ParkUs: A Novel Vehicle Parking Detection System

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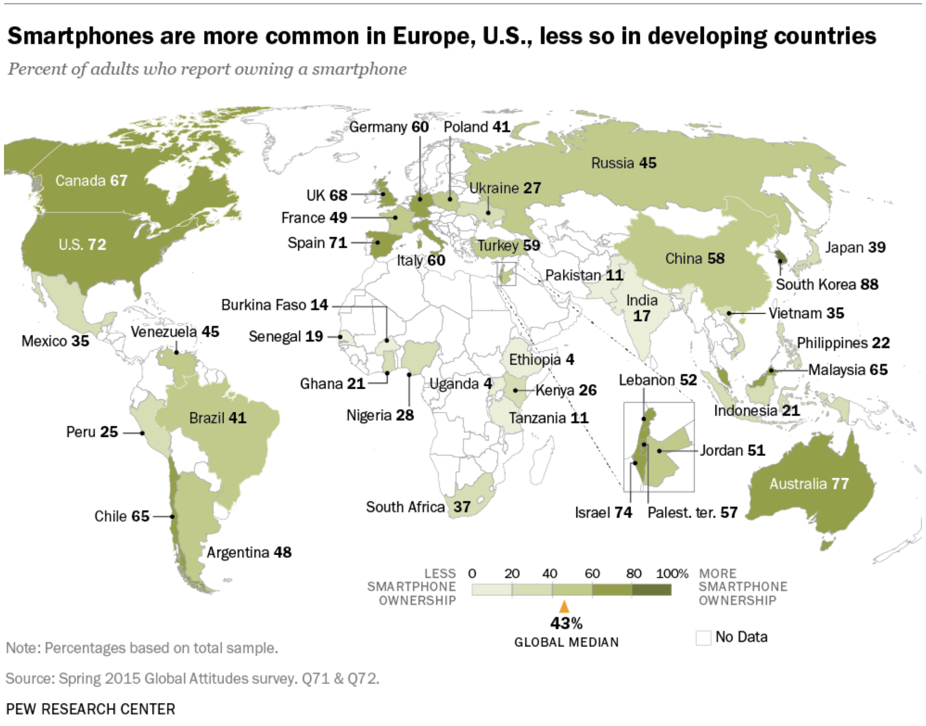
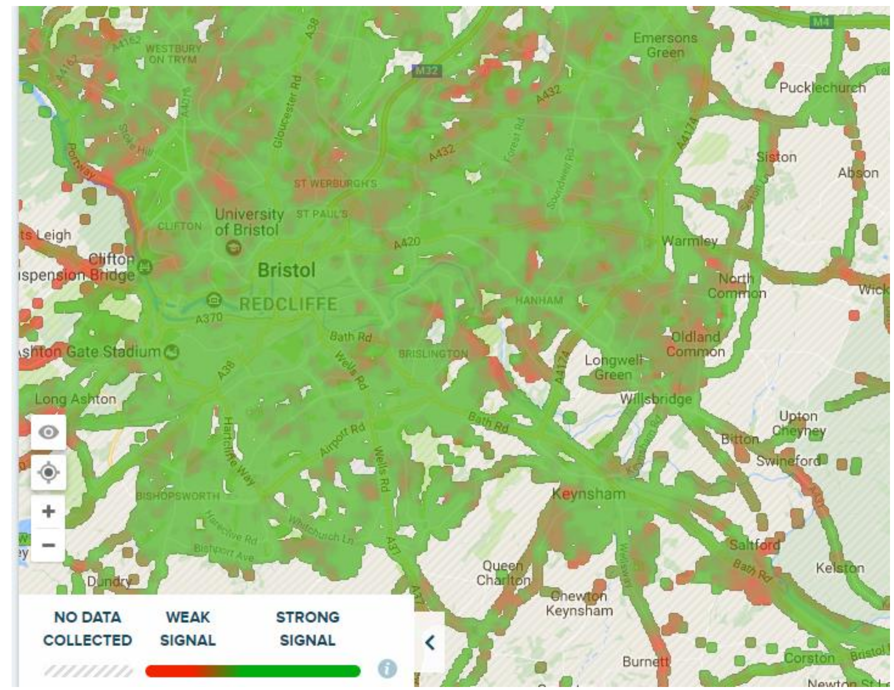
Introduction: Motivation

- Vehicle congestion is a major problem in most developed cities:
  - Searching or “cruising” for a vacant parking space in a city is estimated to account for ~30% of vehicle traffic
  - Park search ~ 8 minutes of any journey in a city
  - Huge waste of time
  - Lots of unnecessary pollution

- For example: Effects of 1 year’s worth of parking search in Westwood Village, LA:
  - Vehicles travelled 1.5M Km
  - Produced 662 tonnes of CO_2

Introduction: Opportunity





[1] OpenSignal, https://opensignal.com/about/
[2] PewResearchCentre, http://www.pewglobal.org/2016/02/22/smartphone-ownership-and-internet-usage-continues-to-climb-in-emerging-economies/

