Analysis of Self-Measured EV Data and Driver Specific Range Prediction

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Motivation

Electric vehicle owners often experience 'range anxiety' due to the lack of reliability in range estimation inside vehicles. Though battery state of charge is something that is easily monitored, what causes problems is the in-situ range estimation which is affected by many factors such as weather, traffic, route, driver tendencies, as well as battery parameters.

A vast amount of studies have looked into various parts of range estimation from mimicking driver decision processes via a Markov Decision Process[1], to using large historical data sets that take into account traffic, weather, and battery patterns[2]. However, all of these method are used in the hopes of creating a one-size-fits-all model and overlooks the fact that each driver is unique and thus requires a user specific model that varies from driver to driver.

Thus this project sets out to be able to easily create a method to predict energy consumption and thus range at the individual drive, and personal level.

Methodology

Experimental Set Up

• Experimentally determined data using a 2015 Fiat 500e

• GoPro Hero3
- 1 second photos in time lapse mode
- Instantaneous Power and Speed

• GPS
- GPS Kit on iPhone 4
- Real time data: Longitude, latitude, speed, altitude, course, slope, distance between points, total distance

Procedure

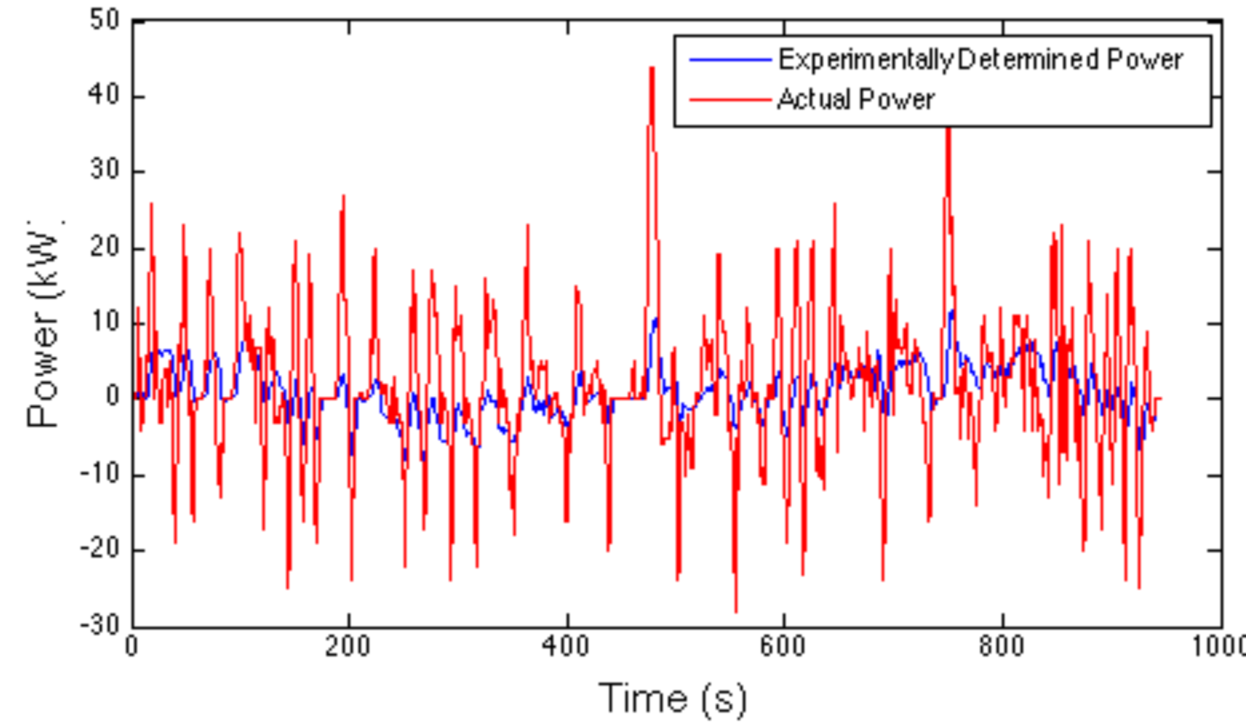
•Trip began by starting both measuring apparatuses at the same time.
•Total of 12 trips were done:
- 6 San Francisco
- 4 San Francisco
- 2 Sanford, Palo Alto

