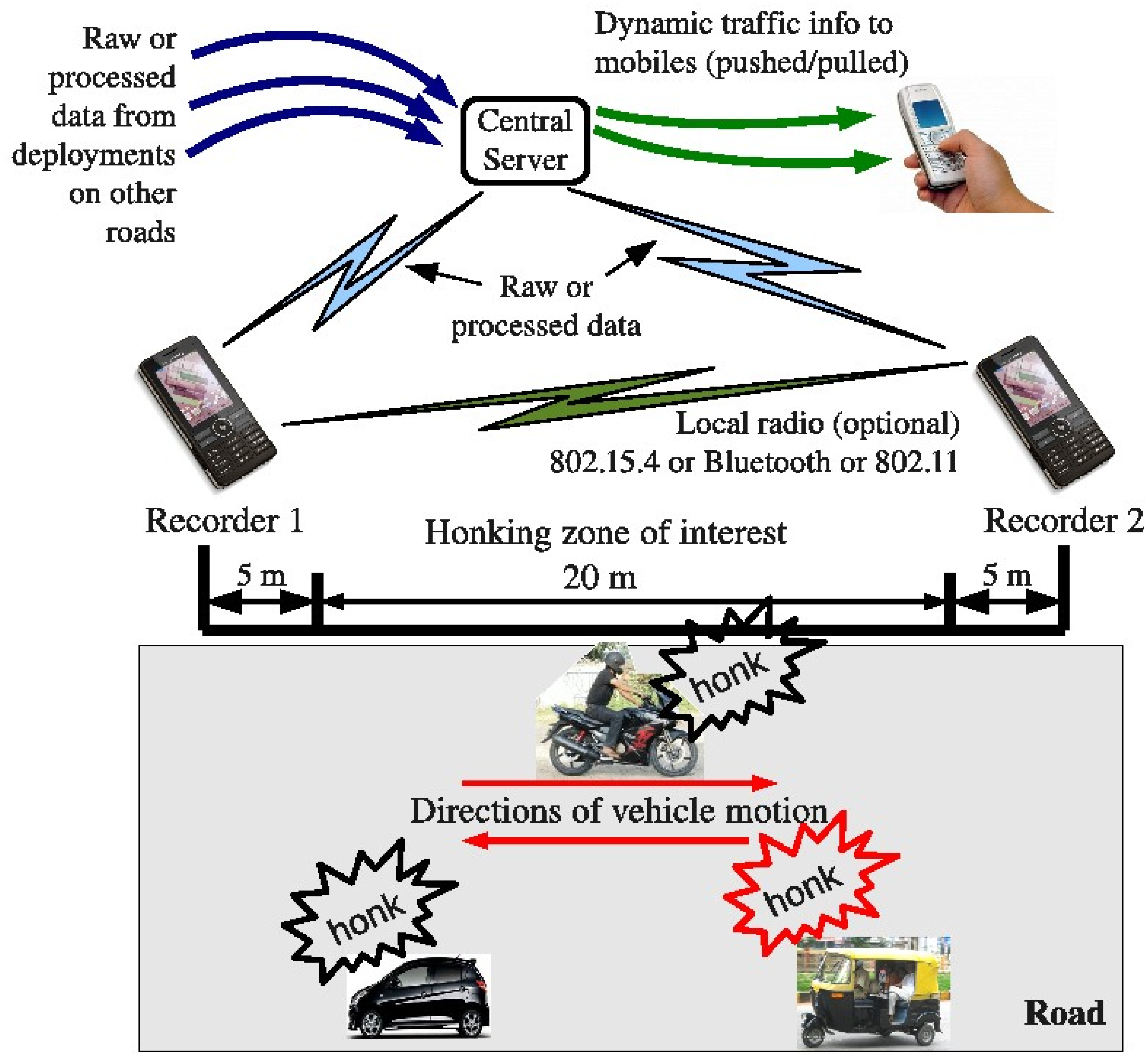
No one technique can be used to solve an issue of this magnitude. Techniques have to be used in conjunction with one another, based on *applicability* and *ease of deployment*

Our Approach : Using *Acoustic* Sensors

Chaotic Traffic is Noisy !!

Can we exploit this ??

System Architecture : Doppler Shift of Honks



Envisioned Architecture

Receding honk

$$f_1 = \frac{v}{(v + v_s)} \times f_0$$

Approaching honk

$$f_2 = \frac{v}{(v - v_s)} \times f_0$$

$$v_s = \frac{(f_2 - f_1)}{(f_2 + f_1)} \times v$$

Underlying Theory

Work Done (Jul-Dec, 2009)

Empirical Data Collection

- Are there *enough* honks on road?
- What is the honk *frequency range*?
- What is the average *honk length*?

Algorithm Design & Evaluation

- How to *detect honks* in the presence of road noise?
- How to *match honks* across the two recorders?
- How to *extract f1 & f2* from a pair of matched honks?
- *How accurate* are our speed estimates?

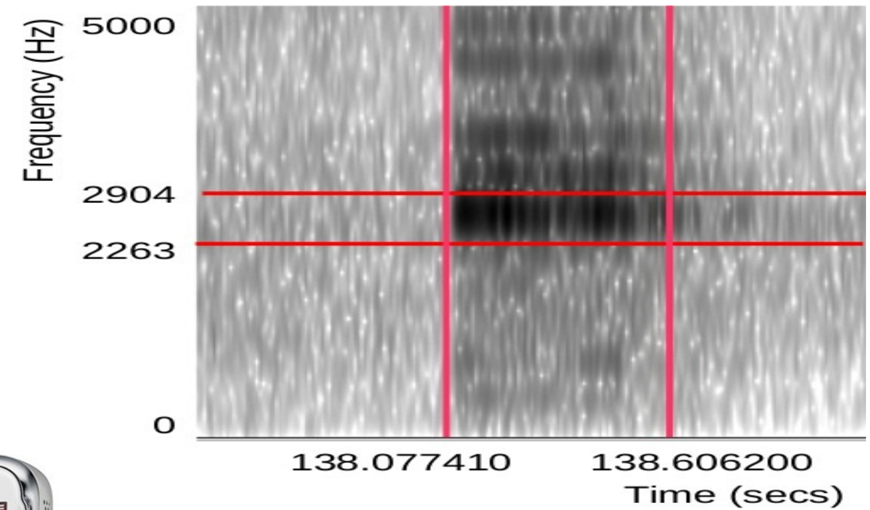
Testing Applicability on Real Roads

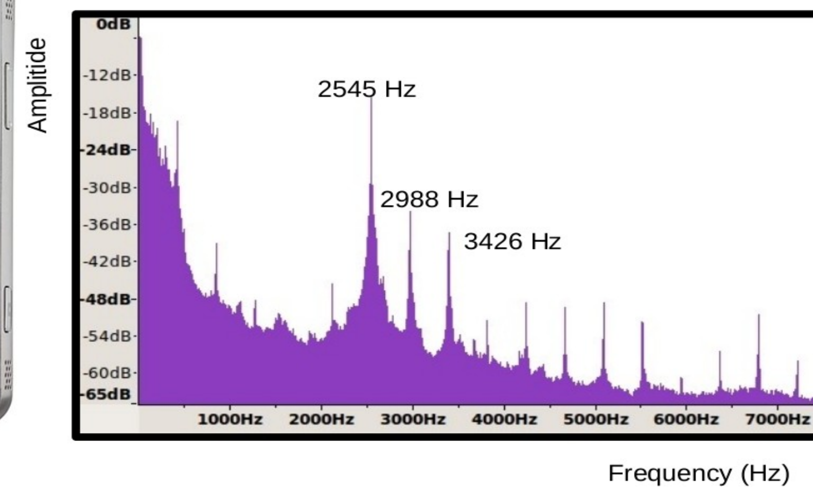
- Do speed estimates from city roads *represent traffic state*?
- Can some metrics *distinguish congestion from freeflow*?
- Can we detect traffic state for *individual directions* on a bidirectional road?
- Will metric values for congested and freeflow be *statistically different*?
- Can we *classify* new traffic data into based on historical data? What is the *classification accuracy*?
- Can we detect the *onset of congestion*?

Experimental approach used all through

Hardwares and Softwares used

- Voice recorder of Nokia N79
- 16 KHz sampling frequency
- Mono channel
- 16 bit encoding
- Wav format
- Audio based synchronization

