

IO-VNBD: Inertial and Odometry Benchmark Dataset for Ground Vehicle Positioning

Uche Onyekpe^{1,3*}, Vasile Palade³, Stratis Kanarachos² and Alicja Szkolnik⁴

¹ Institute for Future Transport and Cities, Coventry University, Coventry, United Kingdom

² Faculty of Engineering and Computing, Coventry University, Coventry, United Kingdom

³ Research Center for Data Science, Coventry University, Coventry, United Kingdom

⁴ Coventry University, Gulson Road, Coventry, United Kingdom

onyekpeu@uni.coventry.ac.uk, ab8522@coventry.ac.uk, ab5839@coventry.ac.uk, szkolnia@uni.coventry.ac.uk

Abstract – Low-cost inertial navigation sensors (INS) can be exploited for a reliable tracking solution for autonomous vehicles. However, position errors grow exponentially due to noises in the measurements. Several deep learning techniques have been investigated to mitigate the errors for a better navigation solution [1-10]. However, these studies have involved the use of different datasets not made publicly available. The lack of a robust benchmark dataset has thus hindered the advancement in the research, comparison and adoption of deep learning techniques for vehicle positioning based on inertial navigation. In order to facilitate the benchmarking, fast development and evaluation of positioning algorithms, we therefore present the first of its kind large-scale and information-rich inertial and odometry focused public dataset called IO-VNBD (Inertial Odometry Vehicle Navigation Benchmark Dataset). The vehicle tracking dataset was recorded using a research vehicle equipped with ego-motion sensors on public roads in the United Kingdom, Nigeria, and France. The sensors include a GPS receiver, inertial navigation sensors, wheel-speed sensors amongst other sensors found on the car as well as the inertial navigation sensors and GPS receiver in an android smart phone sampling at 10HZ. A diverse number of scenarios and vehicle dynamics are captured such as traffic, roundabouts, hard-braking etc. on different road types (country roads, motorways etc.) with varying driving patterns. The dataset consists of a total driving time of about 40 hours over 1,300km for the vehicle extracted data and about 58 hours over 4,400 km for the smartphone recorded data. We hope that this dataset will prove valuable in furthering research on the correlation between vehicle dynamics and its displacement as well as other related studies.

Keywords – Inertial navigation, INS, dataset, Wheel Speed, ECU dataset, autonomous driving, GPS loss, benchmark, tracking, Vehicular Navigation, Positioning, INS/GPS, Deep Learning, Odometry

Introduction

Recent advancements in machine learning has been facilitated by the availability of large and diverse datasets [12], [13]. Due to the urge for the development of information rich databases that will allow benchmarking and thus the fast development and evaluation of positioning algorithms [14], we contribute towards the advancement of autonomous vehicle and robotics research by presenting the largest and most diverse inertial dataset published. Using ego-motion sensors such as accelerometers, gyroscope, magnetometers, wheel encoders, force sensors etc., this dataset provides positioning and dynamics information of several vehicles driven in and across several cities in England, Nigeria and France.

The dataset presented provides features describing the state of the vehicle's motion under a range of driving and environmental scenarios such as varying longitudinal accelerations, hard-brakes, yaw velocities, mud roads, motorway etc. (see Table 2), with information from a wide range of sensors, as shown on Tables A1-1 to A7.



Figure 1 Smartphone and GPS antennae setup

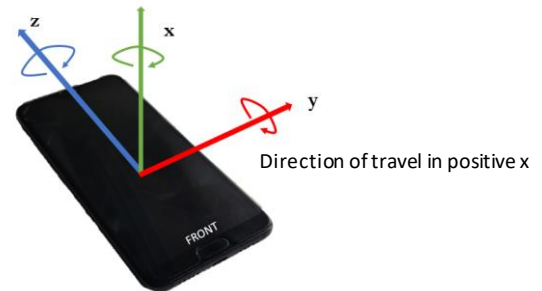


Figure 2 Smartphone sensor axis

* Corresponding author Uche Onyekpe: onyekpeu@uni.coventry.ac.uk

Furthermore, the dataset which is the first of its kind focused on inertial vehicle navigation under complex environmental scenarios and vehicle motion states with a rich combination of sensors is relevant in furthering research in areas not limited to the positioning or tracking of vehicles using noisy low-cost sensors and evaluation of positioning algorithms and techniques on noisy sensor measurements. The labelled dataset is also suitable for the robust training of supervised learning algorithms in learning the correlation between the dynamics of vehicles and its displacement with applications in the tracking or positioning of vehicles in GPS deprived environments.

Equipments

- Racelogic VBOX Video HD2 CAN – Bus data logger (10Hz) [15]
- Racelogic VBOX Video HD2 GPS Antenna (10Hz)[15]
- Huawei P20 pro, Motorola moto G7 power and Blackberry Priv using AndroSensor Application (10Hz).

Experiment Setup

Vehicle Experiment Setup

The vehicle used for the data collection exercise was a front wheel drive Ford Fiesta Titanium as shown in Figure 3. A Racelogic VBOX Video HD2 was used to record the data from the vehicle CAN bus as well as the corresponding GPS coordinates at each sampling instance. As shown in Figures 1 and 3, the GPS antenna was placed centrally at the top of the vehicle to ensure optimal signal reception. The Racelogic VBOX Video HD2 CAN – Bus data logger (10Hz) was used to record the data shown in Table 3 directly from the CAN Bus of the vehicle with a sampling and update frequency of 10Hz.

