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Trajectory Reconstruction of Bicycle Dynamics

ENGR 3199A
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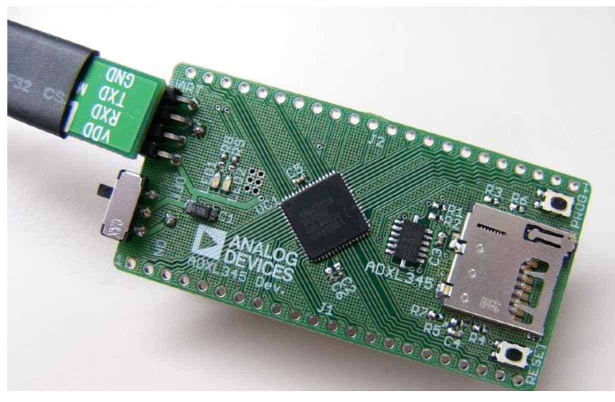
Goal:

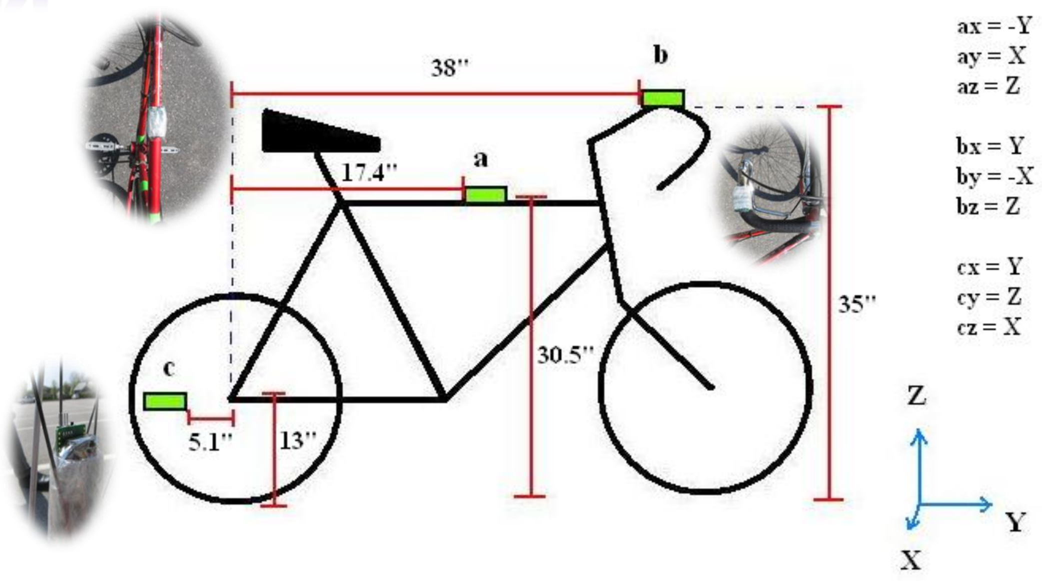
1. Use data loggers equipped with accelerometers to capture acceleration of a bicycle traversing a fixed path
2. Extract useful information from the data like velocity and position of the bicycle.

DATA COLLECTION

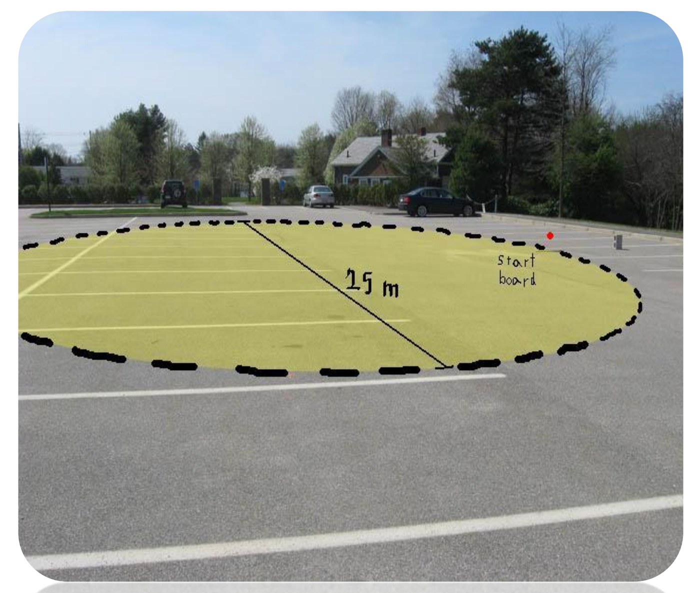
ADXL345 Inertial Sensor Datalogger was used as a sensor platform.