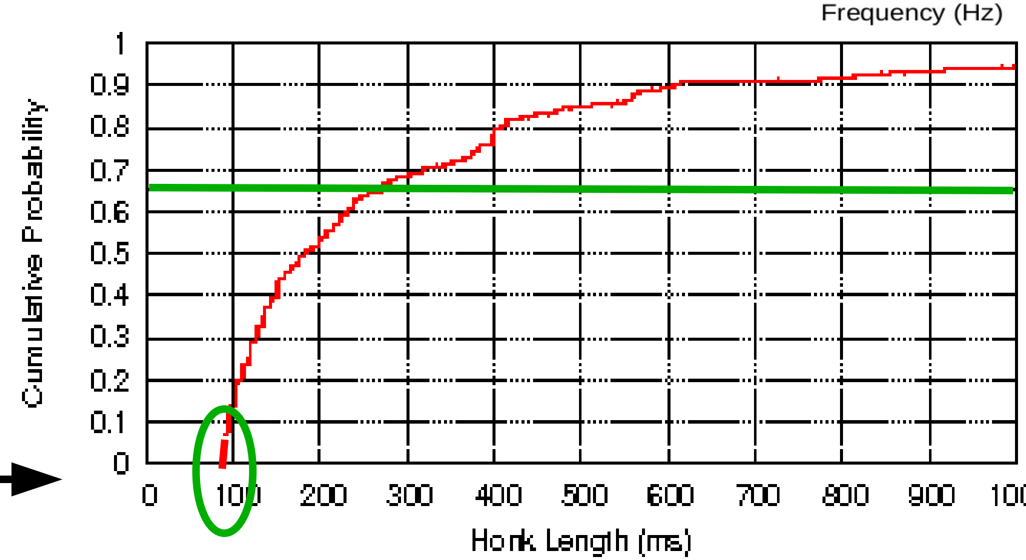




Empirical Data

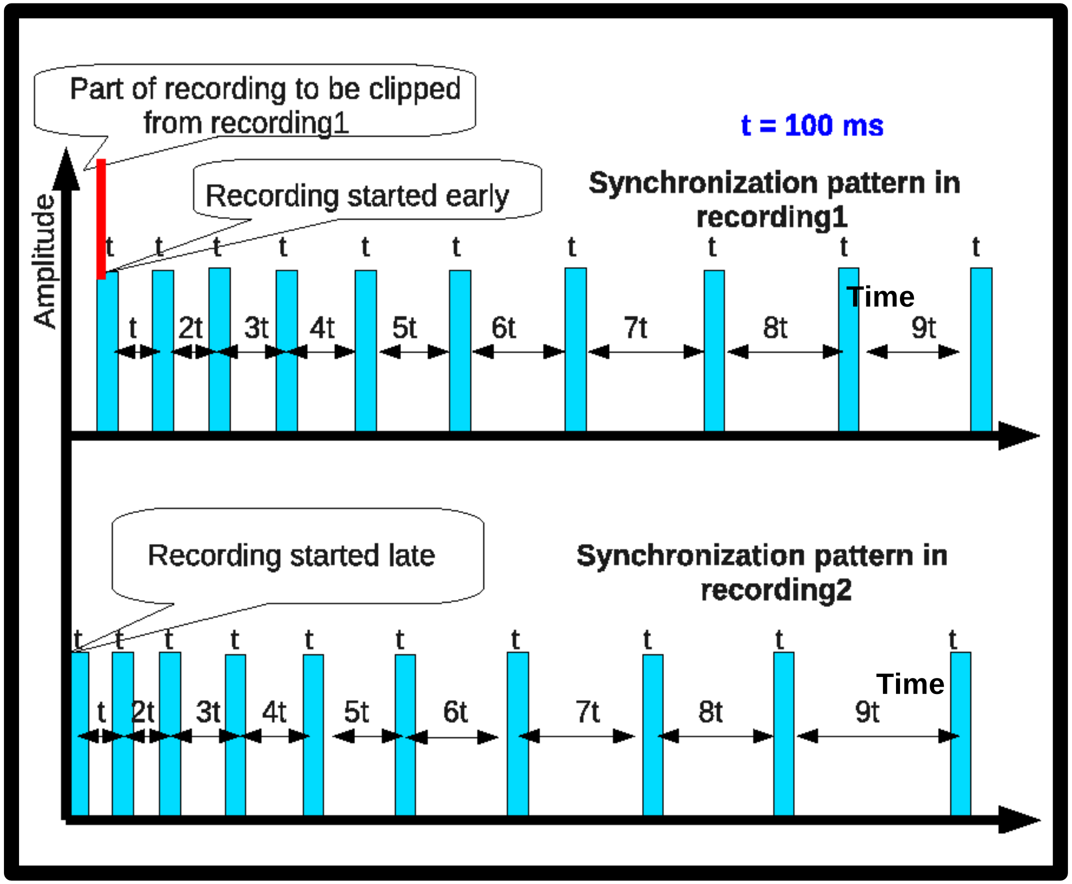
3 hours of data = 18 clips of 10 mins each
manually detected 257 honks

- Honk frequency range – 2-4 Khz
- Average number of honks per clip - 30
- Honk length - CDF

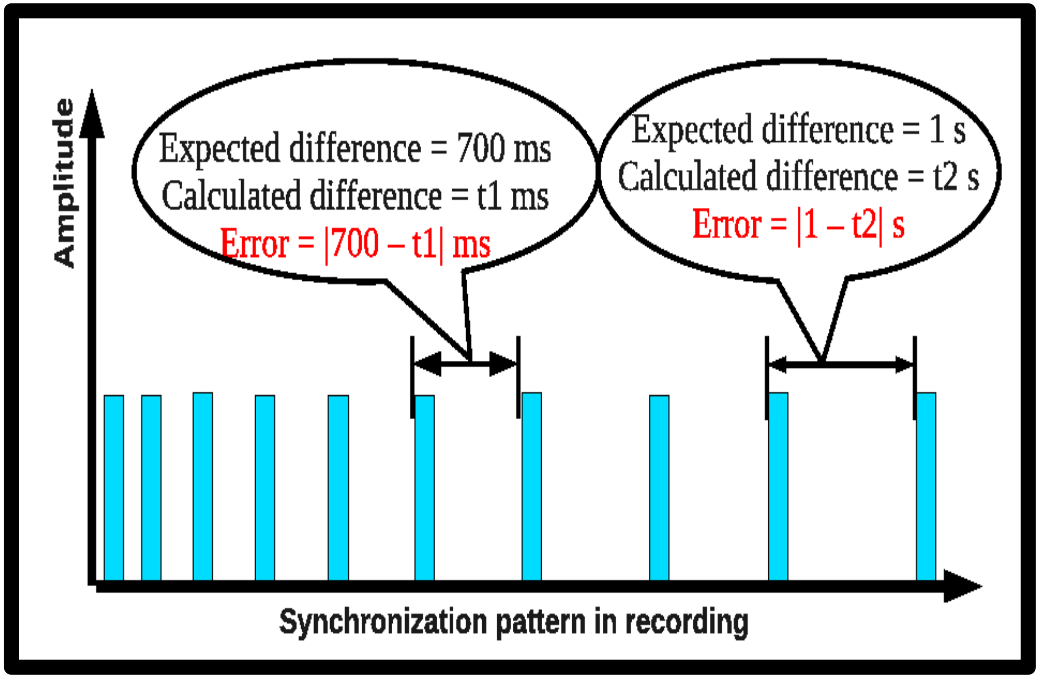


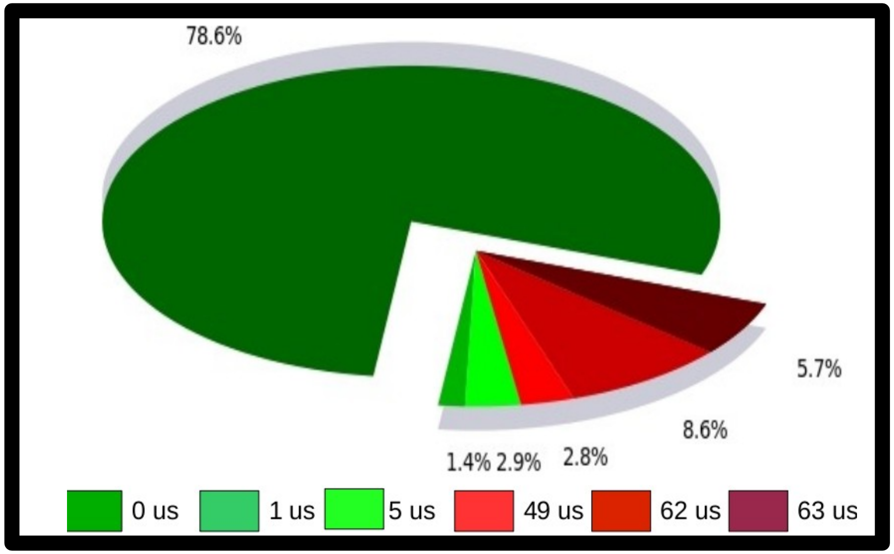
Phone Synchronization

Method



Evaluation





- Audio based synchronization
- Square wave pattern generated in matlab
- Evaluation done across 70 pairs

Honk Detection

Preprocessing

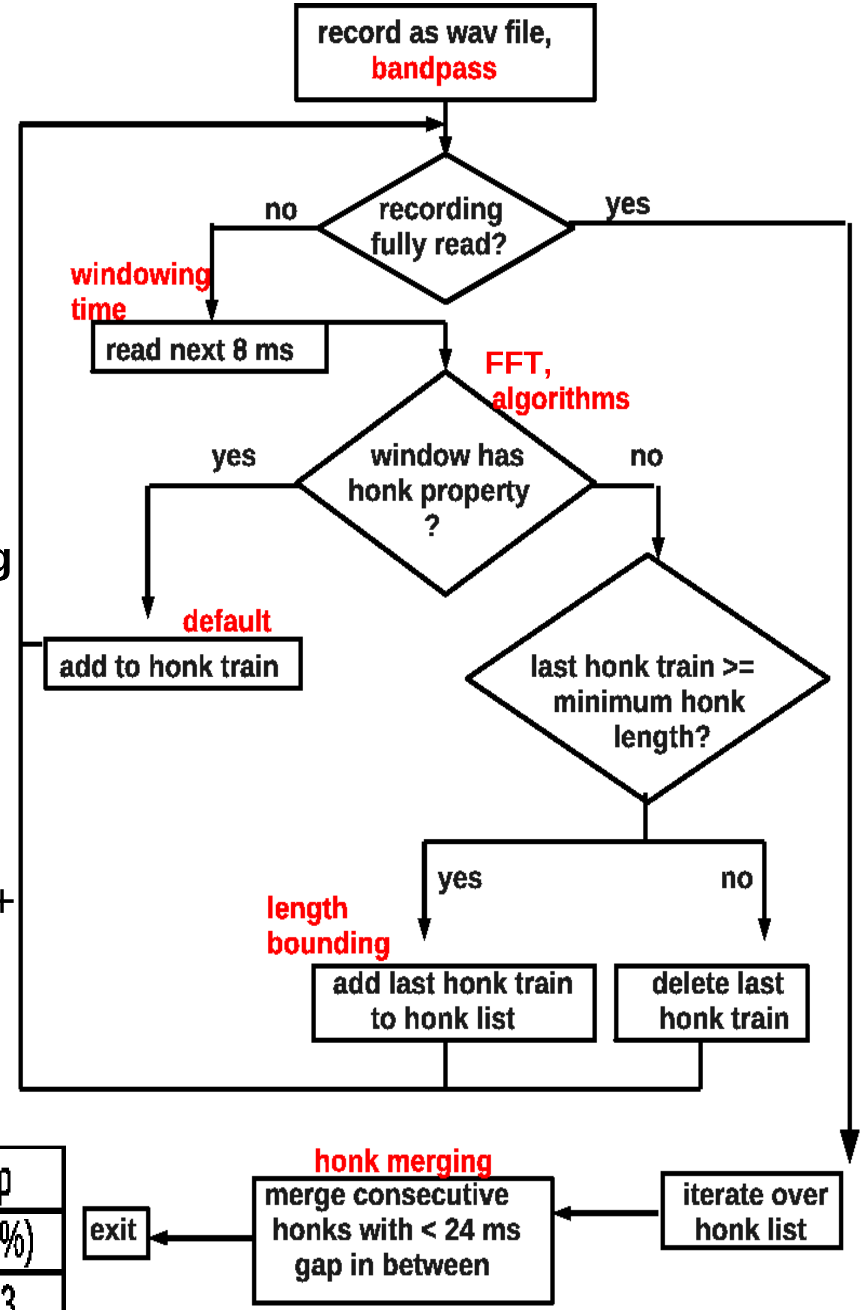
1) Bandpassing
2) Windowing time
3) FFT computation