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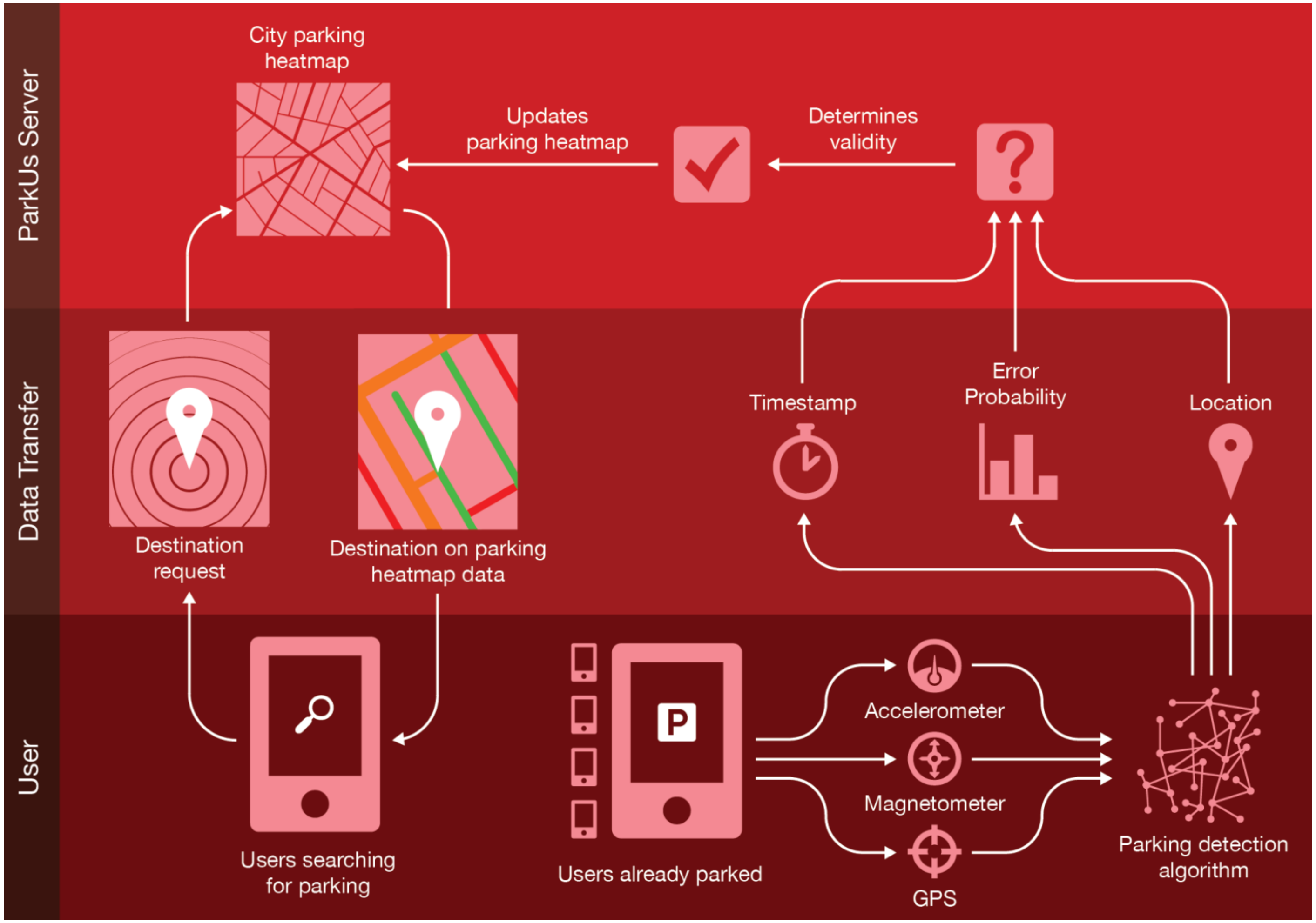
Introduction: Overall ParkUs System