A standard bicycle was instrumented with two dataloggers at a time in 2 tests



20 laps were carried out around a 25m diameter circle in a parking lot



A wooden plank was used to demark the beginning of laps

DATA PROCESSING

Preprocessing:

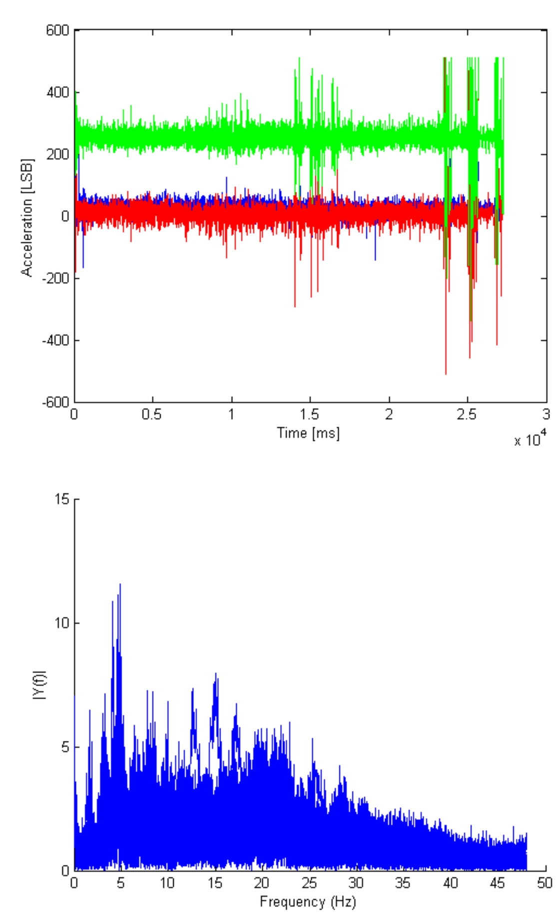
Threshold to identify the beginning of laps → Filter to remove points that are too close together → Slice complete dataset into separate sets for different laps.

Signal Identification:

First four laps of different accelerometers superimposed and analyzed to find artifacts

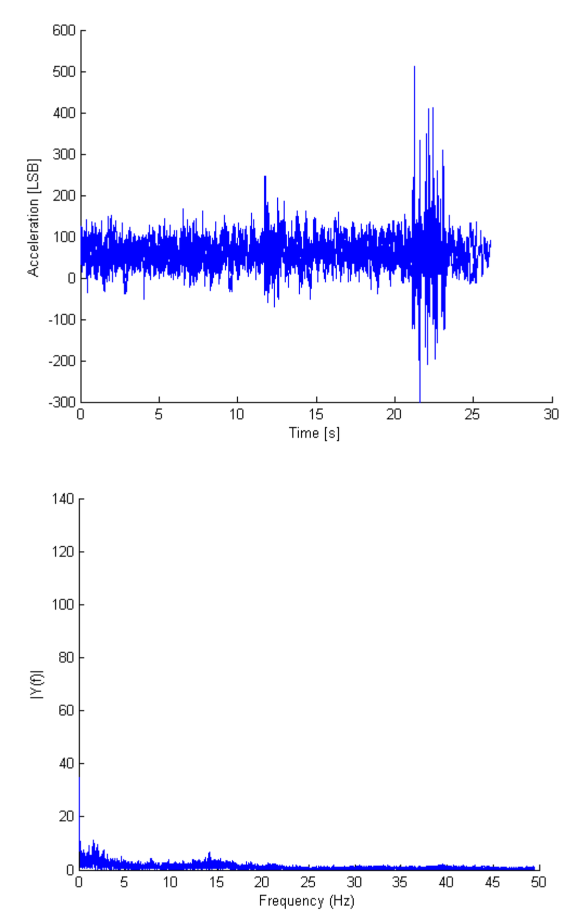
Since only the acceleration data from the top tube has any significant information, the normal acceleration from the top tube will be used to reconstruct the bicycle's trajectory in 1D.