Algorithms

1) PeakVsAvgAllFreq
2) PeakVsAvgHonkFreq
3) PeakAbsAmp

Postprocessing

1) Length bounding
2) Honk merging



flowchart

Evaluation:

- 257 honks from empirical data used
- An 8 ms window marked as *honk* & *not detected* -> fn++
- An 8 ms window marked as *non-honk* & *detected* -> fp++
- fn/(total number of honk windows) * 100 = fn(%)
- fp/(total number of non-honk windows) * 100 = fp(%)

Winner (PeakVsAvgAllFreq)

	PeakVsAvgAllFreq		PeakVsAvgHonkFreq		PeakAbsAmp	
Stage	fp (%)	fn (%)	fp (%)	fn (%)	fp (%)	fn (%)
Default	22.3	0.2	9.8	43	18.9	0.3
length bounding	5.6	0.7	2.1	74.7	10	1.04
honk merging	5.7	0.4	2.1	73.8	10.3	1.01

fp(%) falls

fn(%) falls

T = 10 (PeakVsAvgAllFreq) **T = 2** (PeakVsAvgHonkFreq)

Honk Matching

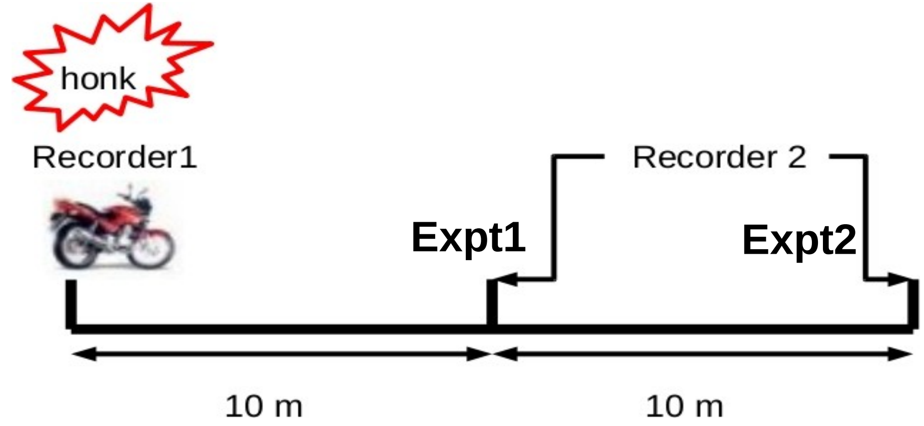
Criteria :

1) starttime_difference

2) duration_ratio

$$d_1 f_1 = d_2 f_2$$

$$\frac{d_2}{d_1} = \frac{f_1}{f_2} = \frac{(v - v_s)}{(v + v_s)}$$

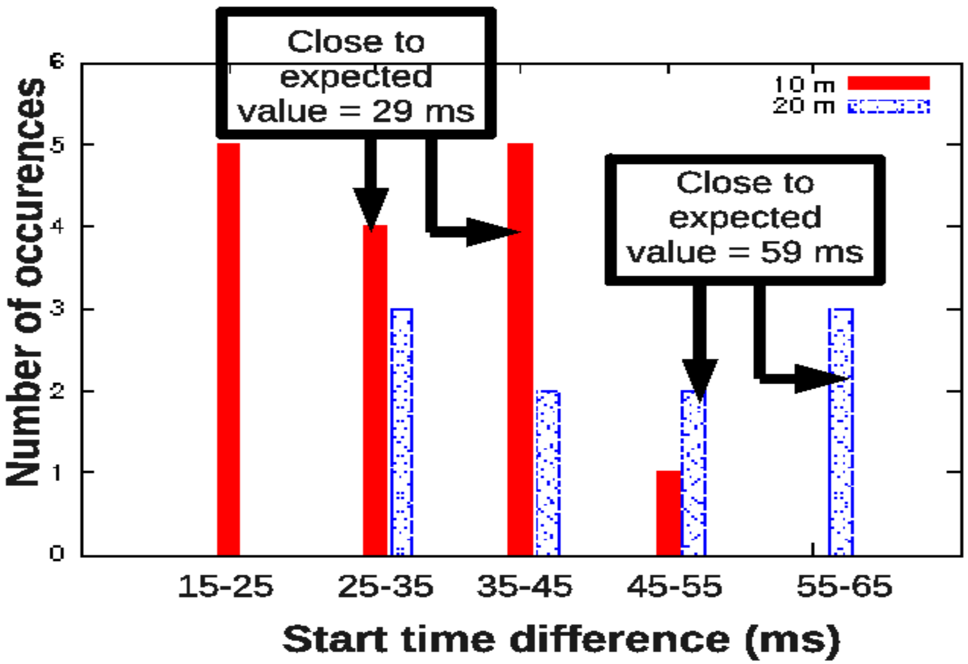


Experimental Setup

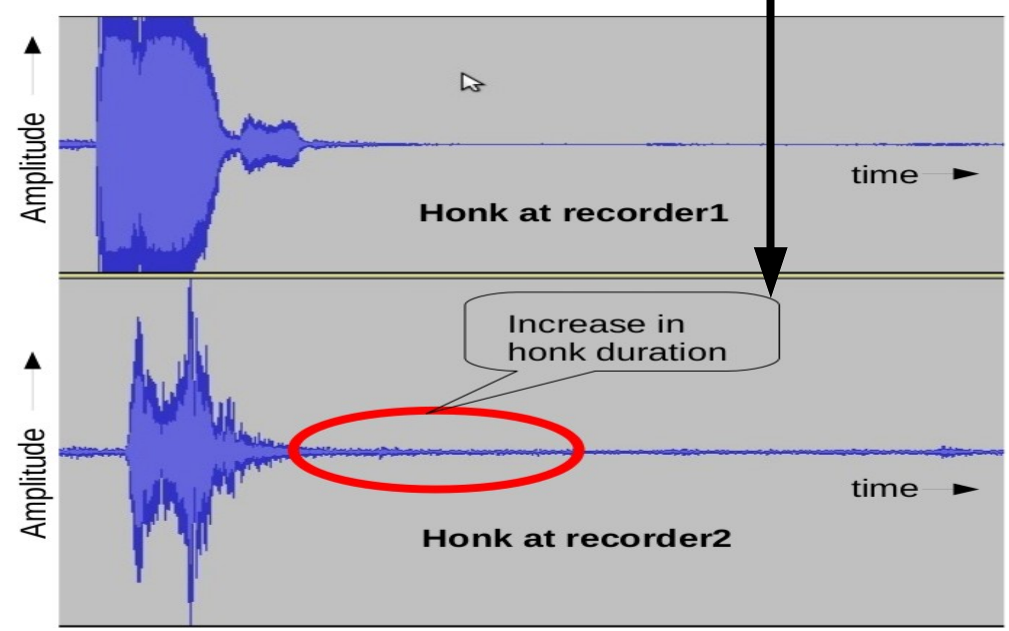
15 honks at 10m
10 honks at 20m

To be done:

- Analyze cause



Start time difference hould be 28-30 ms at 10 m and 57-59 ms at 20 m with sound speed 340-350 m/sec