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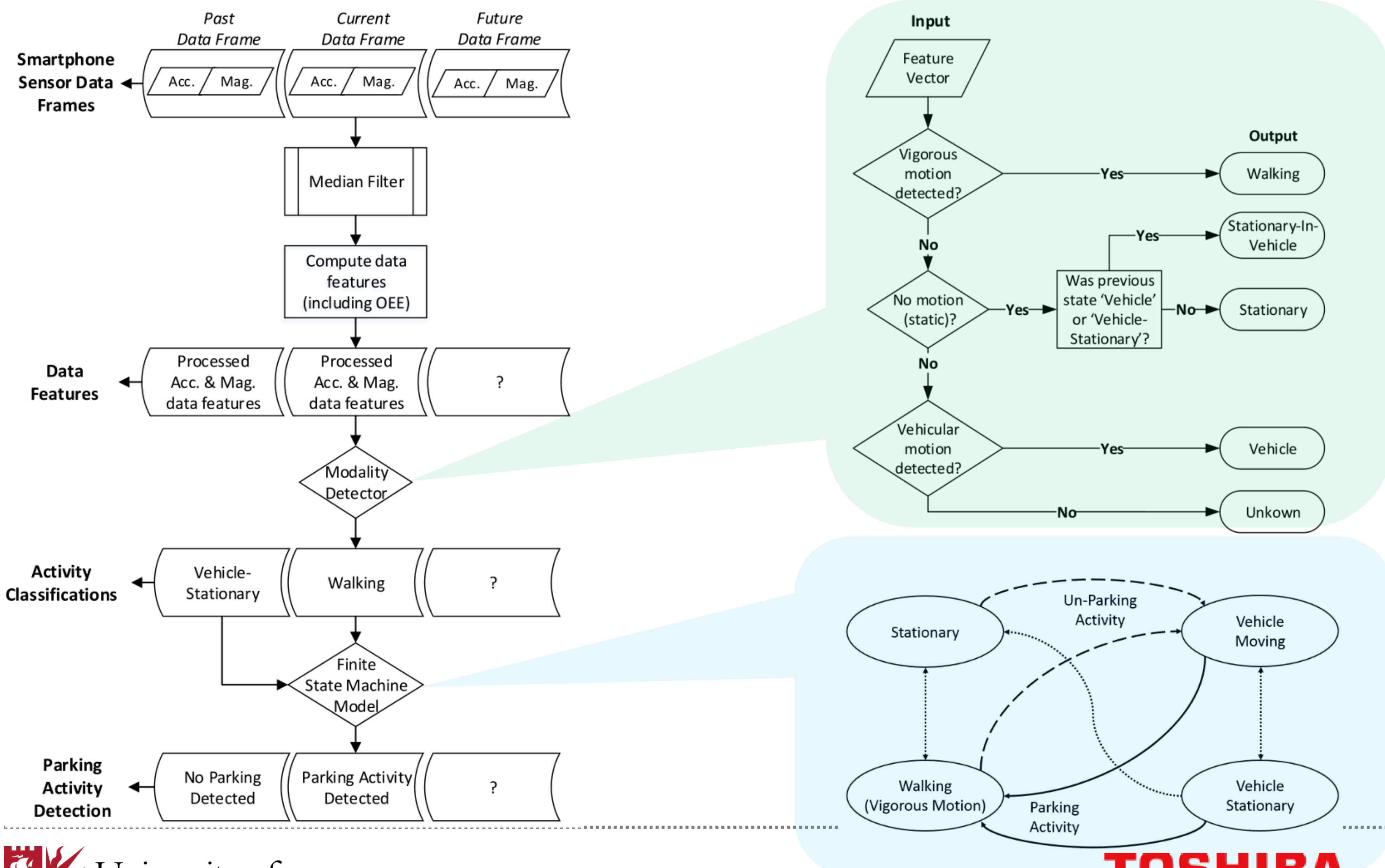
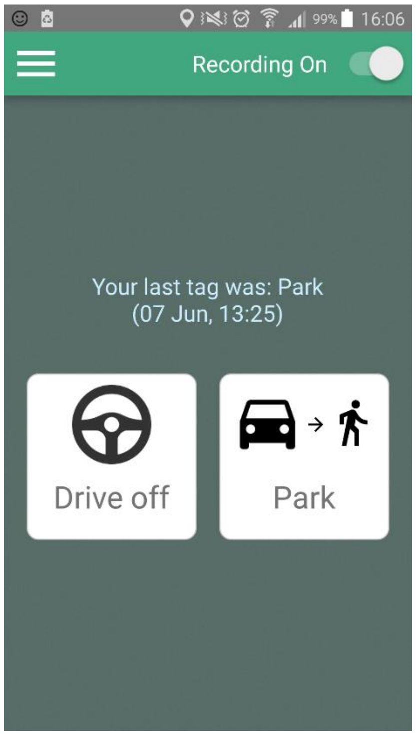
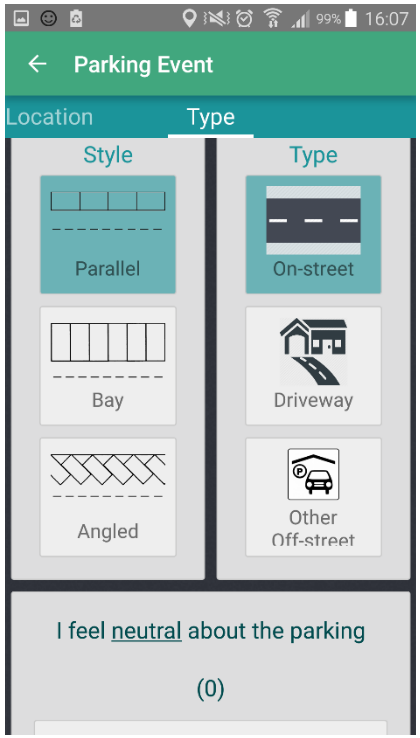
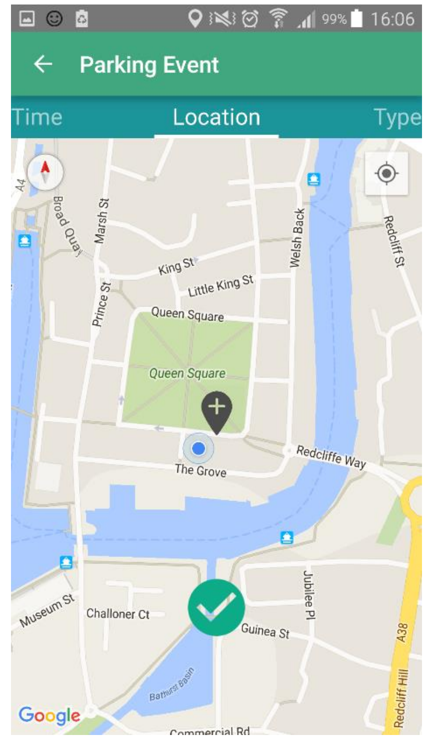
ParkUs: Detection Architecture