Top Tube



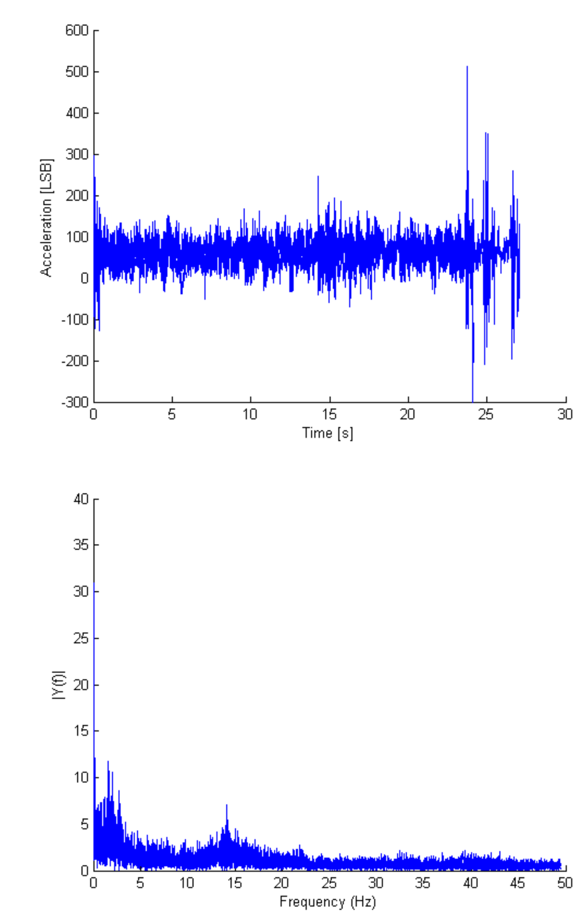
Data from ax (blue), ay (red) and az(green) makes sense based on orientation of the datalogger. Spectrum of ay (normal acceleration) shows a broad range of frequencies, corresponding to a smoothly varying input.