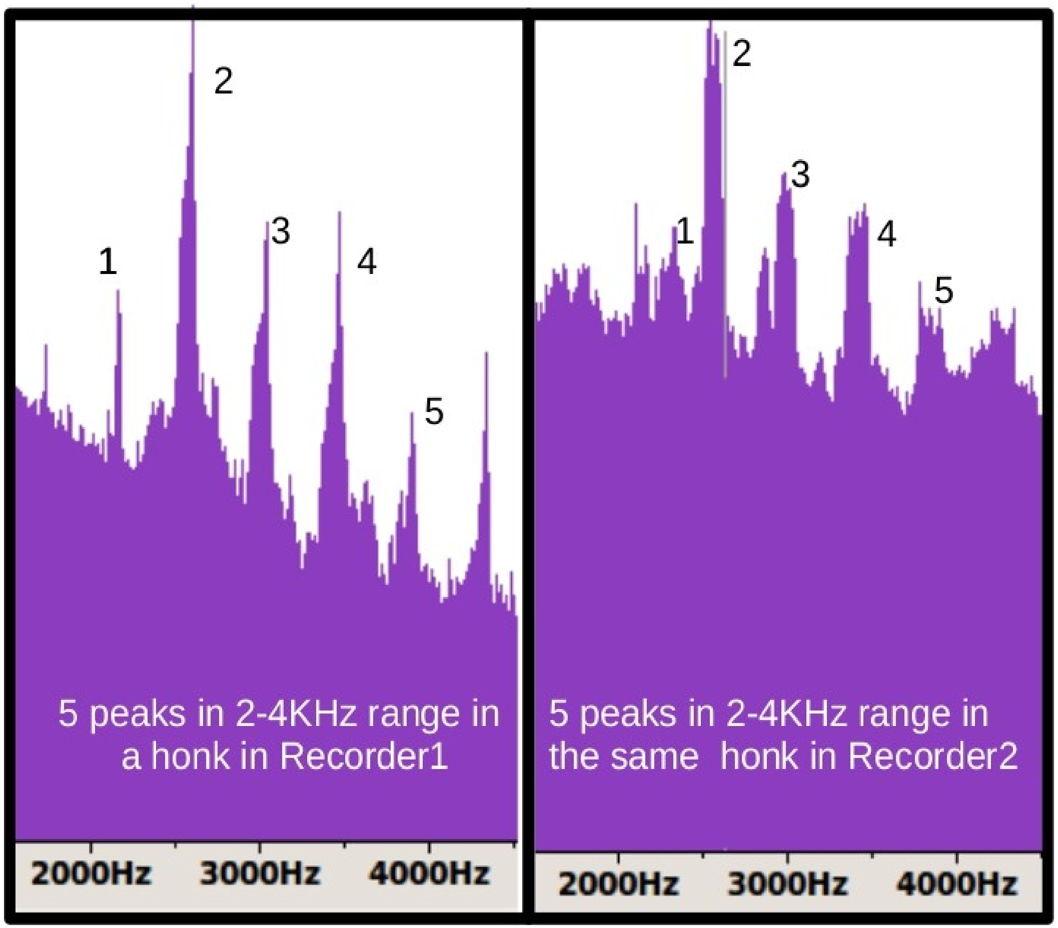


duration_ratio problem

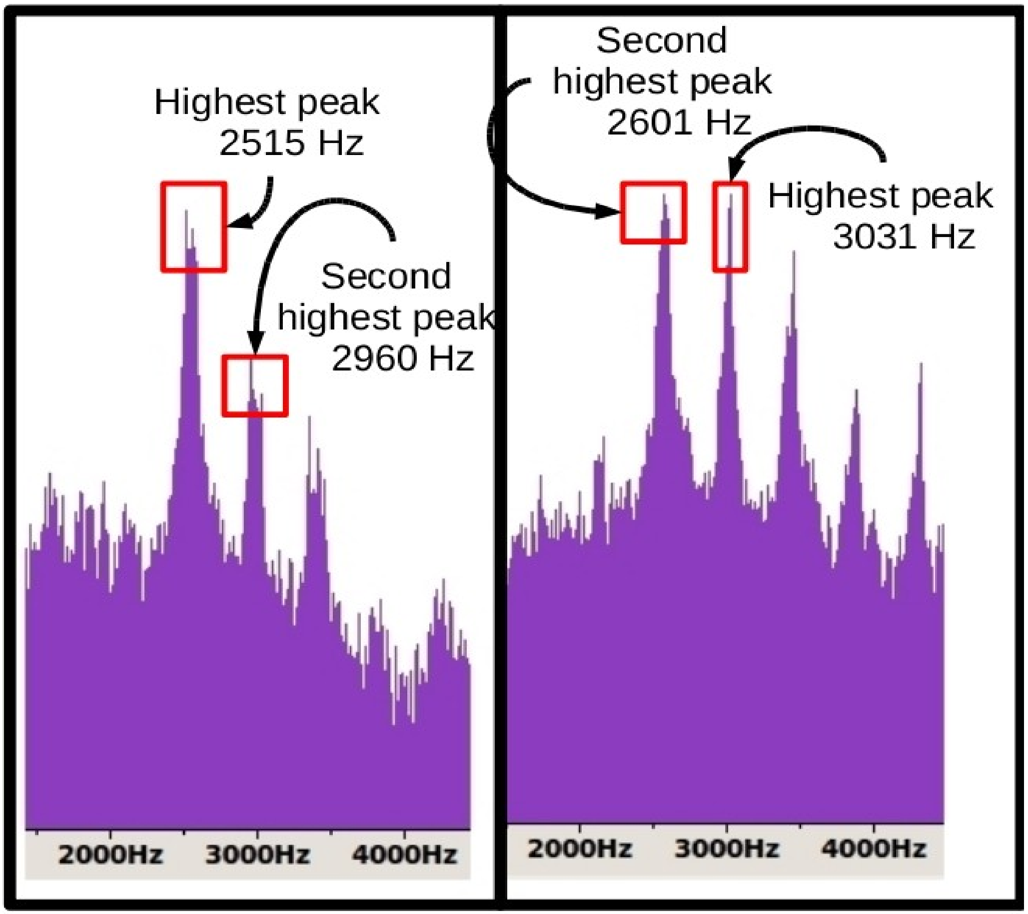
Duration ratio should be 1 for stationary bike, which is not so. So only starttime_difference is used for matching.

Frequency Extraction

2048 point FFT used (1024 point FFT for honks < 128 ms length)



Local maximas same after Doppler shift

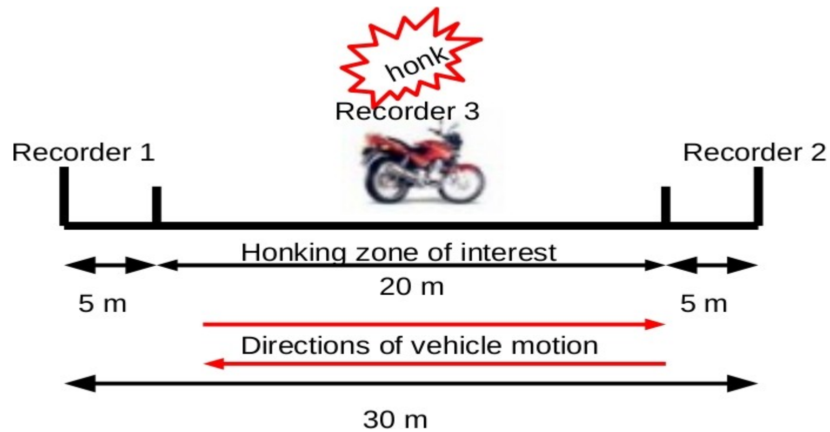


Exchange of top two local maximas

How accurate **are the speed estimates?**

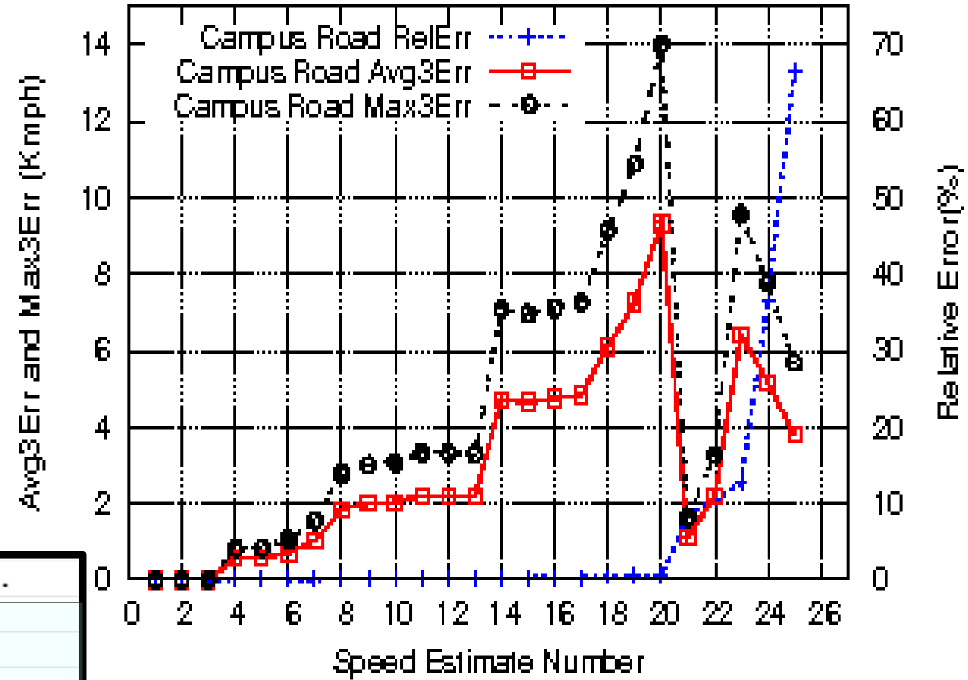
campus_speed_vary

Setup



type	v12	v13	v23	mean	s.d.
sta	0	0	0	0	0
sta	0	0	0	0	0
sta	0	0	0	0	0
sta	1.89	7.57	3.77	4.41	2.89
slow	11.2	14.79	7.53	11.17	3.63
slow	13	18.38	7.5	12.96	5.44
slow	14.88	18.38	11.3	14.85	3.54
slow	14.93	18.43	11.33	14.9	3.55
slow	16.82	18.43	15.16	16.8	1.64
med	20.55	19.03	22.03	20.53	1.5
med	20.56	22.05	19.01	20.54	1.52
med	20.56	19.01	18.93	19.5	0.92
med	22.39	22.81	21.99	22.4	0.41
med	22.39	22.81	21.99	22.4	0.41
med	23	15.62	25.19	21.27	5.01
med	23	25.08	26.27	24.78	1.65
med	24.22	22.81	25.58	24.2	1.38
med	25.5	26.04	24.98	25.51	0.53
med	25.5	20.83	29.98	25.44	4.57
high	27.99	20.83	20.23	23.02	4.32
high	27.99	20.83	34.83	27.88	7
high	30.73	29.98	31.52	30.74	0.77
high	33.36	34.97	31.66	33.33	1.66
high	33.36	31.66	34.97	33.33	1.66
high	33.36	29.98	36.93	33.42	3.48