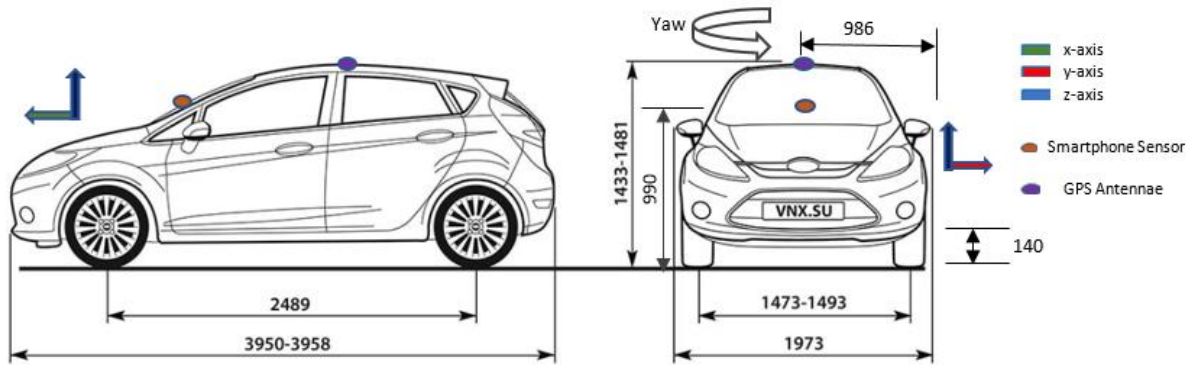


Figure 3 Sensor locations and dimension of vehicle[16]

Smartphone Measurement Setup

Four vehicles; a Ford Fiesta Titanium, Volvo XC70, Renault Megane and Toyota Corolla Verso were used to collect the smartphone datasets. The smartphone was held with a phone holder attached to the vehicle as shown in figure 1. Using the Androsensor app, all data were sampled every tenth of a second with a GPS (smartphone) update rate of 1Hz. Figure 2 shows the axis alignment of the smartphone sensors. The smartphone sensors employed were: a 3-axis accelerometer, a 3-axis gyroscope, a 3-axis magnetometer and heading as well as the GPS latitude and longitude coordinates all present within the phone. Other information such as the vehicles velocity and acceleration were recorded from the smartphones GPS. Table 4 highlights the data recorded from the smartphone data. The datasets described in Tables A1-1 to A6 were collected using the Huawei P20 pro smartphone.

Data Description

The total dataset consists of about 100 hours of recorded driving data on public roads by 8 different drivers with different driving styles as defined on Table 1. The data is divided into sets based on cities and towns driven via, road conditions, weather conditions, driving length and time, driving style and driving features (see Tables A1-1 to A7). The dataset also contains more than 20 minutes of data recorded from the stationary vehicle to aid in the estimation of the sensors bias. To add to the diversity of the data consisting of a number of complex driving scenarios as shown on Table 2, the data was recorded with different tyre pressures. Datasets with each unique tyre pressures are indicated in Tables A1-1 to A6 using Table 5 as a guide. Tables A1-1 to A7 reveal more detailed information on each sets of the data. The data logged from the vehicles CAN bus are denoted with the prefix “V-” and the smartphone data denoted with the prefix “S-”. The “S-” datasets are acquired from the sensors in a smartphone attached to the vehicle mimicking its motion*. While all the “V-” datasets were collected only in England, the “S-” datasets were collected in England, France and Nigeria.

Over the course of the data collection, communication difficulties between the GPS receiver and satellites were encountered. Information on data indexes recorded during these periods are provided in as well in a txt file. Where possible, the “S-” and “V-” datasets which were collected simultaneously¹ are manually synchronised and stored in the folder named “*Synchronised V and S datasets*”.

Importantly, despite the effort lent towards an accurate alignment of the smartphones sensor axis with that of the vehicle, the precision of the measurement were interfered by vehicular vibrations. Information on the amount of gravitational acceleration measured by each of the three axis are provided in the “S-” datasets to help in the correction of the measured acceleration. The data is stored in csv format in <https://github.com/onyekpeu/IO-VNBD> along with useful python development tools.

Table 1 Driving pattern of each driver

Driver	Driving Style
A	Defensive
B	Defensive
C	Defensive
D	Defensive
E	Aggressive
F	Defensive
G	Defensive
H	Defensive

* It is difficult to truly determine the centre of gravity of the car under different dynamic conditions, hence the smartphone recording approximates the true motion of the car.

¹ Not all “V-” and “S-” dataset were collected simultaneously. All the “V-” datasets without a corresponding “S-” dataset and vice-versa are not placed in the “Synchronised V and S datasets” folder.

Table 2 Environmental and driving scenarios investigated

No	Scenarios
1	Hard Brake
2	Sharp Turn Left and Right
3	Swift Maneuvers
4	Round-about
5	Rain
6	Night and Day
7	Skid
8	Mountain/Hills
9	Dirt Roads/ Gravel Roads
10	Country Roads
11	Motorway
12	Town Centre driving
13	Traffic Congestion
14	Successive left and right turns
15	Varying Accelerations within a short duration
16	A -Roads
17	B- Roads
18	Wet roads
19	U-turns / Reverse drives
20	Mud Road
21	Varying Tyre Pressure
22	Drifts
23	Bumps
24	Inner City driving
25	Winding Roads
26	Zig-Zag drives
27	Approximate Straight-line Motion
28	Parking
29	Potholes
30	Residential Roads
31	Stationary (No Motion)
32	Valley

Table 3 Information recorded from the Ford Fiesta's ECU

No	Column Heading	Unit
1	No of GPS satellites available	N/A
2	Time since start of day	Seconds
3	Latitude	degrees
4	Longitude	degrees
5	velocity	kmh
6	Heading	degrees
7	Height	km
8	Vertical velocity	Km/hr
9	Sampleperiod	seconds
10	Steering Angle	degrees
11	Wheel Speed Front Left	Rad/sec
12	Wheel Speed Front Right	Rad/sec
13	Wheel Speed Rear Left	Rad/sec
14	Wheel Speed Rear Right	Rad/sec
15	Yaw Rate	Deg/sec
16	Indicated Vehicle Speed	Km/hr
17	Indicated Longitudinal Acceleration	g
18	Indicated Lateral Acceleration	g
19	Handbrake	Activated or not (0 or 1)
20	Gear Requested	Number of gear employed (1-5)
21	Gear	Number of gear employed (1-5)
22	Engine Speed	Rev/min
23	Coolant Temperature	Degree celcius
24	Clutch Position	Activated or not (0 or 1)
25	Brake Pressure	PSI
26	Brake Position	Activated or not (0 or 1)
27	Battery Voltage	Volts
28	Air Temperature	Degrees celcius
29	Accelerator Pedal Position	% activation