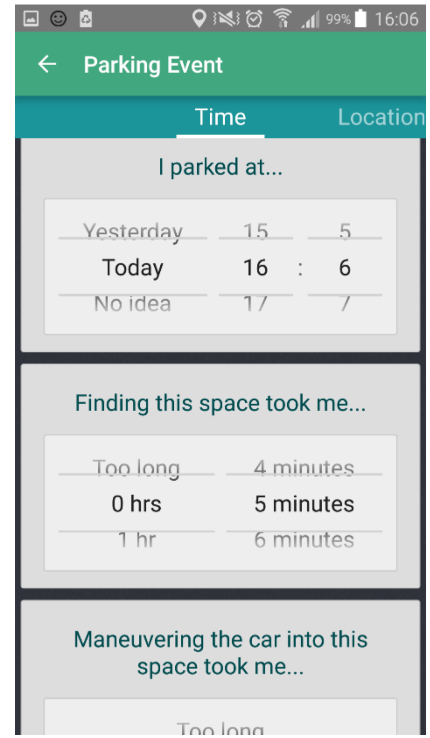


Training Data Collection Trial



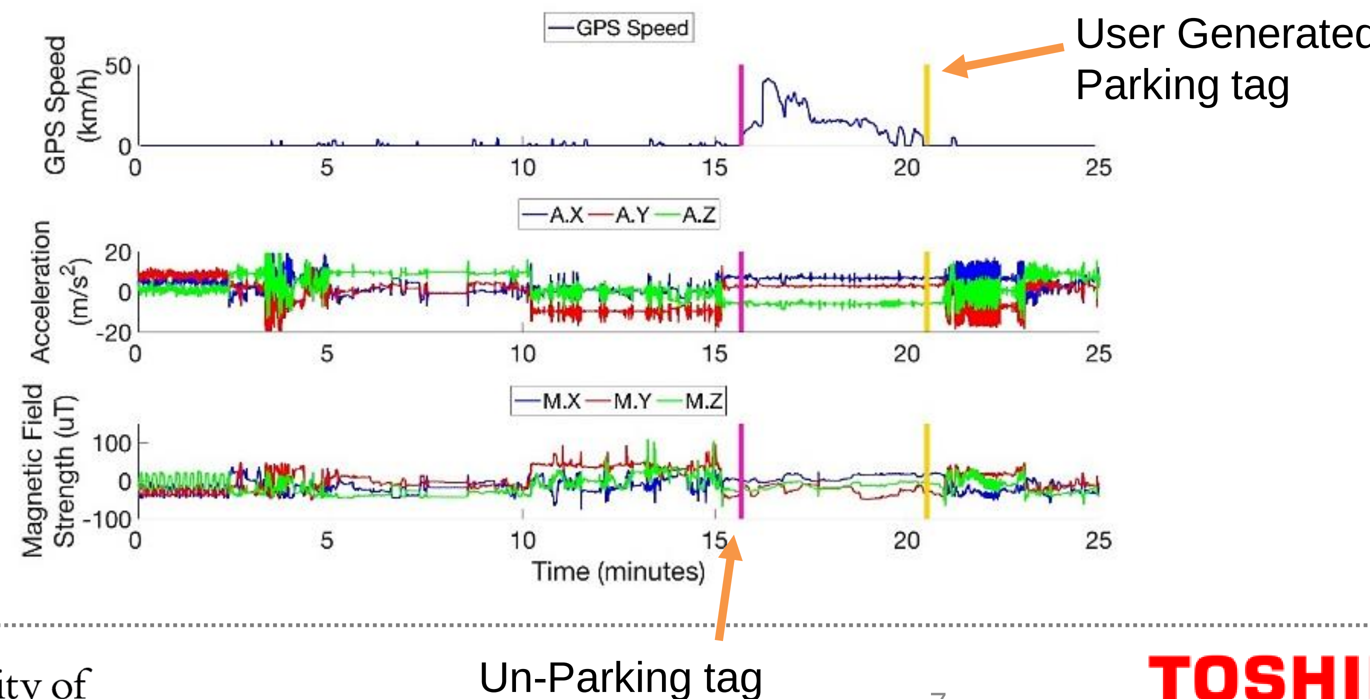




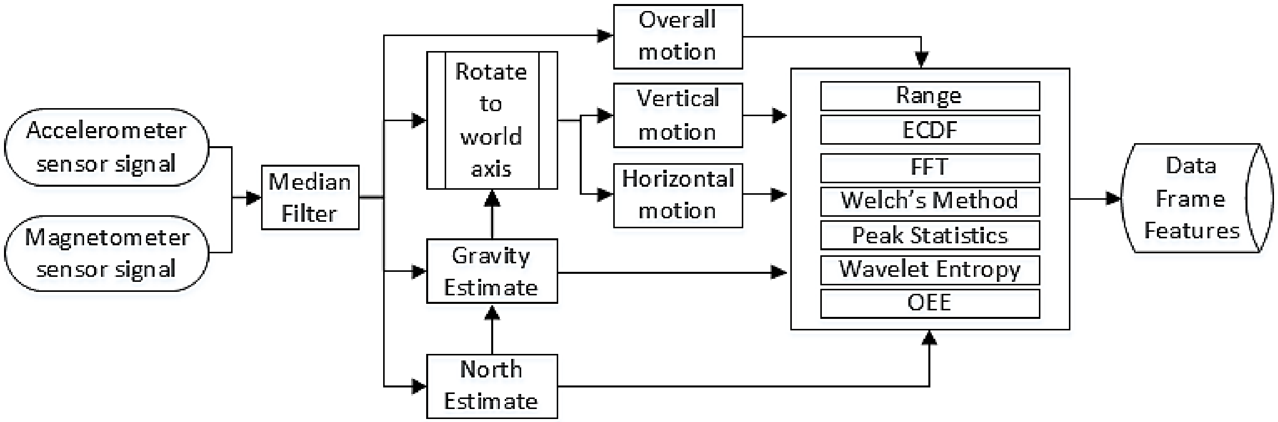


Typical Journey and Data Collected

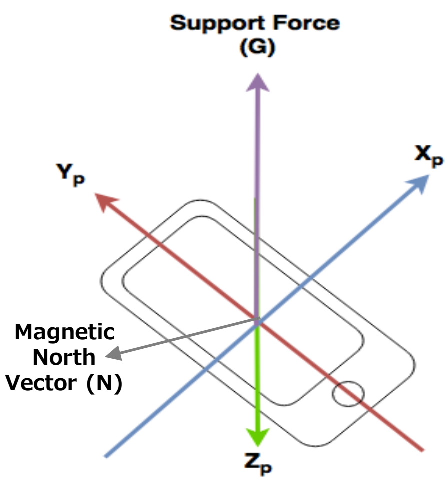
Smartphone Sensor	Sampling Frequency (Hz)
Accelerometer	25
Magnetometer	5
GPS (speed and location)	~1
Ambient light	5
Ambient Noise Level	10



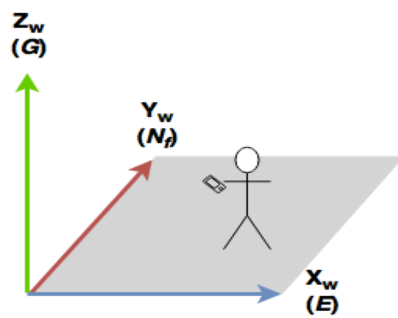
Modality Classification and novel OEE feature