Speeds in Kmph



Error Measures

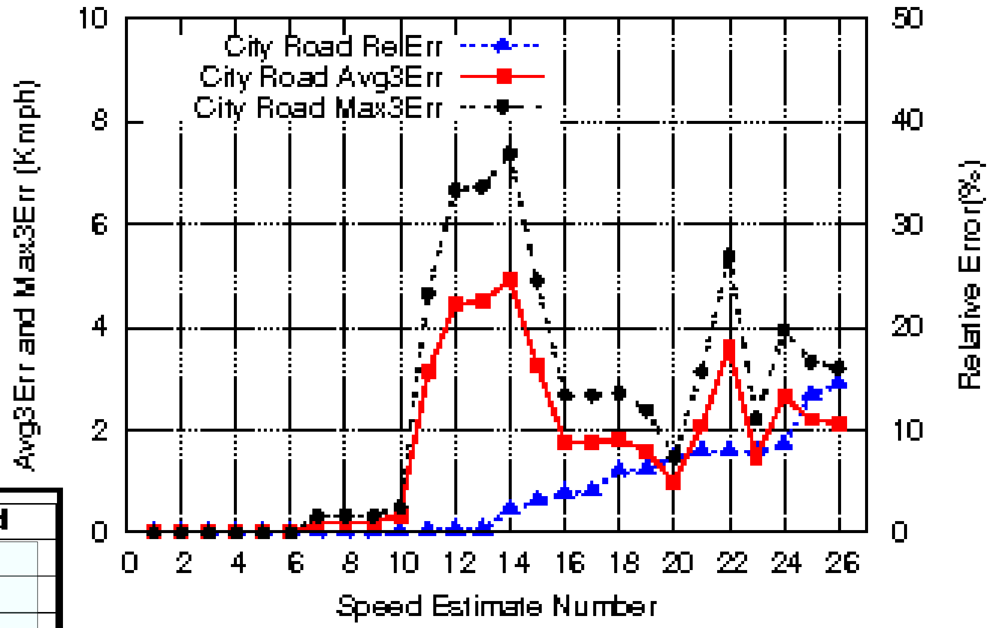
- 30 honks
- 25 matched across all three
- stddev(|v12|,|v13|,|v23|)
- max(|v12-v13|,|v12-v23|,|v13-v23|)
- avg(|v12-v13|,|v12-v23|,|v13-v23|)
- |v12|/(|v13|+|v23|)*100

road_speed_vary

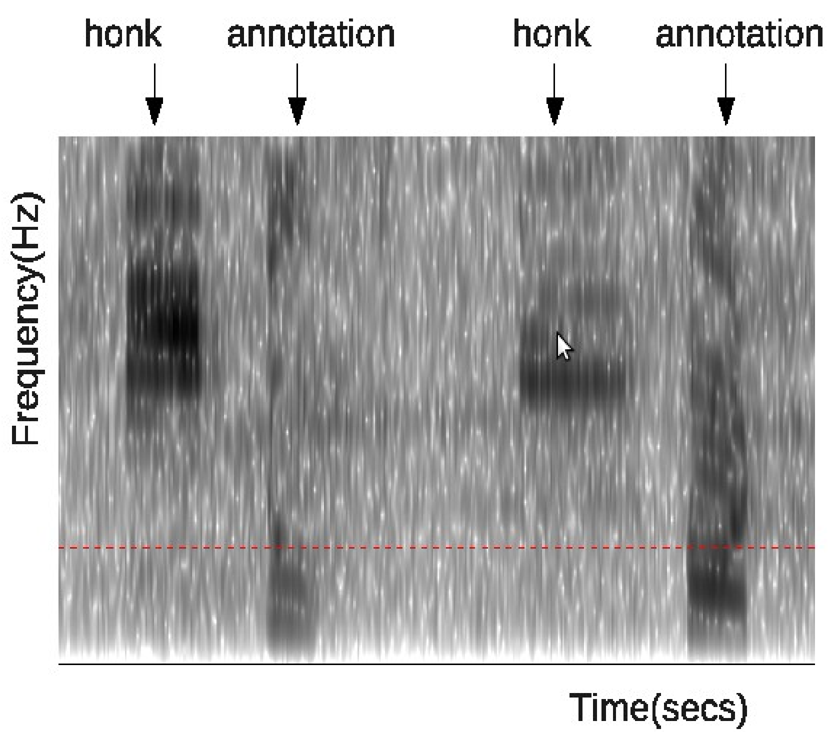
- 36 honks
- 4 lost due to annotation errors
- 26 matched across all three

type	v12	v13	v23	mean	s.d
sta	0.00	0.00	0.00	0	0
sta	0.00	0.00	0.00	0	0
sta	0.00	0.00	0.00	0	0
sta	0.00	0.00	0.00	0	0
sta	0.00	0.00	0.00	0	0
sta	0.00	0.00	0.00	0	0
sta	4.65	3.11	7.05	4.94	1.99
slow	9.50	8.75	11.46	9.9	1.4
slow	13.95	10.58	17.96	14.16	3.69
slow	13.95	10.58	17.24	13.92	3.33
slow	14.11	17.43	15.15	15.56	1.7
slow	14.11	17.44	10.71	14.08	3.37
slow	14.15	13.99	14.32	14.15	0.16
slow	14.15	13.99	14.32	14.15	0.16
slow	14.15	13.99	14.32	14.15	0.16
slow	15.30	12.39	17.29	14.99	2.46
med	17.49	17.24	17.74	17.49	0.25
med	19.10	17.63	17.95	18.23	0.77
med	21.04	18.93	17.84	19.27	1.63
med	22.00	24.27	21.60	22.62	1.44
med	22.00	24.20	21.54	22.58	1.43
med	22.96	20.75	21.80	21.84	1.11
med	24.60	24.14	21.47	23.4	1.69
high	26.42	24.14	28.80	26.45	2.33
high	26.42	27.51	28.80	27.57	1.19
high	29.00	34.19	28.80	30.66	3.06

Speeds in Kmph

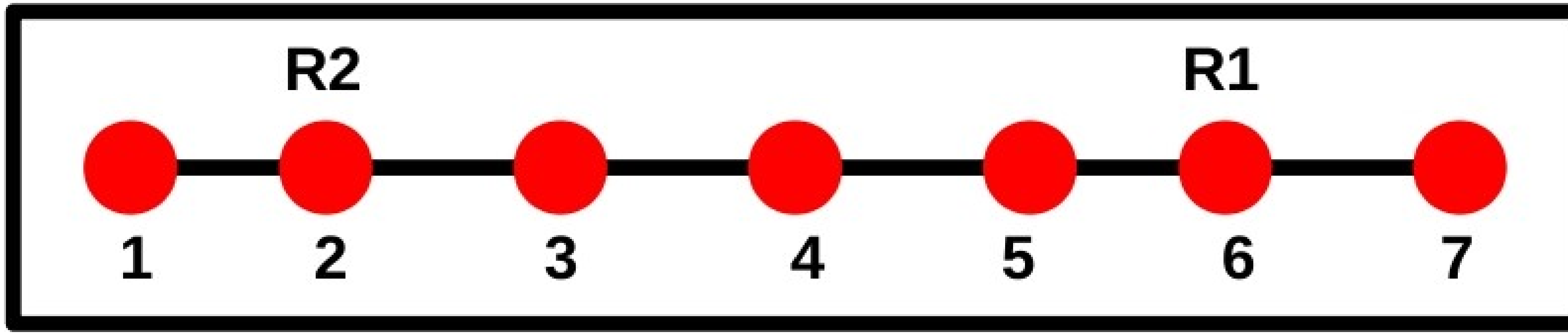


Error Measures

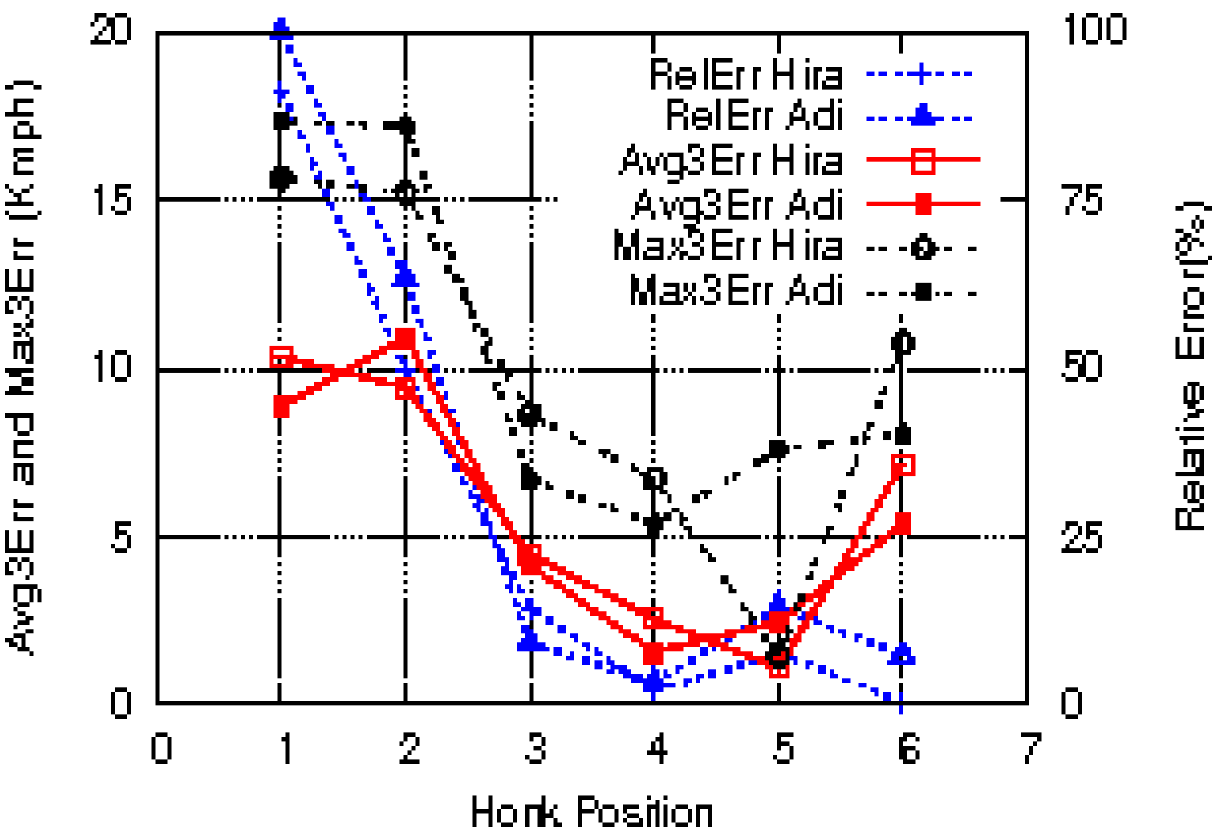


Annotations

road_position_vary



Honking positions



Error measures

✗ Wrong matches at 1 and 2

✔ R2 does not detect honks at 7

↓

Vehicle honks are *directional*

To be done:

- Improve matching algorithm
- Ascertain accurate speed ground truth

Can we apply these speed estimates on real city roads to detect congestion ?

