Sensor Systems and Data Analytics to Measure Cognitive Ability while Driving

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Objective

- Continuous monitoring of instrumental activities of daily living as an alternative to repetitive cognitive testing.
- Driving is a high cognition activity.
- Hypothesis:
  - The repetitive nature of routine trips can be compared over time to identify changes.
  - Navigational ability and trip planning
  - Vehicle operation (turn signal use)

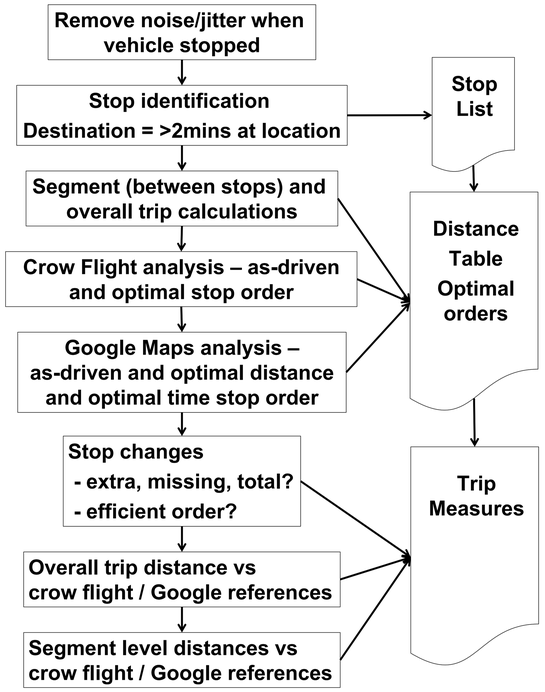
Background

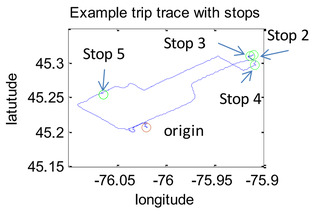
- Increasing numbers patients with dementia / Alzheimer's Disease.
- Clinical cognitive measurement challenges
  - Time consuming and costly
  - Variable: patient tiredness, focus, time of day
- Risk of driving with dementia vs. benefit of maintaining social engagement
  - Social engagement slows cognitive decline.
  - Driving enables social engagement
- Proposed driving variables vs. cognition:
  - reduced variety of destinations
  - reduced driving distance
  - avoiding distant destinations
  - reduced complexity of trips
  - variation in use of turn signals

Methodology

- 10 trips captured with 2 healthy drivers.
- Sensors: GPS, dashboard video
- Signal detection from dashboard video
- Trip Planning analysis:
  - Identification of the destinations/stops
  - Analysis to identify optimal order
- Route Planning analysis:
  - Measurement of the path travelled.
  - Comparison to gold standard routing.
- Turn signal usage
  - Indicator use from dashboard video analysis
  - Turns: from GPS location trace and post drive GIS turn by turn instructions

Algorithm (Navigation)





Training Trip: Counter clock-wise travel starting at red circle.

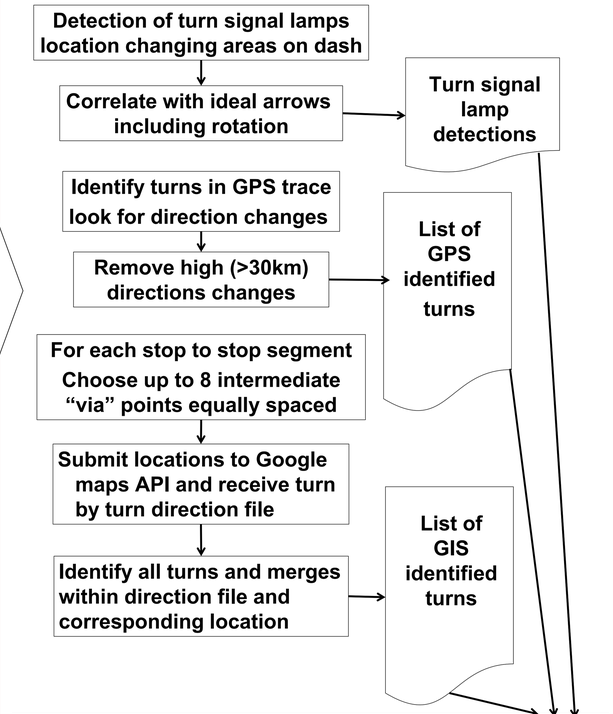
Origin stop	Destination stop	As-driven (km)	Crow flight (km)	Google (km)	As-Driven (min)	Google (min)
1	2	21.26	14.48	21.19	19.80	19.93
2	3	0.56	0.46	1.14	2.50	3.85
3	4	2.01	1.59	2.24	4.92	5.17
4	5	17.30	13.03	17.31	18.82	22.92
5	1	12.71	6.34	12.62	14.82	18.28