• MATLAB Optimal Character Recognition code on photos produced csv files containing power (kW) and speed (mph) for every second

•GPS data saved as a GPX and KMZ file and then made into a csv file

Analysis and Predictive Modeling

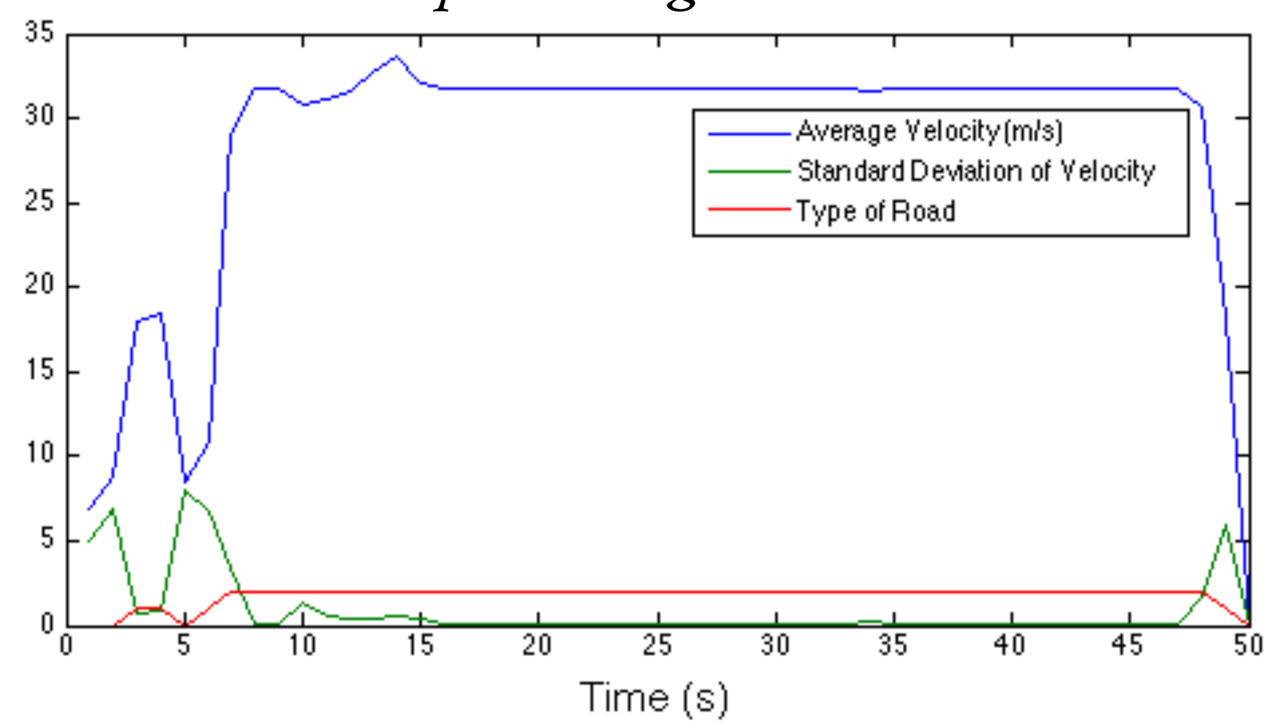
Verification of Experimental Data



• Experimentally determined power calculated using forces acting on car:
- Aerodynamic Drag
- Mechanical Drag
- Rolling Resistance

• Experimentally determined power found to vary from the actual power, however overall trends are the same.

