I Know How You Drive!
Driving Profiling via smartphone

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Literature study and Motivation
Auto insurance and UBI products

- Auto insurance is the essential line of business in Property-Casualty (P&C) insurance industry.
  - In 2017, the total volume of the automobile insurance industry was about $267 billion (about 42% of the U.S. P&C industry).

- Usage based Insurance (UBI) first appear in 2004 by Progressive insurance company.
  - Pay As You Drive (PAYD): the driving habits - the average driven distance per year, typical times of day for driving
  - Pay How You Drive (PHYD): the driving style of the driver - hard braking or accelerating, taking steep turns, changing lanes.
Pay How You Drive

- Nikulin (2016) constructs a driving profile using average speed, average acceleration and deceleration, and average turning speeds.
- Weidner et al. (2017, 2016) uses pattern recognition methods and Fourier analysis for constructing a driving profile.
- Wüthrich (2017) suggests using v-a heatmap as a new type of driving profile.
- Gao et al. (2019a,b) examines the predictive power of v-a heatmap in claim frequency models.
What is our research motivation?

“Similar graphs could be provided for left- and right-turns (using the changes in angles obtained from the GPS data).”

- Wuthrich (2017)

- Literature hasn’t paid attention to the LATERAL acceleration much.
- GPS data is popular in the literature, but it is NOT suitable for the analysis of the lateral movement of vehicle.
- Acceleration data used in the literature including actuarial science has NOT been calibrated for driving profile construction.
Research in other fields use other types of data beside GPS data

- Recognize driving events such as turns, swerving, and braking using IMU data format (Johnson & Trivedi, 2011)
- Aljaafreh et al. (2012) clusters the driving style into categories using accelerometer.

The accelerometer is also popular, and it is one of the inertial measurement units (IMUs) of smartphones.
Smart phone sensors and Data recording
Global Positioning System

GPS sensor receives the information about the sensor position from multiple satellites.

- Latitude, longitude, altitude, speed, and sensor heading
- GPS position error: approx. 4.9 m (16 ft.) under open sky

In urban areas accuracy falters due to blocking & reflection; buildings, bridges, and trees
Below is a toy model of the accelerometer

The accelerometer records the force that applied to the wall of the box in the figure.

- At rest on a flat, horizontal surface it measures: \( g \approx 9.81 \text{ m/s}^2 \).
- In free fall, it measures zero.

(a) A box model for understanding accelerometer

(b) The three directions of accelerometer
A gyroscope is a device used for measuring angular velocity.

- Three measurements come from each axis of gyroscope: Roll, Pitch, and Yaw
- Absolute orientation of smartphone can be calculated from gyroscope by integrating the angular velocity

(a) The interpretation of roll, pitch, and yaw
(b) The three directions of gyroscope
Data recording

IMU data are generated by a smartphone attached to a vehicle as follows;

- Sampling rate: 25 Hz (25 data points per 1 sec.)
- Device: iPhone 6
- Data recording app: Sensor play

(a) Device installation in the vehicle

(b) Three axes of sensors that the vehicle shares with the installed smartphone
Sample test route

The sample route for the calibration consisted of complicated road components

- Flat road, uphill incline, downhill decline, and turns

Figure: Sample route for the calibration
Data recording result and calibration
Accelerometer data

The below is the sample plot of accelerometer values for the first 50 seconds of sample route.

- From the longitudinal accelerometer data, the vehicle speed can be estimated by using the following integration formula:

\[ \text{speed}_t = \text{speed}_{t-1} + \Delta t \times \text{acc}_t \]
There is a difference between the estimated speed from the accelerometer values and vehicle speed.

- **Uphill (25 sec.)** and **downhill (125 sec.)**, stopped at the tilted road (50 sec.)
Road grade effect

The integration method does not work, because of the road grade effect.

- Accelerometer measures the acceleration applied to the sensor body, which includes the gravity force accused by the road grade $\alpha$.

$$a_t = acc_t - g \times \sin(\alpha_t)$$

(a) $acc_y = a_y + g \sin(\alpha)$

(b) Green line is the approximation of ground truth acceleration from OBD using spline
Road grade estimation

Gyroscope measures pitch angle which is an angle between the horizontal plane and the plane that the smartphone attached to.