Road Experiments

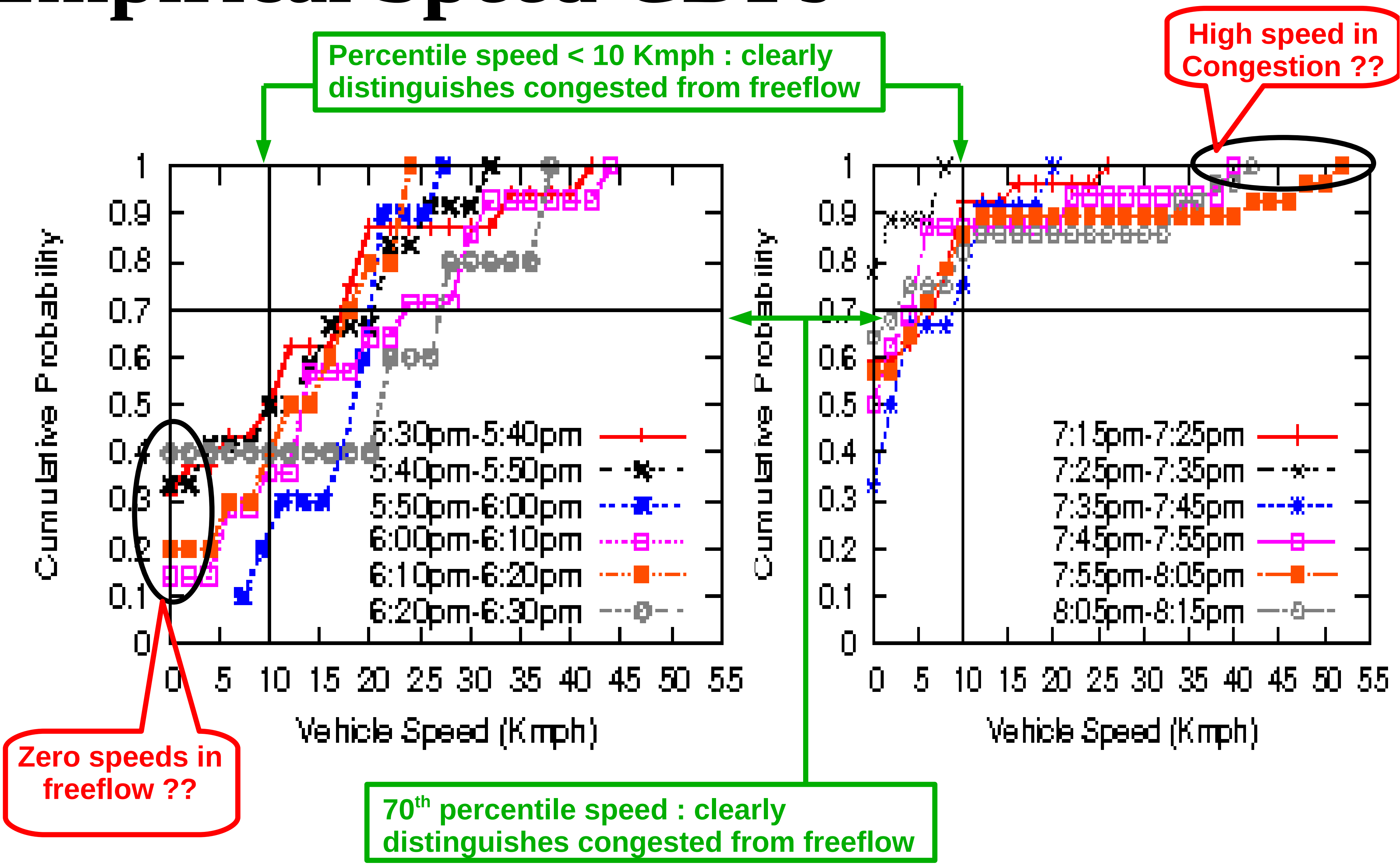
- 18 hours of road data collection
- 2 different roads
- Different times of the day
- Different weather conditions

4.30 pm : Freeflowing

7.30 pm : Highly Congested

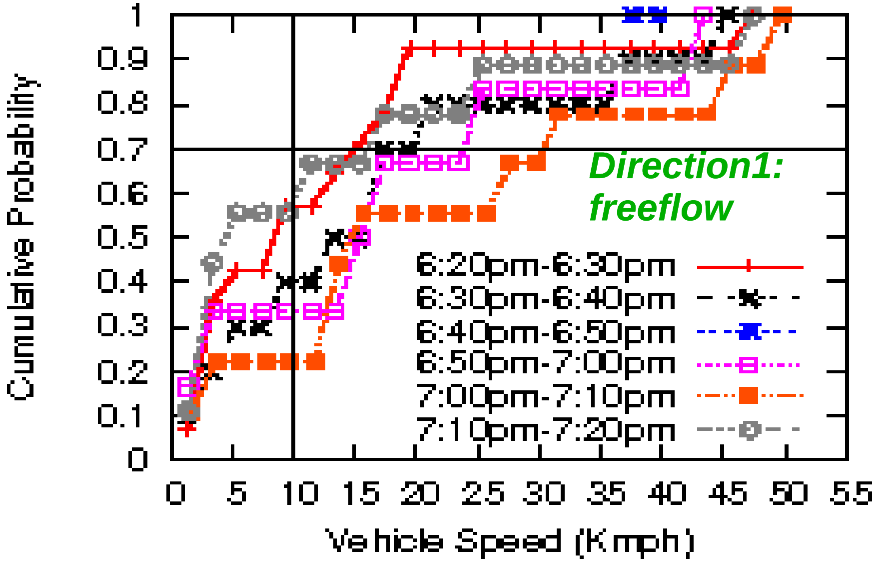
Adi Shankaracharya Marg (outside IITB, notorious for congestion)

Empirical Speed CDFs



Freeflowing Traffic **Congested Traffic**

Same Road : Opposite Directions



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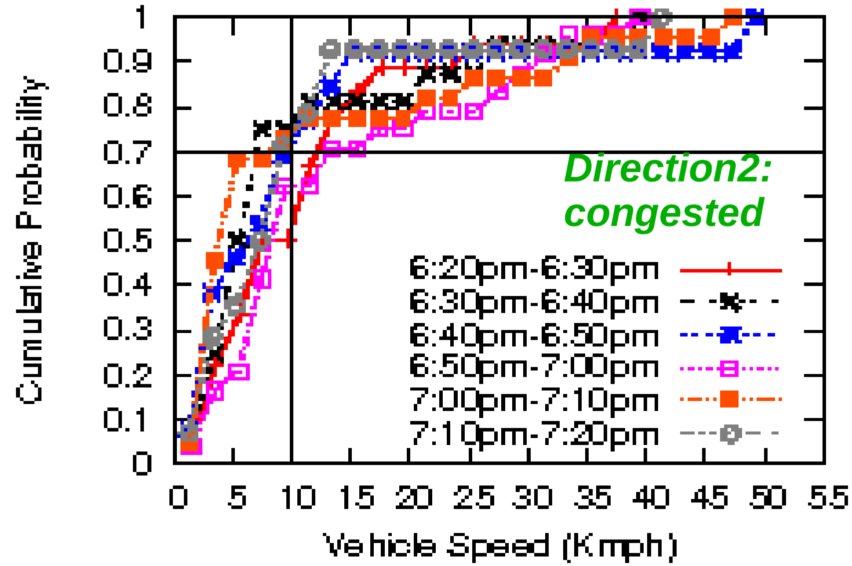
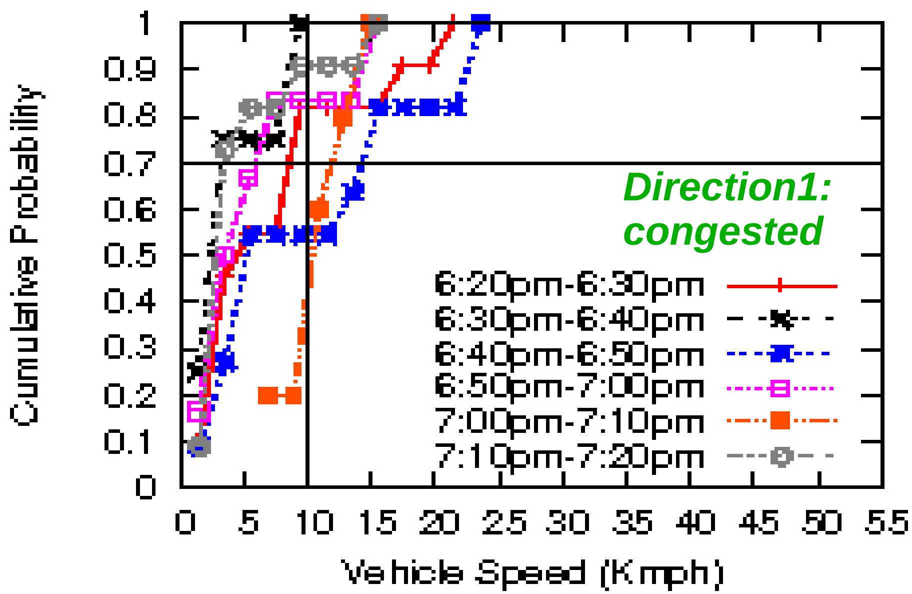


(1) Speed estimates give traffic direction (2) Show freeflow and congestion in opposite directions on a normal day (3) On a rainy day, both directions show congestion, as rain causes vehicles to be slower.