Local (smartphone) Axis



World Axis



$$\theta_{GN} = \cos^{-1}\left(\frac{G \cdot N}{|G| \cdot |N|}\right)$$

$$OEE = |\theta_{GN} - 90°|$$

OEE feature: measures/estimates angle between gravity and magnetic North Vector

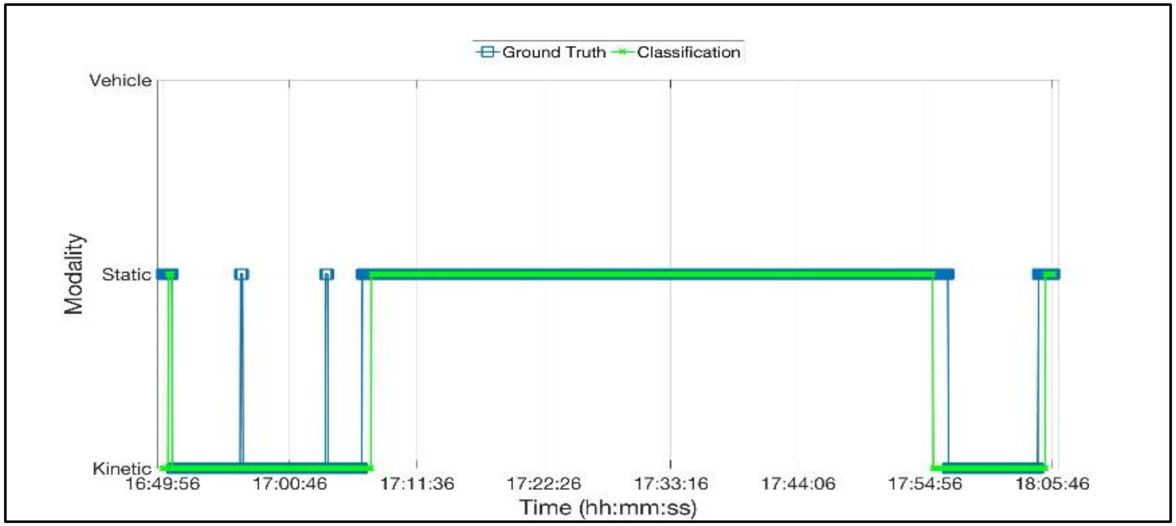
Example Classifications

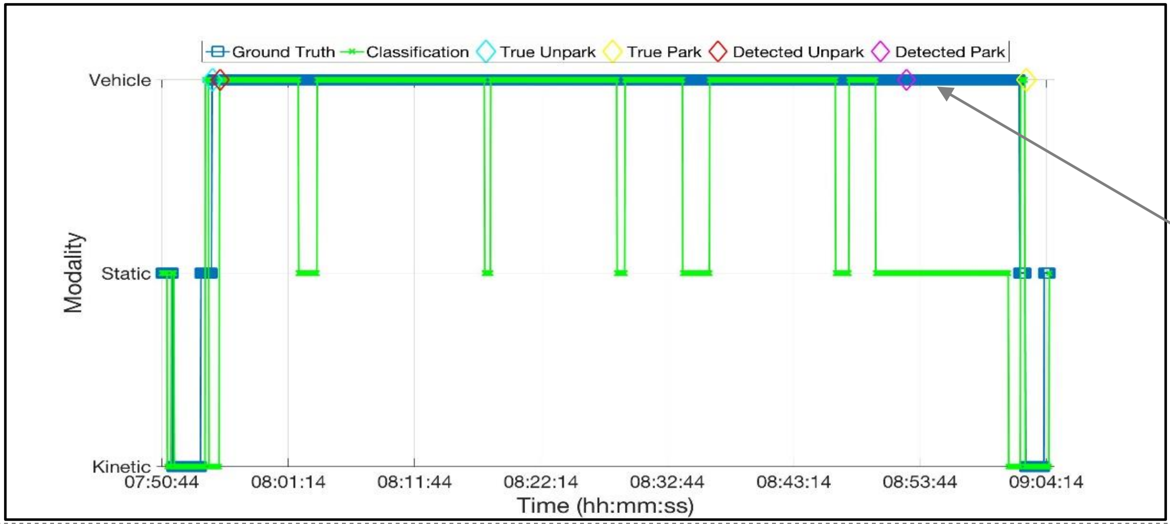
Note that parking activity tags (diamonds) are very close to the classified results

Classification = ParkUs application detection results (green crosses)
Ground truth = collected user data (blue boxes)