Table 4 Information recorded from the smartphone sensors

No	Column Heading	Unit
1	GPS Latitude	degrees
2	GPS Longitude	degrees
3	GPS Altitude	m
4	GPS Speed	Kmh
5	GPS Accuracy	m
6	GPS Orientation	\hat{A}°
7	GPS Satellites In Range	N/A
8	Time Since Start	ms
9	Date	YYYY-MO-DD HH-MI-SS_SSS
10	Accelerometer X	m/s^2
11	Accelerometer Y	m/s^2
12	Accelerometer Z	m/s^2
13	Gravity X	m/s^2
14	Gravity Y	m/s^2
15	Gravity Z	m/s^2
16	Gyroscope (Yaw)	rad/s
17	Gyroscope (Pitch)	rad/s
18	Gyroscope (Pitch)	rad/s
19	Magnetic Field X	$\hat{I}/4T$
20	Magnetic Field Y	$\hat{I}/4T$
21	Magnetic Field Z	$\hat{I}/4T$
22	Orientation (Yaw)	\hat{A}°
23	Orientation (Roll)	\hat{A}°
24	Orientation (Pitch)	\hat{A}°

Table 5 Various Tyre pressures experimented on

Notation	Tyre Pressure (Psi)
A	Front right - 16
	Front left - 15
	Rear right - 14
	Rear left - 14
B	Front right - 31
	Front left - 31
	Rear right - 25
	Rear left - 25
C	Front right - 33
	Front left - 33
	Rear right - 31
	Rear left - 27
D	Front right - 33
	Front left - 33
	Rear right - 26
	Rear left - 26
E	Front right - N/A
	Front left - N/A
	Rear right - N/A
	Rear left - N/A

Conclusion

This paper presents a dataset with complex driving and environmental scenarios for autonomous vehicle navigation research. It is our hope that the dataset will be useful in the development, evaluation and testing of positioning and tracking algorithms and techniques on noisy low-cost sensor data. The dataset could also find use in modelling the relationship between the vehicle's position and its dynamics and other similar studies. In total, the dataset consists of about 5,700 km of data over 98 hours of driving time.

In the future, the collection of data under more challenging scenarios will be investigated. Also, a benchmark platform will be created for the performance comparison of positioning algorithms and techniques.

Acknowledgements

We would like to thank Mr Andy Thompson, Mr Thierry Touzet, Miss Sarah Tomkins, Mr Yannick Weber, Dr. Maciej Cieslak and Google LLC for their help on the project.

References

- [1] H. fa Dai, H. wei Bian, R. ying Wang, and H. Ma, "An INS/GNSS integrated navigation in GNSS denied environment using recurrent neural network," *Def. Technol.*, 2019.
- [2] W. Fang *et al.*, "A LSTM Algorithm Estimating Pseudo Measurements for Aiding INS during GNSS Signal Outages," *Remote Sens.*, vol. 12, no. 2, p. 256, Jan. 2020.
- [3] R. Sharaf, A. Noureldin, A. Osman, and N. El-Sheimy, "Online INS/GPS integration with a radial basis function neural network," *IEEE Aerosp. Electron. Syst. Mag.*, vol. 20, no. 3, pp. 8–14, Mar. 2005.
- [4] A. Noureldin, R. Sharaf, A. Osman, and N. El-Sheimy, "INS/GPS data fusion technique utilizing radial basis functions neural networks," pp. 280–284, 2004.
- [5] A. Noureldin, A. El-Shafie, and M. Bayoumi, "GPS/INS integration utilizing dynamic neural networks for vehicular navigation," *Inf. Fusion*, vol. 12, no. 1, pp. 48–57, 2011.
- [6] M. Malleswaran, S. Angel Deborah, S. Manjula, and V. Vaidehi, "Integration of INS and GPS using radial basis function neural networks for vehicular navigation," *11th Int. Conf. Control. Autom. Robot. Vision, ICARCV 2010*, no. January, pp. 2427–2430, 2010.
- [7] M. Malleswaran, V. Vaidehi, A. Saravanaselvan, and M. Mohankumar, "Performance analysis of various artificial intelligent neural networks for GPS/INS Integration," *Appl. Artif. Intell.*, vol. 27, no. 5, pp. 367–407, 2013.
- [8] M. Malleswaran, V. Vaidehi, S. Manjula, and S. A. Deborah, "Performance comparison of HONNs and FFNNs in GPS and INS integration for vehicular navigation," *Int. Conf. Recent Trends Inf. Technol. ICRTIT 2011*, no. June, pp. 223–228, 2011.
- [9] M. Malleswaran, V. Vaidehi, and S. A. Deborah, "CNN based GPS/INS data integration using new dynamic learning algorithm," *Int. Conf. Recent Trends Inf. Technol. ICRTIT 2011*, no. June, pp. 211–216, 2011.
- [10] K.-W. Chiang and N. El-Sheimy, "INS/GPS Integration using Neural Networks for Land Vehicle Navigation Applications," pp. 535–544, 27-Sep-2002.
- [11] K. Chiang, "INS / GPS Integration Using Neural Networks for Land Vehicular Navigation UCGE Reports Number 20209 Department of Geomatics Engineering INS / GPS Integration Using Neural Networks for Land Vehicular Navigation Applications by Kai-Wei Chiang," no. April, 2004.
- [12] A. Krizhevsky, I. Sutskever, and G. E. Hinton, "ImageNet Classification with Deep Convolutional Neural Networks."
- [13] C. Chen, X. Lu, A. Markham, and N. Trigoni, "IONet: Learning to Cure the Curse of Drift in Inertial Odometry," pp. 6468–6476, 2018.
- [14] S. Kanarachos, S. R. G. Christopoulos, and A. Chroneos, "Smartphones as an integrated platform for monitoring driver behaviour: The role of sensor fusion and connectivity," *Transportation Research Part C: Emerging Technologies*, vol. 95. Elsevier Ltd, pp. 867–882, 01-Oct-2018.
- [15] "VBOX Video HD2." [Online]. Available: <https://www.vboxmotorsport.co.uk/index.php/en/products/video-loggers/vbox-video>. [Accessed: 25-Feb-2020].
- [16] "Ford Fiesta Interior Dimensions - Our Houzz." [Online]. Available: <http://ourhouzz.site/ford-fiesta-interior-dimensions>. [Accessed: 25-Feb-2020].