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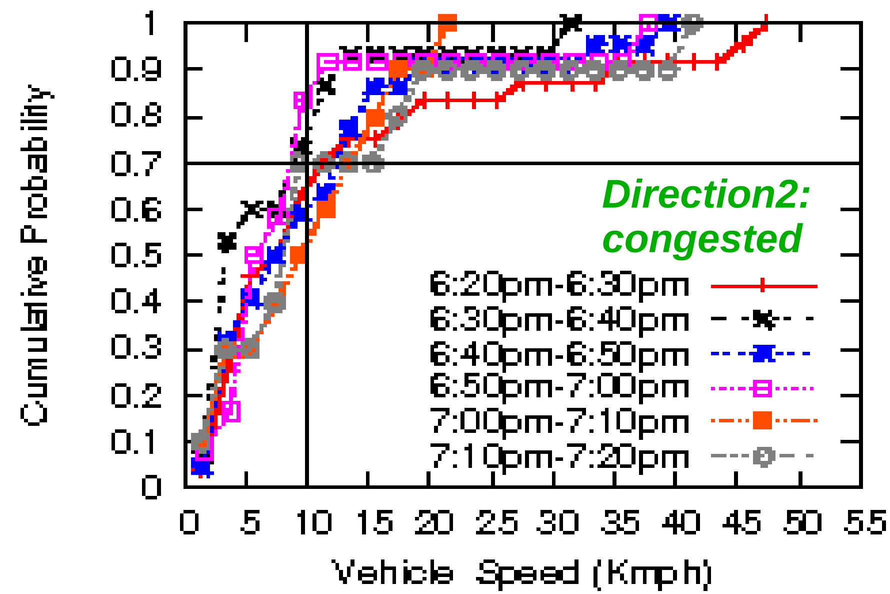


Congested *vs* Freeflowing : Metrics

70th Percentile Speed(Kmph)

direction sensitive

Percentile of Speed < 10 Kmph

	Hira		*Adi*	
Metric	Congested mean (s.d) [24 samples]	Free-flow mean (s.d) [54 samples]	Congested mean (s.d) [27 samples]	Free-flow mean (s.d) [27 samples]
70th perc. speed (kmph)	12.2 (4.0)	18.2 (6.2)	7.7 (6.1)	21.1 (6.1)
Perc. speed < 10Kmph	65.6 (11.6)	51.1 (16.3)	79.5 (16.1)	37.6 (20.2)

Speed based metrics

Number of honks

direction insensitive

Duration of honks (secs) in 10 mins

	Hira		*Adi*	
Metric	Congested mean (s.d) [24 samples]	Free-flow mean (s.d) [30 samples]	Congested mean (s.d) [27 samples]	Free-flow mean (s.d) [27 samples]
Num. Honks	113 (30.4)	55.5 (21.1)	149.4 (27.8)	57.6 (21.2)
Honk duration (sec)	45.1 (12.4)	21.8 (9)	71.5 (21.4)	21.7 (9.2)

Non speed based metrics

Noise level (db) can be used in *Hira* but not in *Adi*

Statistical divergence tests

	Mann-Whitney U test		Kolmogorov-Smirnov test	
Metric	*Hira*	*Adi*	*Hira*	*Adi*
70[th] perc. Speed	2.00E-006	7.48E-007	6.16E-005	4.48E-004
Perc. Speed < 10 Kmph	1.05E-005	2.28E-004	3.57E-006	5.95E-004
Num. Honks	5.33E-015	2.13E-014	3.30E-014	5.36E-019
Honk duration	3.86E-014	3.89E-014	6.19E-014	6.53E-017

p-values

Noise(db) has p-value of 0.0131 in MWU test in *Adi*

Statistical divergence of congested vs freeflowing data, based on all four metrics, is verified at 99.9% confidence using the Mann-Whitney U and two sample Kolmogorov-Smirnov tests.

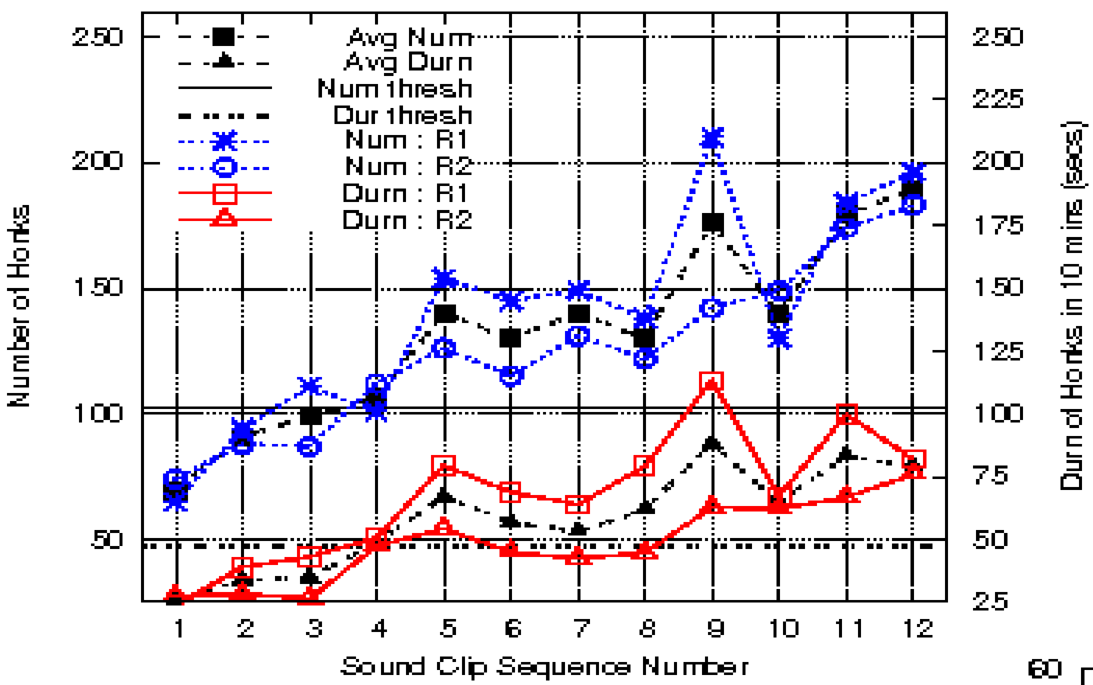
Threshold based congestion detection

	Hira		*Adi*	
Metric	Fp (%)	Fn (%)	Fp (%)	Fn (%)
70th perc. Speed	24.1	8.3	12.1	5.6
Perc. Speed < 10Kmph	20.9	25.3	27.2	18.3
Num. Honks	10.7	17.4	0.0	5.9
Honk duration	7.1	19.6	0.0	5.9

Noise(db) has 74.3% fp and 65.6% fn in *Adi*

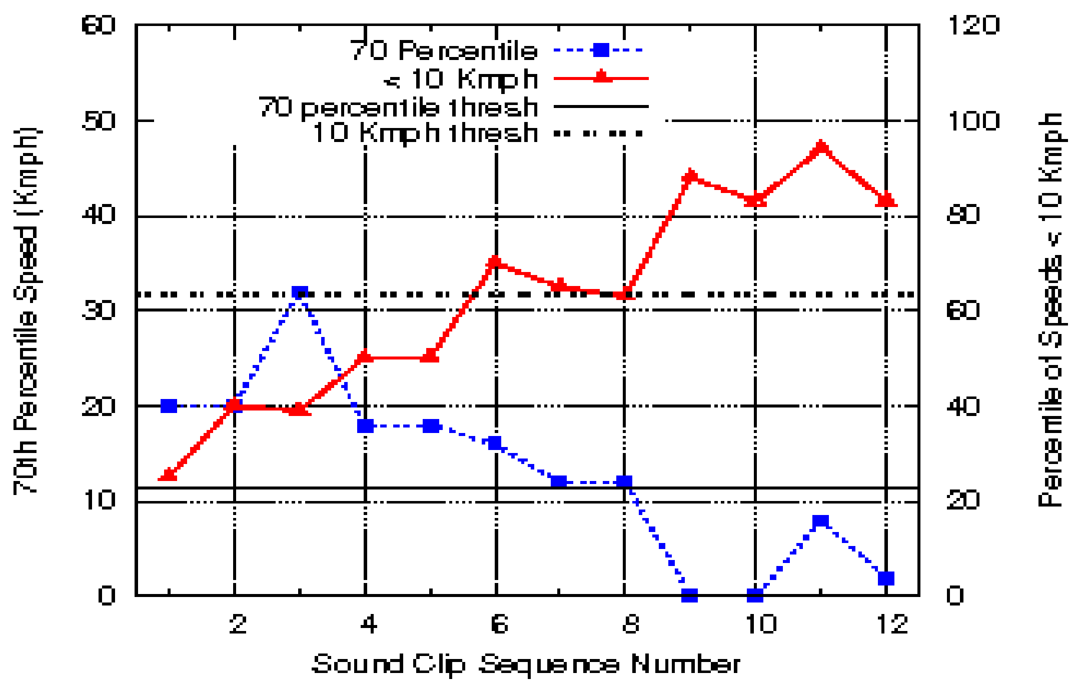
Maximum false positive is 27.2% and maximum false negative is 25.3%

Freeflow To Congested : Transition



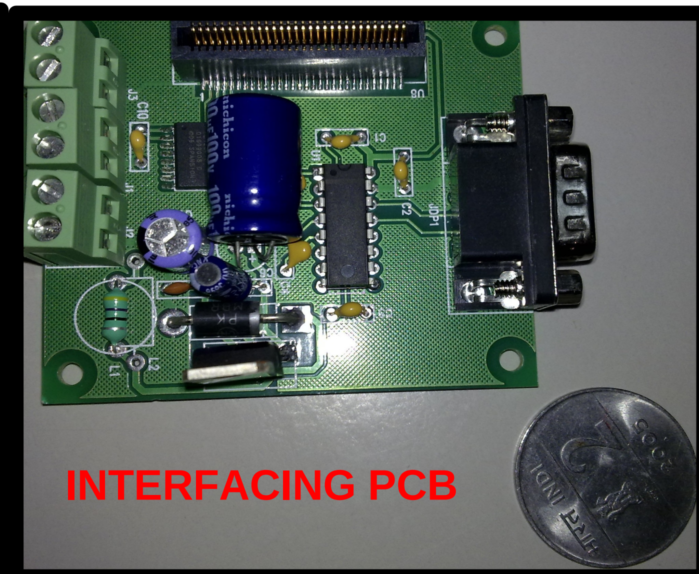
Continuous recording of road sound from 6 pm – 8 pm on 4th December, 2009, in Adi Shankaracharya Marg, showed transtion from freeflow to congestion, based on all four metrics.