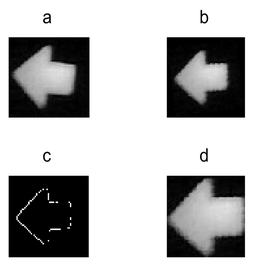
Comparison of training trip segment results to Crow flight and Google routing references

Case	Distance (km)	Stop Order
As-driven	54.3	1, 2, 3, 4, 5
Crow flight as driven	35.9	1, 2, 3, 4, 5
Crow flight optimal	34.9	1, 4, 2, 3, 5
Google as driven	54.5	1, 2, 3, 4, 5
Google optimal distance	53.4	1, 4, 3, 2, 5
Google optimal time	53.4	1, 4, 3, 2, 5

Trip level analysis and stop order optimizations for training trip.

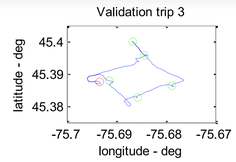
Algorithm (Turns)



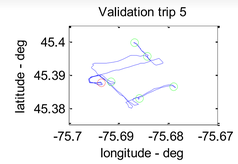


Example of arrow detection algorithm image processing steps.
a – Difference image for raw window containing potential signal arrow.
b – Candidate image rotated to position with optimal correlation.
c – Edge detection results for rotated candidate arrow.
d – Cropped candidate arrow used for correlation.

Results



Trip 3: Counter clock-wise travel, starts at red circle.



Trip 5: Travel with backtracking to start (red circle)

Attribute	Count
Total stops on trips	58
Stops found by algorithm	58
Extra stops found (false positive)	0
Stops missed (false negative)	0

Performance of the stop detection algorithm for all stops within the validation data set.

Attribute \ Trip		Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10
Actual stops		6	6	6	7	5	5	5
trip stop difference from baseline		0	0	0	1	-1	-1	-1
Number of baseline stops missed		0	0	0	0	1	4	4
Baseline stop missed	stop #	none	none	none	none	4	3 4 5 6	3 4 5 6
Count of non baseline stops		0	0	0	1	0	3	3
Overall trip delta from baseline average	m	-266	4904	482	1596	-1266	3060	1461
Overall trip distance change	#sd	1.01	18.63	1.83	6.06	4.81	11.6	5.5
Trip variation from Google as-driven route	#sd	1.98	20.78	1.32	6.22	6.37	12.7	5.62
Trip variation from Google distance optimal route	#sd	2.75	77.87	8.92	26.28	18.34	49.1	24.2
Trip variation from Google time optimal route	#sd	2.75	77.76	8.90	26.24	18.32	49.0	24.1
Segment variation from baseline Google segments	#sd	1.37	10.40	0.25	0.67	1.20	2.52	0.79

Summary of the analysis results for the 7 validation trips as compared to the baseline trip formed from trips 1, 2 and 3..

Turns	GPS only	Google only
Right turns (n=131)		
Detected turns	73%	62%
False Positive errors	3%	5%
False Negative errors	14%	23%
Left turns (n=86)		
Detected turns	72%	55%
False Positive errors	2%	6%
False Negative errors	15%	24%
Total (n=215)		
Detected turns	73%	58%
False Positive errors	3%	4%
False Negative errors	14%	21%

Summary of the performance for the GPS and GIS remapping algorithms in the detection of turn and merge events within the trips.

Signalled Turns	GPS only	Google only	Combined
Right turns	81	74	89
Left turns	55	46	62
Total	136	120	151

Summary of the result for the association of signaling events (lamp use) with identified turns.

Summary

- The proposed algorithms measure travel navigation, route planning and turn signal use by driver.
- Google Maps Reference: algorithm to automatically use Google Maps as a gold standard providing a comparison point for a drivers performance.
- GIS and GPS Reference: algorithm to automatically detect turn signal use and turns providing a measure for driver performance.
- Summary: use of ongoing analysis of high cognition activities of daily living such as driving could be proxy for change in a patient's cognitive ability.