Appendix

Table A1-1 Dataset description from Driver A, B and C

Driver	Dataset name	Features	Cities and Towns covered	Weather Conditions	Collection Date	Velocity and acceleration range	Total time driven and distance covered	Total number of data points	Corresponding Smartphone Dataset
A	V-S1	B-Road(B4101), Round-About (x9), Reverse (x5), Hilly Road, A4053(Ring Road), Hard Brake, Tyre Pressure - E	Coventry	15 / 4 °C, Sunny, Humidity:73%, Wind:2.486 mph N	08/09/2019	0.0 - 93.8 km/hr, -.59 - 0.34 g	86.3 mins, 38.16 km	51790	S-S1
	V-S2	B-Road(B4112, B4065), Round-About (x18), Reverse (x8), Motorway, Dirt Road, U-Turn (x5), Country Road, Successive Left-Right Turns, Hard Brake, A-Roads (A4600), Tyre Pressure - E	Coventry, Nuneaton	17 / 15 °C Passing clouds. Humidity:47% Wind:3.728 mph N	08/09/2019	0.0 - 105.2 km/hr, -0.56 - 0.43 g	156.5 mins, 75.64 km	93900	S-S2
	V-S3a	Round-About (x15), U-turn/Reverse (x4), Motorway (M6), A-Road(A4600, A426), Hard Brake, Zig-Zag, Country Roads, Change in Speed, Night-time, Sharp Turn Left/Right, Tyre Pressure - E	Coventry, Rugby	17 / 12 °C, Passing clouds. Humidity:65% Wind:6.836 mph W	04/09/2019	0.0 - 98.0 km/hr, -0.57 - 0.4 g	41.1 mins, 26.0 km	24660	S-S3a
	V-S3b	Successive Left-Right Turns (x21), Reverse/U-Turns (x1), Tyre Pressure - E	Rugby		04/09/2019	0.0 - 44.8 km/hr, -0.37 - 0.3 g	11.4 mins, 3.8 km	6840	S-S3b
	V-S3c	Round About (x4), A-Road (A428), Country Roads, Tyre Pressure - E	Rugby, Coventry		04/09/2019	0.0 - 117.1 km/hr, -0.36 - 0.35 g	62.0 mins, 44.28 km	37220	S-S3c
	V-S4	Round-About (x14), U-turn, A-Road, Successive Left-Right Turns, Zig-Zag, Change in Speed, Night-time, A-Road (A429, A45, A46), Ring Road (A4053), Tyre Pressure - E	Coventry	13 / 12 °C, Passing clouds. Humidity:83% Wind:8.078 mph WNW	06/09/2019	0.0 - 109.6 km/hr, -0.48 - 0.41 g	163.0 mins, 93.9 km	97824	S-S4
B	V-M	Round-About (x30), Successive Left-Right Turns, Hard Brake (x21), Zig-Zag (x5), Country Roads, Sharp Turn Left/Right, Daytime, U-Turn (x1), U-Turn Reverse (x7), Tyre Pressure - E	Coventry	15 / 12 °C, Partly sunny. Humidity:80% Wind:8.078 mph NW	07/09/2019	0.0 - 100.7 km/hr, -1.01 - 0.44 g	176.7 mins, 105.44 km	105995	S-M
C	V-St1	Roundabout (x9), A-Road (A452), B-Road, Car park Navigation, Tyre Pressure - E	Coventry, Kenilworth	13 / 10 °C, Passing clouds. Humidity:56% Wind:7.457 mph ESE	01/04/2019	0.0 - 73.3 km/hr, -0.39 - 0.45 g	95.4 mins, 47.05 km	57213	N/A

Table A1-2 Dataset description from Driver C and D

Driver	Dataset name	Features	Cities and Towns covered	Weather Conditions	Collection Date	Velocity and acceleration range	Total time driven and distance covered	Total number of data points	Corresponding Smartphone Dataset
C	V-St4	Round About(x1), A-Road (A4114, A444, A46), Motorway (M40), Tyre Pressure - E	Coventry, Warwick, Chesterton	9 / 4 °C Scattered clouds. Humidity:72% Barometer:991 mbar W Wind:12.428 mph	04/03/2019	0.0 - 101.4 km/hr, -0.27 - 0.13 g	22.7 mins, 28.48 km	13591	N/A
	V-St6	Motorway(M40), Daytime, Tyre Pressure - E	Stokenchurch, Headington Oxford	11 / 9 °C, Passing clouds. Humidity:62% Wind:10.564 mph SSW	05/03/2019	0.0 - 122.1 km/hr, -0.32 - 0.35 g	85.6 mins, 113.63 km	51360	N/A
	V-St7	Motorway(M40), Residential roads, A-Road (A46), Tyre Pressure - E	Stokenchurch, Headington Oxford, Coventry, Kenilworth, Warwick	7 / 6 °C Light rain. Partly sunny. Humidity:85% Wind:14.914 mph W	07/03/2019	0.0 - 117.9 km/hr, -0.3 - 0.3 g	74.0 mins, 90.06 km	44427	N/A
D	V-Y1	Round-About (x20), Succesive Left-Right Turns, Hard Brake, Zigzag, Sharp Turn Left/Right, Reverse/U-Turn (x8), Tyre Pressure - E	Coventry	22 / 16 °C, Passing clouds. Humidity:74% Wind:6.836 mph SSW	30/08/2019	0.0 - 87.5 km/hr, -0.85 - 0.36 g	117.2 mins, 60.86 km	70341	S-Y1
	V-Y2	Round About(x9), U-Turn/Reverse(x1), A-Road, B-Road, Country Road, Tyre Pressure - E	Coventry, Kenilworth	7 / 6 °C Light rain. Partly sunny. Humidity:85% Wind:14.914 mph W	08/03/2019	0.0 - 73.3 km/hr, -0.39 - 0.45 g	95.4 mins, 47.05 km	57213	N/A