Speed Categorization



• In order to predict energy consumption for a future trip, energy needs to be calculated without knowing velocity
• Categorized 1 km distances of any trip into one of three categories by observing the average velocity and standard deviation of velocity over 1 km for every trip:
- City Driving (speed < 10 m/s)
- City-Highway Hybrid Driving (speed < 25 m/s)
- Highway Driving (speed > 25 m/s)

Future Work

• In-depth analysis of temperature effects on range
• Look into weather effects (rain, wind)
• Easy to measure individually, expand to different electric vehicles

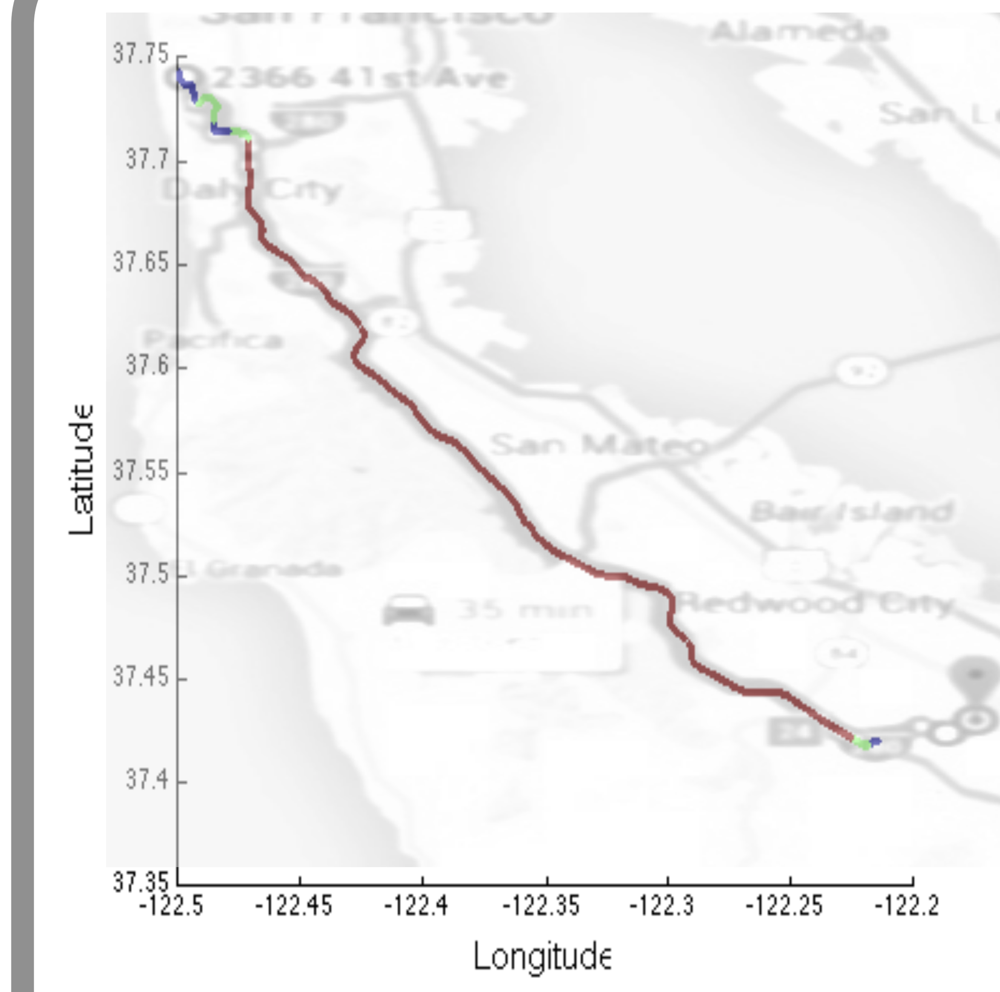
Acknowledgements

Patrick's Fiat 500e

References

1. P. Ondruska, "The Route Not Taken: Driver Centric Estimates of Electric Vehicle Range" 2014
2. R. Habiballah "Big Data Framework for Electric Vehicle Range Estimation" 2014