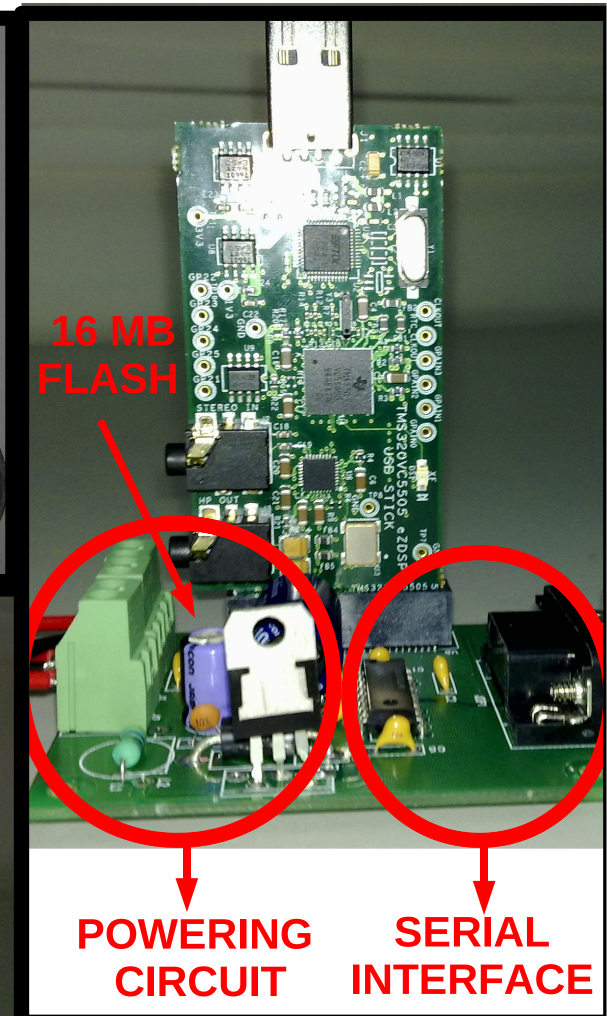
- Directionality of honks, road fork
- Non-speed based metrics show earlier rise than speed based
- Metrics to be used in conjunction (clip 10)

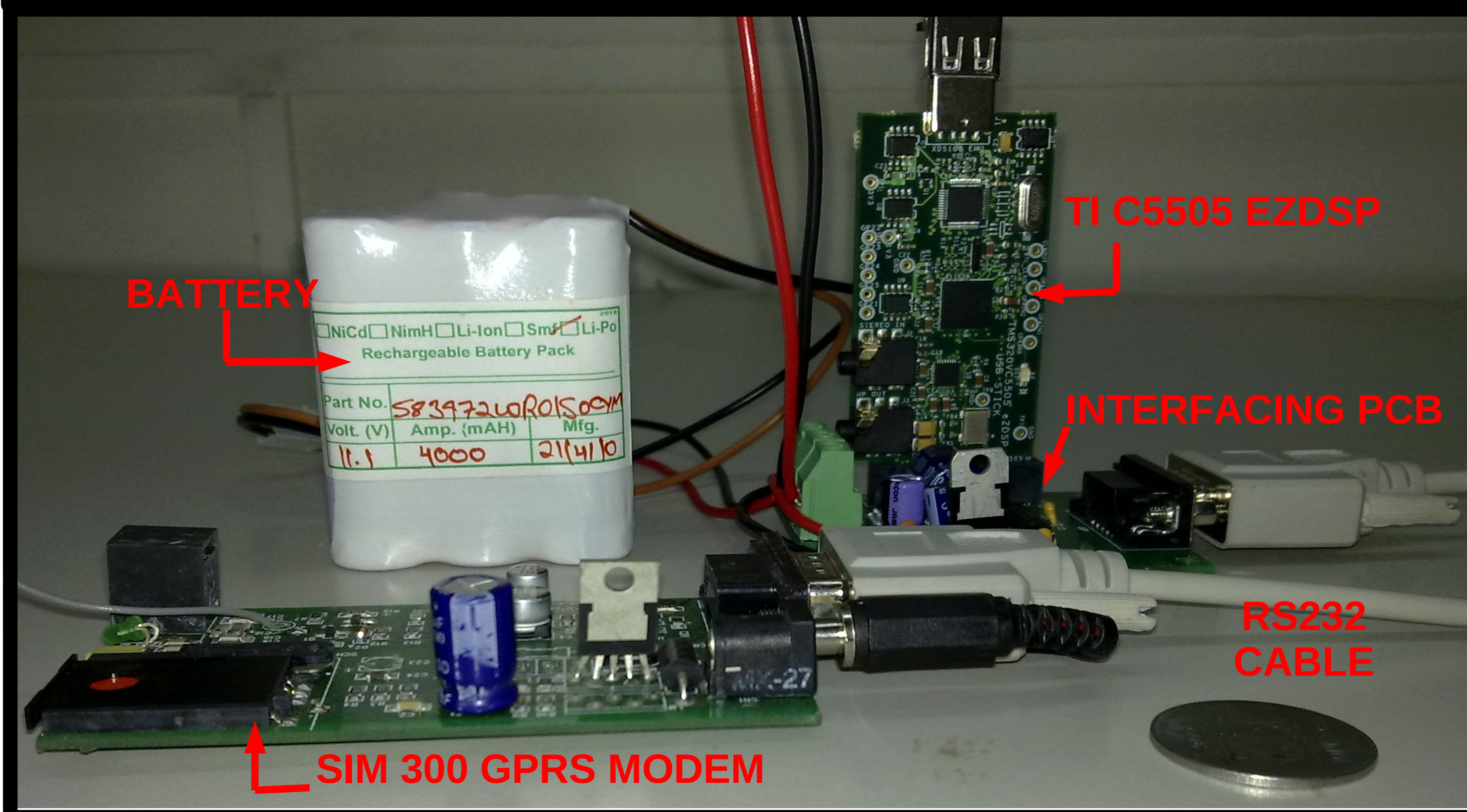


Ongoing Work

Sensor Platform Design







- C5505 EZDSP will sample and process road noise
- Results will temporarily be stored in flash memory
- Stored results will be sent to server over GPRS

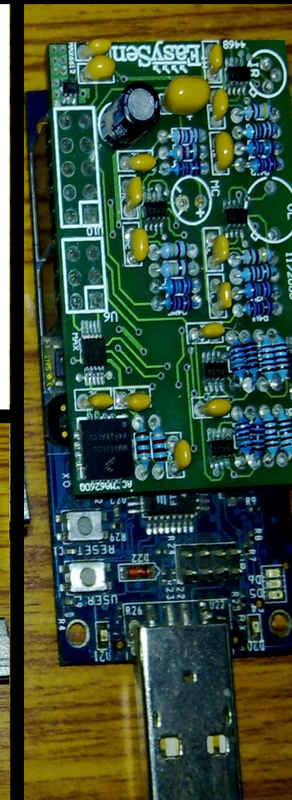
Enhancements

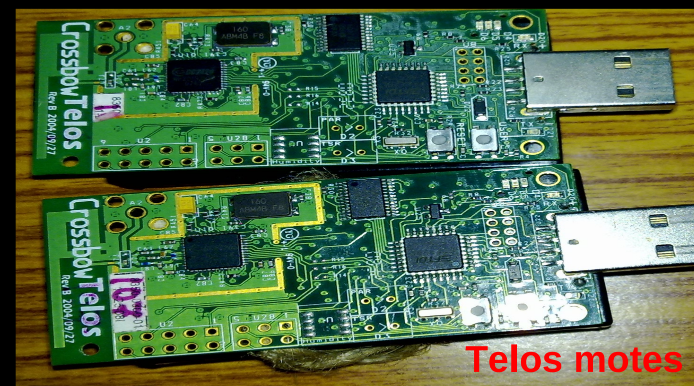
① Reducing hardware

- Mic + FM receiver with C5505 stick (bottom) instead of first phone.
- Mic + FM transmitter (left) at 30 m instead of second phone

② Beyond acoustic sensor

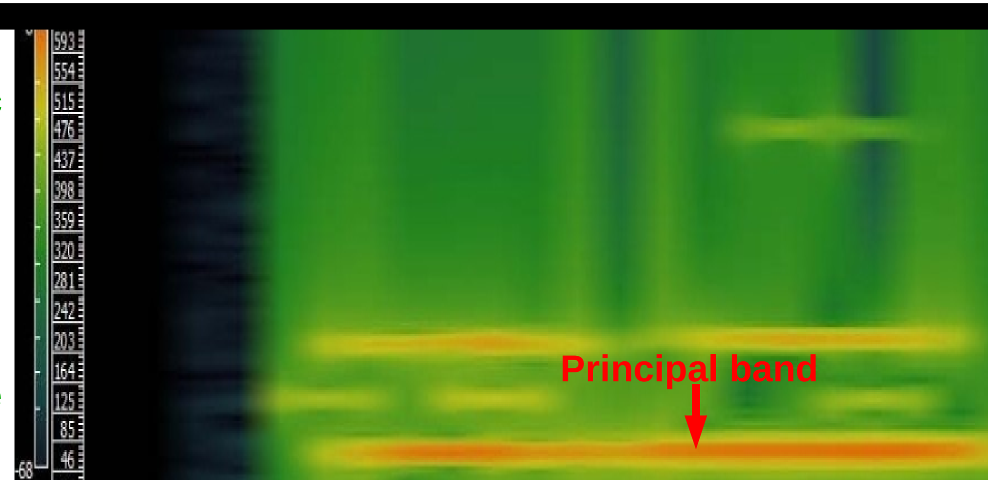
- Using RSSI and LQI variation, packet error rates between Zigbee tx-rx pair (bottom) across road as metrics to measure congestion
- Using magnetic sensor module SBT80 from Honeywell (right)





③ Beyond honks

- Using characteristic road sounds other than honks
- Auto engine (left) and heavy vehicle sound (right)



Thank You

Questions??