Table A2-1 Dataset description from Driver E

Driver	Dataset name	Features	Cities and Towns covered	Weather Conditions	Collection Date	Velocity and acceleration range	Total time driven and distance covered	Total number of data points	Corresponding Smartphone Dataset
E	V-Vta1a	Wet Road, Gravel Road, Country Road, Sloppy Roads, Round About (x3), Hard Brake on wet road, Tyre Pressure A	Nuneaton, Walton on Trent	4-10 / 3-6 °C Passing clouds, Broken Clouds, Scattered Clouds. Humidity:75-93% SE Wind:4.971 mph	14/112019	0.0 - 103.4 km/hr, -0.54 - 0.35 g	43.0 mins, 40.74 km	25821	S-Vta1a
	V-Vta1b	Hard Brakes on Mud, Wet Road, Country Road, Tyre Pressure A	Coton in the Elms, Walton on Trent			0.1 - 77.7 km/hr, -0.49 - 0.28 g	1.6 mins, 1.26 km	956	S-Vta1b
	V-Vta2	Round About (x2), A Road (A511, A5121, A444), Country Road, Hard Brake, Tyre Pressure A	Walton on Trent, Burton on Trent			0.0 - 81.6 km/hr, -0.59 - 0.38 g	18.3 mins, 11.07 km	10995	S-Vta2
	V-Vta3	Round-About (x1), Manoeuvres, Tyre Pressure A	Burton on Trent			0.0 - 45.8 km/hr, -0.31 - 0.27 g	1.5 mins, 0.38 km	875	S-Vta3
	V-Vta4	A-Road (A511), Tyre Pressure A	Burton on Trent			5.9 - 51.7 km/hr, -0.37 - 0.28 g	3.0 mins, 2.02 km	1809	S-Vta4
	V-Vta5	Round-About (x1), A-Road (A511), Tyre Pressure A	Burton on Trent			29.2 - 51.1 km/hr, -0.26 - 0.09 g	0.6 min, 0.42 km	357	S-Vta5
	V-Vta6	A-Road (A511), Tyre Pressure A	Burton on Trent			43.8 - 103.9 km/hr, -0.24 - 0.13 g	2.3 mins, 2.62 km	1393	S-Vta6
	V-Vta7	Round-About (x2), A-Road (A511), Hard Brake, Tyre Pressure A	Burton on Trent			22.4 - 113.1 km/hr, -0.54 - 0.18 g	1.4 mins, 1.54 km	857	S-Vta7
	V-Vta8	Town Roads (Build-up), A-Roads (A511), Tyre Pressure A	Hatton Derby			0.0 - 77.6 km/hr, -0.45 - 0.3 g	6.2 mins, 3.43 km	3697	S-Vta8
	V-Vta9	Hard-Brake, A – Road (A50), Tyre Pressure A	Derby			48.9 - 87.7 km/hr, -0.6 - 0.14 g	0.4 min, 0.43 km	226	S-Vta9
	V-Vta10	Round About (x1), A – Road (A50), Tyre Pressure A	Sudbury Ashburne			38.8 - 118.0 km/hr, -0.28 - 0.13 g	2.6 mins, 3.95 km	1570	S-Vta10
	V-Vta11	Round About (x2), A – Road (A50), Tyre Pressure A	Oaks Green Ashburne			26.8 - 97.7 km/hr, -0.45 - 0.15 g	1.0 min, 0.92 km	589	S-Vta11
	V-Vta12	Change in Speed, A-Road (A515), Tyre Pressure A	Ashburne			44.7 - 85.3 km/hr, -0.44 - 0.13 g	1.1 mins, 1.27 km	690	S-Vta12
	V-Vta13	A-Road (A515), Country Road, Hard-Brake, Tyre Pressure A	Ashburne			72.7 - 103.6 km/hr, -0.38 - 0.12 g	0.8 mins, 1.14 km	473	S-Vta13
	V-Vta14	Hard-Brake, Change in Speed, A – Road (A515), Tyre Pressure A	Ashburne			52.8 - 91.0 km/hr, -0.32 - 0.13 g	4.8 mins, 5.45 km	2893	S-Vta14
	V-Vta15	A – Road (A515), Tyre Pressure A	Ashburne			60.1 - 78.8 km/hr, -0.12 - 0.06 g	1.4 mins, 1.72 km	869	S-Vta15
	V-Vta16	Round-About (x3), Hilly Road, Country Road, A-Road (A515), Tyre Pressure A	Thorpe Ashburne, Clifton			0.0 - 93.9 km/hr, -0.49 - 0.42 g	18.9 mins, 13.72 km	11361	S-Vta16
	V-Vta17	Hilly Road, Hard-Brake, Stationary (No Motion), Tyre Pressure A	Ilam, Blore			0.0 - 56.2 km/hr, -0.51 - 0.28 g	7.7 mins, 4.19 km	4594	S-Vta17