Results

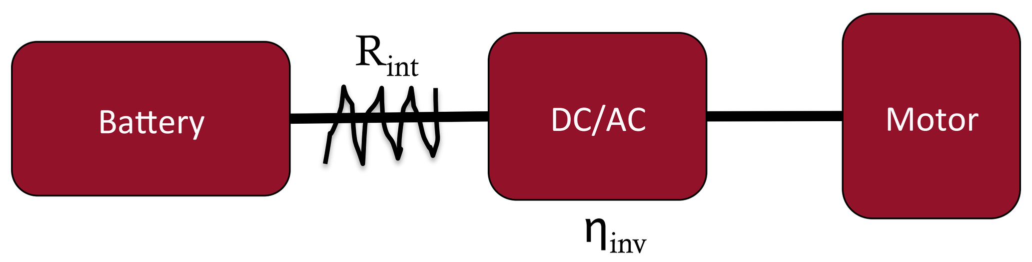


• Applied the speed categories, K_i, to all points for all trips to give energy consumption in terms of kWh/km at each point
- City Driving – Blue ($K_i = 0$)
- City-Highway Hybrid Driving – Green ($K_i = 1$)
- Highway Driving – Red ($K_i = 2$)

• Energy consumption now calculated using only distance and K_i and is thus independent of exact velocity values.

• The discrepancy between actual battery consumption and energy calculated with power from dashboard is due to reading power at the motor level and not at the battery

Battery and Inverter Model



• Obtain real power consumption by taking into account internal resistance, R_{int}, and inverter efficiency, η_{inv}*

• Optimization of R_{int} and η_{inv}:

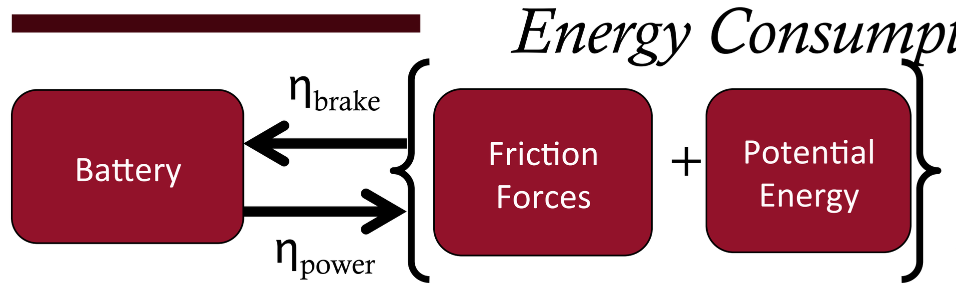
$$P_{batt} = \begin{cases} \eta_{inv} P_{measured} - R_{int}\left(\frac{P_{batt}}{V_{batt}}\right)^2, & if\ \ P_{measured} < 0 \\ \frac{P_{measured}}{\eta_{inv}} + R_{int}\left(\frac{P_{batt}}{V_{batt}}\right)^2, & if\ \ P_{measured} > 0 \end{cases}$$

• $R_{int} = 0.283\ \Omega$, $\eta_{inv} = 77.9\%$

* η_{inv} would include all upstream loss not from R_{int} (including parasitic)

Actual Battery Consumption (kWh)	Calculated Power from Dashboard (kWh)	Power Using Optimized Coefficients (kWh)
10.80	7.57	10.73
0.96	0.73	1.11
1.44	0.78	1.35
0.72	0.34	0.63
0.48	0.24	0.81
10.80	7.56	10.65
0.96	0.58	1.11
0.24	0.22	0.34
12.00	8.10	11.84
10.80	8.61	12.73
10.80	7.25	10.38
8.40	3.80	5.91

Energy Consumption Prediction Model



• Model energy consumption during a trip by minimizing the difference in power calculated experimentally and actual power: $\min\{E - E'\}$

where, $E' = (f_i \cdot d + mg\Delta h) \cdot \begin{cases} \eta_{power}, & if\ \ (f_i \cdot d + mg\Delta h) > 0 \\ \eta_{brake}, & if\ \ (f_i \cdot d + mg\Delta h) < 0 \end{cases}$

$$f_i = \begin{cases} f_0, & if\ K_i = 0 \\ f_1, & if\ K_i = 1 \\ f_2, & if\ K_i = 2 \end{cases}$$

d is the distance between point
mg Δ h is the potential energy due to the change in altitude, f in kWh/km.