Example Classifications

Successful all negative (walking) test





Only false negative result in data set

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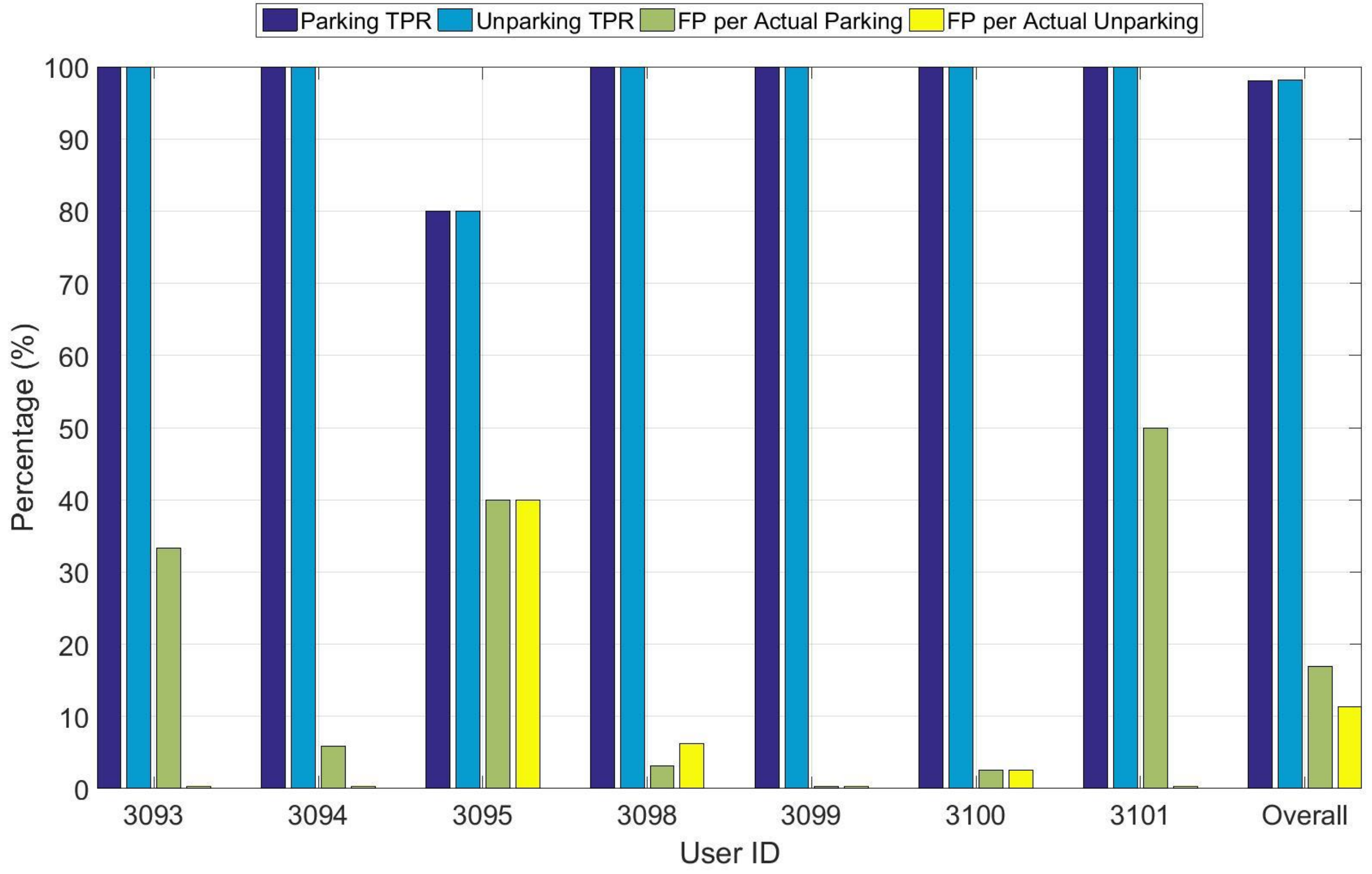
Detection Results



Performance Comparison

Study	Modality Detection Accuracy	Unparking True Positive Rate	Parking True Positive Rate	Probability of false positive	Detection Delay (minutes)	Size of Dataset	2400 mAh, 3.7V Battery Drain Estimate (%)
ParkUs	0.96	0.98	0.98	0.19	0.90	111 events 7 users	8.00
ParkUs-SA		0.98	0.98	0.12	1.00		12.0
PhonePark[1]	0.93	0.85	0.80	N/P	N/P	N/P events 5 users	67.0
ParkSense[2]	0.93	0.83	N/P	N/P	5.30	41 events N/P users	21.0
Park Here![3]	0.90	1.00	1.00	0.11 (No Bluetooth) 0.00 (With Bluetooth)	N/P	40 events N/P users	12.5

[1] L. Stenneth, O. Wolfson, B. Xu, and P. S. Yu, "PhonePark: Street parking using mobile phones," *Proc. - 2012 IEEE 13th Int. Conf. Mob. Data Manag. MDM 2012*, pp. 278–279, 2012.
[2] S. Nawaz, C. Efstratiou, and C. Mascolo, "ParkSense : A Smartphone Based Sensing System For On-Street Parking," in *MobiCom'13*, 2013, pp. 75–86.
[3] R. Salpietro, L. Bedogni, M. Di Felice, and L. Bononi, "Park Here! a smart parking system based on smartphones' embedded sensors and short range Communication Technologies," in *IEEE World Forum on Internet of Things, WF-IoT 2015 - Proceedings*, 2016, pp. 18–23.