Table A2-2 Dataset description from Driver E

Driver	Dataset name	Features	Cities and Towns covered	Weather Conditions	Collection Date	Velocity and acceleration range	Total time driven and distance covered	Total number of data points	Corresponding Smartphone Dataset
E	V-Vta19	Hilly Road, Tyre Pressure A	ilam	4-10 / 3-6 °C Passing clouds, Broken Clouds, Scattered Clouds. Humidity:75-93% SE Wind:4.971 mph	06/112019	0.0 - 55.2 km/hr, -0.35 - 0.22 g	0.5 min, 0.26 km	310	S-Vta19
	V-Vta20	Hilly Road, Approximate Straight-line travel, Tyre Pressure A	ilam			0.0 - 44.8 km/hr, -0.19 - 0.3 g	5.4 mins, 0.39 km	3223	S-Vta20
	V-Vta21	Hilly Road, Tyre Pressure A	Ilam			0.0 - 74.8 km/hr, -0.44 - 0.24 g	3.5 mins, 2.76 km	2088	S-Vta21
	V-Vta22	Hilly Road, Hard Brake,, Tyre Pressure A	ilam			14.8 - 55.8 km/hr, -0.53 - 0.16 g	2.6 mins, 1.67 km	1572	S-Vta22
	V-Vta23	Hilly Road, Hard Brake,, Tyre Pressure A	Thorpe			0.0 - 51.9 km/hr, -0.57 - 0.42 g	1.9 mins, 1.1 km	1119	S-Vta23
	V-Vta24	Hilly Road, Tyre Pressure A	Thorpe			0.0 - 56.4 km/hr, -0.46 - 0.36 g	2.0 mins, 0.71 km	1184	S-Vta24
	V-Vta25	U-turn, Tyre Pressure A	Thorpe			0.0 - 48.6 km/hr, -0.46 - 0.3 g	1.1 mins, 0.16 km	646	S-Vta25
	V-Vta26	Gravel Road, Dirt Road, Hilly Road, Tyre Pressure A	Thorpe			0.0 - 55.1 km/hr, -0.27 - 0.44 g	3.2 mins, 1.02 km	1947	S-Vta26
	V-Vta27	Gravel Road, Several Hilly Road, Potholes, Country Road, A-Road (A515), Tyre Pressure A	Ashburne			0.0 - 65.0 km/hr, -0.43 - 0.29 g	4.8 mins, 3.16 km	2853	S-Vta27
	V-Vta28	Country Road, Hard Brake, Valley, A-Road (A515)	Milldale			0.0 - 66.0 km/hr, -0.58 - 0.31 g	7.0 mins, 3.94 km	4219	S-Vta28
	V-Vta29	Hard Brake, Country Road, Hilly Road, Windy Road, Dirt Road, Wet Road, Reverse (x2), Bumps, Rain, B-Road (B5053), Country Road, U-Turn (x3), Windy Road, Valley, Tyre Pressure A	Wetton, Milldale			0.0 - 102.0 km/hr, -0.8 - 0.38 g	39.6 mins, 26.12 km	23737	S-Vta29
	V-Vta30	Rain, Wet Road, U-Turn (x2), A-Road (A53, A515), Inner Town Driving, B-Road (B5053) , Tyre Pressure A	Buxton			0.0 - 100.0 km/hr, -0.47 - 0.36 g	28.6 mins, 11.77 km	17179	S-Vta30

Table A3 Dataset description from Driver E

Driver	Dataset name	Features	Cities and Towns covered	Weather Conditions	Collection Date	Velocity and acceleration range	Total time driven and distance covered	Total number of data points	Corresponding Smartphone Dataset
E	V-Vtb1	Valley, rain, Wet-Road, Country Road, U-Turn (x2), Hard-Brake, Swift-Maneuver, A – Road (A6, A6020, A623, A515), B-Road (B6405), Round About (x3), day Time, Tyre Pressure A	Bakewell, Tideswell, Ashford on water, Buxton	4-8 / 4 °C Rain, Passing clouds, Broken Clouds, Chilly. Humidity:94-98% Barometer:1004 mbar N Wind:10.564 mph	06/11/2019	0.0 - 101.2 km/hr, -63 - 0.36 g	54.1 mins, 41.94 km	32459	S-Vtb1
	V-Vtb2	Country Road, Wet Road, Dirt Road, Tyre Pressure A	Youlgreave			0.0 - 61.1 km/hr, -0.36 - 0.39 g	9.5 mins, 4.35 km	5712	S-Vtb2
	V-Vtb3	Reverse, Wet Road, Dirt Road, Gravel Road, Night -time, Tyre Pressure A	Youlgreave			0.0 - 37.5 km/hr, -0.23 - 0.33 g	13.8 mins, 0.71 km	8289	S-Vtb3
	V-Vtb4	Dirt Road, Country Road, Gravel, Wet Road, Tyre Pressure A	Youlgreave			0.0 - 32.7 km/hr, -0.31 - 0.27 g	1.0 min, 0.27 km	625	S-Vtb4
	V-Vtb5	Dirt Road, Country Road, Gravel Road, Hard Brake, Wet Road, B Road (B6405, B6012, B5056), Inner Town Driving, A-Road, Motorway (M42, M1), Rush hour(Traffic) Round-About (x6), A-Road (A5, A42, A38, A615, A6), Tyre Pressure A	Atherstone, Nuthall, Hilcote, Matlock, Rowsley, Youlgreave			0.0 - 112.9 km/hr, -0.55 - 0.42 g	107.7 mins, 111.66 km	64610	S-Vtb5
	V-Vtb6	A-Road (A5), Tyre Pressure A	Atherstone			52.7 - 73.0 km/hr, -0.11 - 0.11 g	0.8 min, 0.89 km	508	S-Vtb6
	V-Vtb7	Approximate Straight-line Motion, Night-time, A-Road (A5), Tyre Pressure A	Atherstone			29.1 - 69.2 km/hr, -0.37 - 0.13 g	0.8 min, 0.72 km	461	S-Vtb7
	V-Vtb8	Approximate Straight-line Motion, Night-time, Wet Road, A-Road (A5), Tyre Pressure A	Atherstone			60.9 - 76.5 km/hr, -0.35 - 0.08 g	1.2 mins, 1.35 km	699	S-Vtb8
	V-Vtb9	Approximate Straight-line Motion, Night-time, Wet Road, Hard Brake, A-Road (A5), Tyre Pressure A	Nuneaton			66.8 - 92.0 km/hr, -0.14 - 0.1 g	0.8 min, 0.98 km	457	S-Vtb9
	V-Vtb10	Round-About, Wet Road, Night-time, A-Road (A5), Tyre Pressure A	Nuneaton			26.1 - 58.5 km/hr, -0.24 - 0.12 g	0.3 min, 0.23 km	195	S-Vtb10
	V-Vtb11	Approximate Straight-line Motion, Night-time, Wet Road, A-Road (A5), Tyre Pressure A	Nuneaton			65.1 - 75.3 km/hr, -0.05 - 0.12 g	0.7 min, 0.84 km	433	S-Vtb11
	V-Vtb12	Round-About (x1), Wet Road, Night-time, Tyre Pressure A	Nuneaton			22.2 - 71.6 km/hr, -0.38 - 0.17 g	0.8 min, 0.61 km	490	S-Vtb12
	V-Vtb13	Parking, Wet Road, Tyre Pressure A	Nuneaton			7.5 - 43.3 km/hr, -0.31 - 0.22 g	2.1 mins, 0.99 km	1245	N/A