- Pitch angle is NOT the same as the road grade, $\alpha$, because of the acceleration and deceleration of vehicle.
- Linear accelerometer values are the gravity adjusted accelerometer value using the pitch angle from gyroscope.

![Pitch angle from gyrometer](image)

![Linear accelerometer (gray)](image)
Speed estimation with road grade and Kalman filter

Kalman filter can be used for combining the information from multiple sources:

- **Source 1:**
  - Speed: y-axis accelerometer
  - Road grade: gyroscope pitch angle

- **Source 2:**
  - Speed: GPS
  - Road grade: $v_{long}$ and $v_{up}$ (GPS)
Calibration result - Longitudinal acceleration

Kalman filtered (blue) vs. raw accelerometer (black)

- Kalman filtered accelerometer (blue) synchronized with the longitudinal acceleration estimated from OBD (green)
Calibration result - Speed graph

- Kalman filtered speed (blue) synchronized with the speed from OBD (green)
- the estimated speed from the raw accelerometer (black)
- the estimated speed from the linear accelerometer (grey)
Lateral acceleration can be obtained as follows:

\[ a_x = acc_t^x - g \times \sin(\phi_t) \]

where \( \phi_t \) is roll angle from gyroscope.

- The roll angle can capture the road grade effect for the lateral movements of the vehicle since it is relatively stable than pitch angle.
R package *ikhyd*¹ can do this for you;

¹https://github.com/issactoast/ikhyd
The driving style analysis
Test route for the analysis

- The test route for the driving style analysis for four drivers.
- We control time (5pm - 6pm) and vehicle (Ford fusion 2015)
- Route takes about 25 min. per each driver.
One way of constructing a driving profile using the calibrated telematics data is to draw a Lon-Lat plot.

- Discrete density plot of the calibrated telematics data
  - Interpretable
  - Suitable for lateral acceleration analysis
Comparison of the calibrated Lon-Lat plot

The comparison between driver 1 and 3. Which one is riskier?

(a) Driver 1  

(b) Driver 3

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Comparison of the linear acc. based Lon-Lat plot

The comparison between driver 1 and 3.

(a) Driver 1

(b) Driver 3

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Calibrated vs. GPS Lon-Lat

The calibrated Lon-Lat is more suitable for the lateral acceleration analysis than the GPS data.

(a) Calibrated based Lon-Lat (Driver 2)  
(b) GPS based Lon-Lat (Driver 2)
The telematics data from smartphone sensors need a careful calibration process.

Traditional telematics data used in actuarial science could lead to a miss interpretation of lateral movement of driving behavior.

- GPS data could have an erroneous interpretation about the lateral vehicle movement.
- Linear accelerometer data lose the information about driver’s driving style.

Since the calibrated telematics data contains the longitudinal and lateral movement behavior of the driver, it could become a fundamental building block for more realistic telematics analysis.
Thank you!


Appendix
Calibrated acc. based Lon-Lat plots for four drivers

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Linear acc. based Lon-Lat plots for four drivers
Using the lateral acceleration, we can draw v-a heatmap instead of using the longitudinal acceleration.

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Calibrated vs. Linear Lon-Lat

The calibrated Lon-Lat is more interpretable than the linear accelerometer-based Lon-Lat plot.

(a) Calibrated acc. data based Lon-Lat (Driver 1)

(b) Linear acc. data based Lon-Lat (Driver 1)
Transform to a v-a heatmap using IMU data

The calibrated 3-tuples of long. and lat. acceleration and speed also can be used to draw v-a heatmap.
GPS driving profiling (Driver 1 vs. Driver 2)

The lateral acceleration information from GPS data could lead to an erroneous decision.

- Driver 1 has sharper and harder turns than Driver 2 in the comparison of the calibrated Lon-Lat plots, but not in the GPS based Lon-Lat.