Handlebars



Nothing distinctive in time or frequency domain

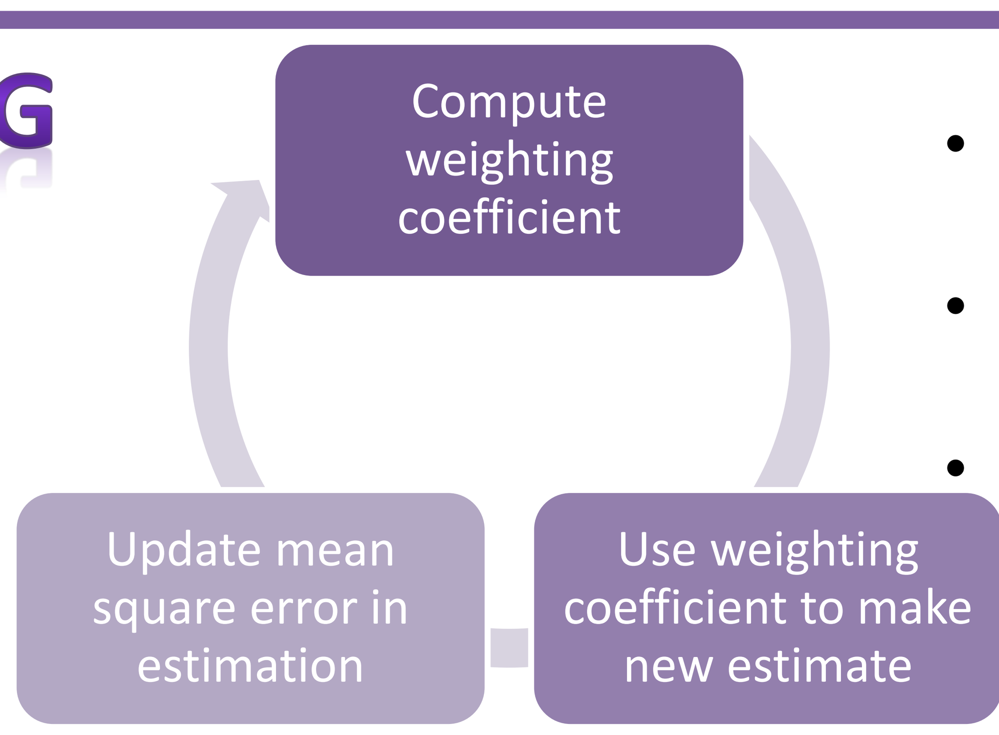
Wheel



Slight peak in spectrum around 1-4 Hz, corresponding to wheel rotation. Surprising peak around 18Hz.

KALMAN FILTERING

- The Statistically Best Filter
- Iterative Filter
- Requires Occasional Zeroing
- Useful for State Space Model



- New calculated position:
  - $\hat{x}_n = (A\hat{x}_{n-1} + B_n u) + K_n(y_{n-1} - C\hat{x}_{n-1})$
- Kalman gain:
  - $K_n = AP_nC^T(CP_nC^T + S_Z)^{-1}$
- Covariance matrix:
  - $P_n = AP_{n-1}A^T + S_W - AP_nC^T{S_Z}^{-1}CP_{n-1}A^T$