Table A4 Dataset description from Driver E

Driver	Dataset name	Features	Cities and Towns covered	Weather Conditions	Collection Date	Velocity and acceleration range	Total time driven and distance covered	Total number of data points	Corresponding Smartphone Dataset
E	V-Vw1	Stationary (No Motion, sensor bias estimation), Daytime, Tyre Pressure C	Nuneaton	10 °C Smoke. Wind: 6 mph N Humidity: 86%	08/01/2020	0.00 - 0.00 km/hr, 0.00 - -0.00 g	34.1 mins, 0.00 km	20475	S-Vw1
	V-Vw2	A- road (A5, A421), Motorway (M5), Daytime, Round About (x22), U-Turn (x2), Inner city driving, Tyre pressure C	Nuneaton, Hinckley Milton Keynes			0.0 - 115.4 km/hr, -0.62 - 0.45 g	87.9 mins, 98.63 km	52712	S-Vw2
	V-Vw3	Round-About (x6), Daytime, B- Road, Inner city driving, Tyre pressure C	Milton Keynes			0.0 - 77.4 km/hr, -0.47 - 0.41 g	6.6 mins, 5.05 km	3942	S-Vw3
	V-Vw4	Round-About (x77), Swift-Maneuvers, Hard-Brake, Inner City Driving, Reverse, A-Road, Motorway (M5, M40, M42), Country Road, Successive Left-Right Turns, Daytime, U-Turn (x3), Tyre Pressure D	Milton Keynes, Buckingham, Droitwich Spa, Kidderminster, Worcester			0.0 - 131.9 km/hr, -0.66 - 0.45 g	211.0 mins, 214.62 km	126573	S-Vw4
	V-Vw5	Successive Left-Right Turns, Daytime, Sharp Turn Left/Right, Tyre Pressure D	Worcester	10 °C Passing clouds. Wind: 2 mph N Humidity: 88%		0.0 - 38.7 km/hr, -0.4 - 0.21 g	1.8 mins, 0.7 km	1050	S-Vw5
	V-Vw6	Bumps, Swift-Maneuvers, Daytime, Sharp Turn Left/Right, Pressure F	Worcester			3.3 - 40.7 km/hr, -0.34 - 0.26 g	2.1 mins, 1.08 km	1288	S-Vw6
	V-Vw7	Successive Left-Right Turns, Daytime, Sharp Turn Left/Right, Tyre Pressure D	Worcester			0.4 - 42.2 km/hr, -0.37 - 0.37 g	2.8 mins, 1.23 km	1689	S-Vw7
	V-Vw8	Successive Left-Right Turns, Daytime, Sharp Turn Left/Right, Tyre Pressure D	Worcester			0.0 - 46.4 km/hr, -0.37 - 0.27 g	2.7 mins, 1.12 km	1599	S-Vw8
	V-Vw9	Zig-Zag Motion, Daytime, Hard Brake, Tyre Pressure D	Worcester			3.8 - 42.0 km/hr, -0.67 - 0.21 g	1.0 min, 0.45 km	601	S-Vw9
	V-Vw10	Hilly Road, Daytime, Pressure F	Worcester			11.8 - 58.9 km/hr, -0.42 - 0.11 g	1.1 mins, 0.74 km	670	S-Vw10
	V-Vw11	Motorway (M5), Daytime, Round About (x5), Tyre Pressure D				0.0 - 98.4 km/hr, -0.37 - 0.33 g	8.2 mins, 5.85 km	4924	S-Vw11
	V-Vw12	Approximate Straight-line Motion, Daytime, Motorway (M5), Tyre Pressure D				7 °C Drizzle. Fog. Wind: 5 mph N Humidity: 93%	82.6 - 97.4 km/hr, -0.06 - 0.07 g	1.75 mins, 2.64 km	1050

Table A5 Dataset description from Driver E

Driver	Dataset name	Features	Cities and Towns covered	Weather Conditions	Collection Date	Velocity and acceleration range	Total time driven and distance covered	Total number of data points	Corresponding Smartphone Dataset
E	V-Vw13	Approximate Straight-line Motion, Daytime, Motorway (M5), Tyre Pressure D		7 °C Drizzle. Fog. Wind: 5 mph N Humidity: 93%	08/01/2020	94.0 - 115.0 km/hr, -0.07 - 0.06 g	0.5 min, 0.82 km	297	S-Vw13
	V -Vw14a	Motorway (M5), Nighttime, Tyre Pressure D				61.9 - 109.4 km/hr, -0.38 - 0.12 g	5.2 mins, 7.92 km	3140	S-Vw14a
	V -Vw14b	Motorway (M42), Nighttime, Tyre Pressure D				12.6 - 120.1 km/hr, -0.28 - 0.28 g	32.7 mins, 41.21 km	19600	S-Vw14b
	V -Vw14c	Motorway (M42), Round About (x2), A-Road (A446), Nighttime, Hard Brake, Tyre Pressure D				0.0 - 100.5 km/hr, -0.53 - 0.41 g	26.4 mins, 17.15 km	15857	S-Vw14c
	V -Vw15	Stationary (No Motion, sensor bias estimation), Nighttime, Tyre Pressure D	Dordon	8 °C Cool. Wind: 2 mph N Humidity: 80%		0.0 - 0.0 km/hr, 0.00 - 0.0 g	2.3 mins, 0.00 km	1391	S-Vw15
	V -Vw16a	A – Road (A5), Round About (x2), Tyre Pressure D	Atherstone	8 °C Rain showers. Overcast. 2 mph N 80%		0.0 - 83.5 km/hr, -0.39 - 0.4 g	10.0 mins, 8.49 km	6000	S-Vw16a
	V -Vw16b	Hard-Brake, Nighttime, A – Road (A5), Approximate Straight-line travel, Tyre Pressure D	Nuneaton			1.3 - 86.3 km/hr, -0.75 - 0.29 g	2.0 mins, 1.99 km	1171	S-Vw16b
	V -Vw17	Hard-Brake, Nighttime, A – Road (A5), Approximate Straight-line travel, Tyre Pressure D	Calcedote			31.5 - 72.7 km/hr, -0.8 - 0.19 g	0.5 min, 0.54 km	329	S-Vw17