Future Work: UWE Planned Trial

- 5,000 users
- 2,000 parking spaces
- Users not supposed to park on streets
- Huge park search problem
- Aim to gather data to test our algorithm and learn to detect park searching behaviour and parking type

Acknowledgements

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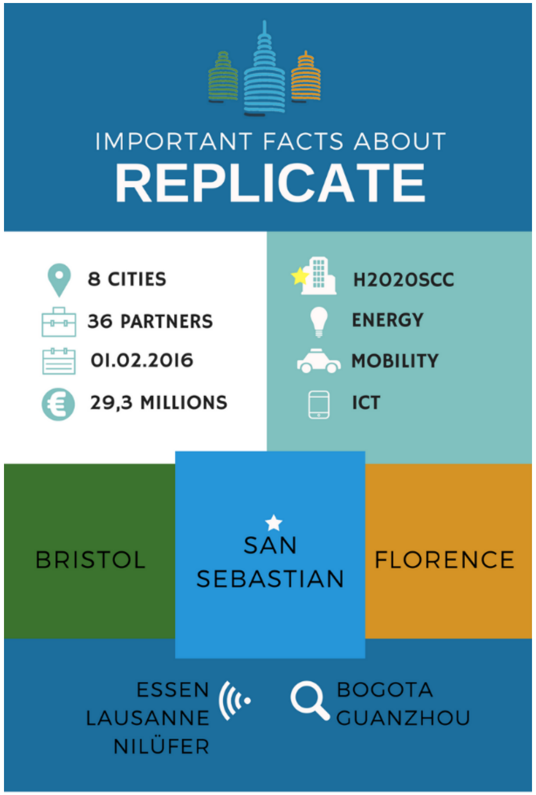

Appendix – Energy Consumption Comparison

Energy Model Test Case Scenario Assumptions

PhonePark: Bluetooth turned off, GPS sampled every 15s, 3G transmission every 15s, accelerometer briefly turned on for 3 minutes after each parking event and no false positives: $E_{go}(T_{out}, T_{out}/15) + E_{gi}(T_{in}, T_{in}/15) + E_{ut}(T, T/15) + E_{ac}(3 \times 60 \times 2) = 10600J$

ParkSense: Wi-Fi scans every 60s when user is away, Wi-Fi scans every 2s when user driving, 3G transmission with GPS location for 4 of the detected events, no false positives. It is assumed that ParkSense is able to detect parking to aid comparison: $E_{ws}(T_{out}, T_{out}/2) + E_{ws}(T_{in}, T_{in}/60) + 4E_{er} = 3330J$

Appendix – Energy Consumption Comparison

Park Here!: Accelerometer and gyroscope turned on throughout, 3G transmission with GPS location for 4 of the detected events, no false positives: $E_{ac}(T) + E_{gy}(T) + 4E_{er} = 1840J$

ParkUS: Accelerometer and compass turned on throughout, 3G transmission with GPS location for 4 of the detected events, 0.192 false positive probability: $E_{ac}(T) + E_{mg}(T) + (4 + 4 \times 0.192)E_{er} = 1240J$

ParkUs-SA: Accelerometer and compass turned on throughout, 4 GPS samples per detected event, 3G transmission for 4 of the detected events, 0.121 false positive probability: $E_{ac}(T) + E_{mg}(T) + (4 + 4 \times 0.121)(E_{er} + 4E_{go}(30, 4)) = 1880J$

Appendix – Energy Consumption Comparison

Table 2: Energy consumption model; governing equations

	Process	Energy Estimate
UMTS	Idle-off	$E_{io}(T,N) = max(min(T + T_{io}, N \cdot T_{io}) \cdot P_i, 0)$
	Active-idle	$E_{ai}(T,N) = max(min(T + T_{iai}, T_{ai} \cdot N) \cdot (P_a, 0)$
	Tail	$E_t(T,N) = E_{ai}(T,N) + E_{io}(T - N \cdot T_{ai}, N)$
	Send	$E_s(N) = N \cdot P_a \cdot T_{tr}$
	Total	$E_u(T,N) = E_s(N) + E_t(T - N \cdot T_{tr}, N)$
GPS	Outdoors	$E_{go}(T,N) = min(T + T_{gpo}, N \cdot T_{gpo}) \cdot (P_{go})$
	Indoors	$E_{gi}(T,N) = min(T + T_{gpo}, N \cdot T_{gpo}) \cdot (P_{gi})$
	Event Report	$E_{er} = E_{go}(1,1) + E_{ut}(1,1)$
	Wi-Fi	$E_{ws}(T,N) = N \cdot T_{wtr} \cdot P_{ws} + T \cdot P_{wi}$
	Gyr.	$E_{gy}(T) = T \cdot P_{gy}$
	Acc.	$E_{ac}(T) = T \cdot P_{ac}$
	Compass	$E_{mg}(T) = T \cdot P_{mg}$

Appendix – Energy Consumption Comparison

Sensor/Component	Average Power Consumption (mW)	Symbol
Wi-Fi Scan	1426	P_{ws}
Wi-Fi Connected	635	P_{wc}
UTMS (3G) active	645	P_{ua}
UTMS (3G) idle	466	P_{ui}
GPS (Outdoors)	597	P_{go}
GPS (Indoors)	357	P_{gi}
Bluetooth Connected	185	P_{bc}
Bluetooth Scan	195	P_{bs}
Gyroscope	103	P_{gy}
Accelerometer	55	P_{ac}
Wi-Fi Idle	42	P_{wi}
Compass (Magnetometer)	45	P_{mg}

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