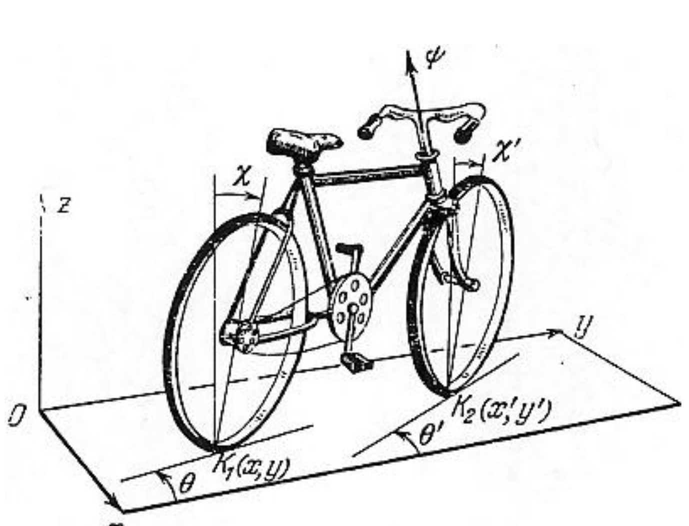
Statistically Best Filter

$$b = \frac{M\sigma_x^2}{M^2\sigma_x^2 + \sigma_\epsilon^2}$$

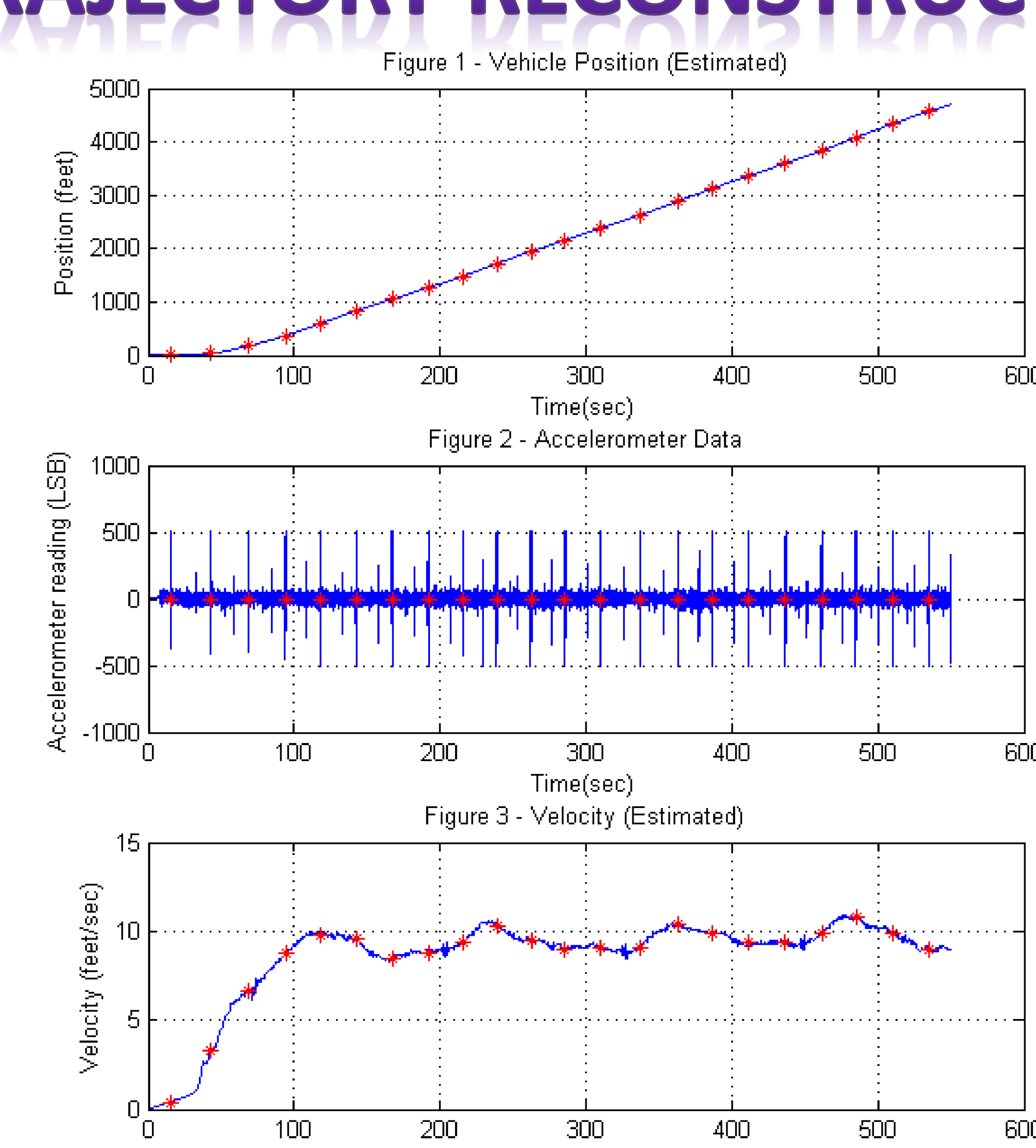
The Kalman filter calculates how strongly it should trust a measurement. By knowing the variance of the measurement and the estimate, the Kalman filter weights the past estimate and the data from the sensor to obtain the best estimate possible. Measurements become more accurate with more measurements

State Space Models

- Represents states and forces on system in Matrix Form
- State Space Equation
  - $X_n = Ax_{n-1} + Bu_{n-1} + wk_{xn}$
  - describes system orientation position and velocity
- Output Function
  - $Y_n = Cx_n + z_n$ yn parameters of state desired to know



TRAJECTORY RECONSTRUCTION



The red dots indicate beginning of laps. The distance between them is precise within 3ft, without any long term drift.

GOING FORWARD

- Recreate 2D trajectories with assistance of gyroscopes
- Integrate data from multiple sensors in order to reduce error

Acknowledgements
We could not have completed this without the assistance of:
- Prof Kent Lundberg
- Josh McCready