Table A6-1 Dataset description from Driver E

Driver	Dataset name	Features	Cities and Towns covered	Weather Conditions	Collection Date	Velocity and acceleration range	Total time driven and distance covered	Total number of data points	Corresponding Smartphone Dataset
E	V-Vfa01	A-Road (A444), Round About (x1), B –Road (B4116) Day Time, Hard Brake, Tyre Pressure A	Nuneaton, Twycross, Measham	6 °C Quite cool. Wind: 8 mph N Humidity: 97% 7 °C, Scattered clouds. Wind: 8 mph N Humidity: 87% 5 °C, Light rain. Passing clouds. Wind: 10 mph N Humidity:87%	08/11/2019	0.0 - 98.4 km/hr, -0.56 - 0.42 g	19.2 mins, 18.8 km	11535	S-Vfa01
	V-Vfa02	B-Road (B4116), Round About (x5), A Road (A42, A641), Motorway (M1, M62) High Rise Buildings, Hard Brake, Tyre Pressure C	Bradford, Measham			0.0 - 117.9 km/hr, -0.67 - 0.48 g	112.9 mins, 163.38 km	67755	S-Vfa02
	V-Vfb01a	City Centre Driving, Round-About (x1), Wet Road, Ring Road, Night, Tyre Pressure C	Bradford			0.0 - 68.9 km/hr, -0.43 - 0.42 g	28.3 mins, 6.81 km	17000	N/A
	V-Vfb01b	Motorway (M606), Round-About (x1), City Roads Traffic, Wet Road, Changes in Acceleration in Short Periods of Time, Night, Tyre Pressure C				0.0 - 83.0 km/hr, -0.38 - 0.23 g	6.5 mins, 4.07 km	3880	N/A
	V-Vfb01c	Motorway (M62), Wet Road, Heavy Traffic, Night, Tyre Pressure C				0.2 - 104.5 km/hr, -0.36 - 0.38 g	10.5 mins, 10.66 km	6320	N/A
	V-Vfb01d	Round-About (x1), A-Road (A650),				0.0 - 56.0 km/hr, -0.46 - 0.36 g	17.9 mins, 3.39 km	10713	N/A
	V-Vfb02a	Motorway (M1), Round About (x2), A-Road (A650), Night, Hard Brake, Tyre Pressure D	East Ardsley,	7 °C, Rain showers. Overcast. Wind: 12 mph N Humidity:86%		0.0 - 122.3 km/hr, -0.5 - 0.37 g	59.9 mins, 96.5 km	35960	N/A
	V-Vfb02b	Round About (x1), Bumps, Successive Left Right Turns, Hard-Brake (x7), Zig-zag (x6),Night, Tyre Pressure D	Nuthall			0.0 - 84.3 km/hr, -0.5 - 0.35 g	18.3 mins, 7.69 km	11000	N/A
	V-Vfb02c	U-Turn (x1), Hard Brake, Night, Tyre Pressure D	Nuthall			2.0 - 52.8 km/hr, -0.53 - 0.26 g	1.1 mins, 0.54 km	640	N/A

Table A6-2 Dataset description from Driver E

Driver	Dataset name	Features	Cities and Towns covered	Weather Conditions	Collection Date	Velocity and acceleration range	Total time driven and distance covered	Total number of data points	Corresponding Smartphone Dataset
E	V-Vfb02d	Round About (x1), Night, Tyre Pressure D	Nuthall	7 °C, Rain showers. Overcast. Wind: 12 mph N Humidity:86%	08/11/2019	0.0 - 57.3 km/hr, -0.33 - 0.31 g	1.5 mins, 0.84 km	880	N/A
	V-Vfb02e	Changes in acceleration in short period of time, Night, Tyre Pressure D	Nuthall			37.4 - 73.9 km/hr, -0.24 - 0.19 g	1.6 mins, 1.52 km	980	N/A
	V-Vfb02f	Round About (x1), Night, Tyre Pressure D	Nuthall			1.6 - 49.5 km/hr, -0.24 - 0.32 g	1.1 mins, 0.47 km	660	N/A
	V-Vfb02g	Motorway (M1), A-Road (A42, A444, A5), Country Road, Round About (x2), Hard Brake, Night, Tyre Pressure D	Nuneaton			0.0 - 119.4 km/hr, -0.51 - 0.35 g	45.3 mins, 63.56 km	27159	N/A

Table A7 Information on other Smartphone Dataset captured independently from drivers F, G and H

Driver	Datasetname	Location	Comments	Vehicle Model	Phone Model	Total Time driven (mins)	Total distance covered (km)	Total number of data points
F	S-T1, S-T2, S-T3, S-T4, S-T5, S-T6, S-T8, S-T9	France	Information on 3-axis orientation and magnetic field not available.	Renault Megane	Motorola moto G7 power	1005.70	1508.39	603425
	S-T10, S-T11	France	-	Renault Megane	Motorola moto G7 power	20.60	8.86	12389
G	S-I	Nigeria	-	Toyota Corolla Verso	Huawei P20 pro,	9.70	0.06	5800
H	S-A1, S-A2, S-A3, S-A4, S-A5, S-A6, S-A7, S-A8, S-A9, S-A10, S-A11, S-A12, S-A13	England	-	Volvo XC70	Blackberry Priv	638.30	1511.93	382956