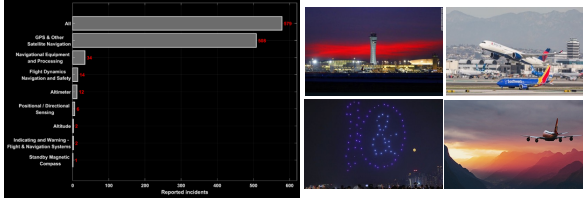# CAREER: Situational Awareness Strategies for ... in ... Uncertain Environments

Zak M. Kassas, The Ohio State University
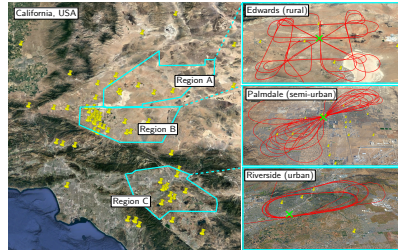https://ece.osu.edu/aspin

Aviation Safety Reporting System

Objective:
- Develop radio SLAM: a GPS-less reliable and accurate autonomous navigation system, exploiting ambient terrestrial signals
- Demonstrate radio SLAM on high-altitude US Air Force aircraft

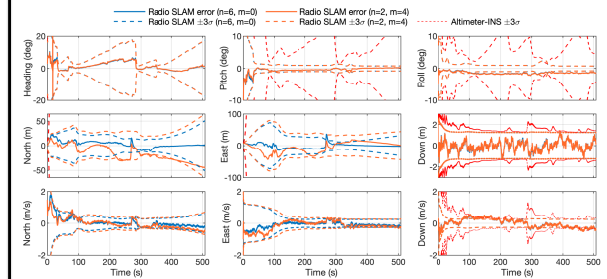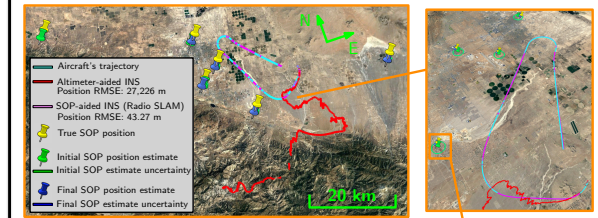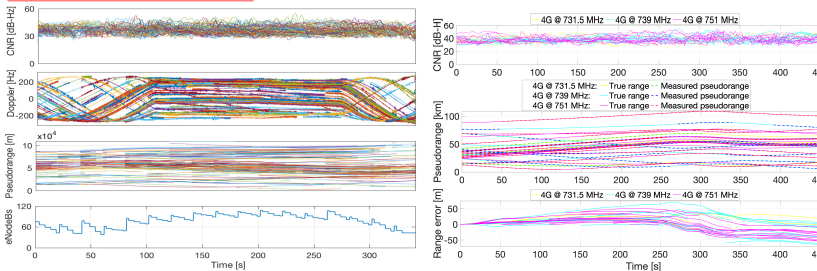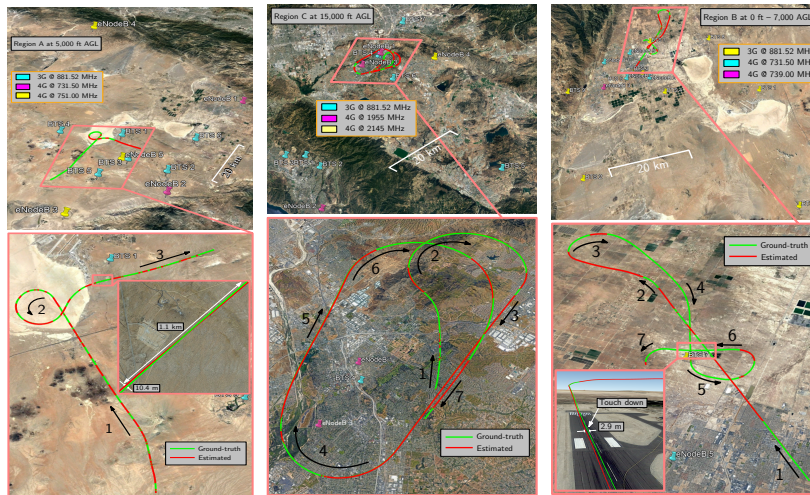## SNIFFER: Signals of opportunity for Navigation In Frequency-Forbidden EnviRonments

GPS antennas · Hardware setup · Equipment rack · C-12 aircraft "Ms. Mabel" · Cellular antennas · Layer A

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Region A: Altitude Range (AGL): 10,761 – 9,777 ft

Flight Regions and Trajectories

California, USA · Region A · Region B · Region C · Edwards (rural) · Palmdale (semi-urban) · Riverside (urban)

Navigation Performance with Cellular Signals

Metric	Region A	Region B	Region C
Cellular towers {3G, 4G}	{6, 5}	{9, 5}	{7, 4}
Cellular frequencies (MHz)	881.52	881.52	881.52
	731.5	731.5	1955
	751	739	2145
Flight duration (mins)	9	11	8.5
Flight length (km)	51	57	55
Altitude AGL (ft)	5,000	0 – 7,000	15,000
Position RMSE (m)	10.53	4.96	11.67
Velocity RMSE (m/s)	0.58	0.50	0.71
Maximum position error (m)	22.67	15.04	25.89
Maximum velocity error (m/s)	2.29	3.19	3.94

Region A at 5,000 ft AGL · Region C at 15,000 ft AGL · Region B at 0 ft – 7,000 ft AGL

3G @ 881.52 MHz · 4G @ 731.50 MHz · 4G @ 751.00 MHz · 4G @ 1955 MHz · 4G @ 2145 MHz · 4G @ 739.00 MHz

Ground-truth · Estimated · Touch down · 2.9 m

CNR [dB-Hz] · Doppler [Hz] · Pseudorange [m] · eNodeBs

4G @ 731.5 MHz · 4G @ 739 MHz · 4G @ 751 MHz · True range · Measured pseudorange · Range error [m]

3G @ 881.52 MHz · 4G @ 731.5 MHz · 4G @ 739 MHz

(Right column figures)

Aircraft's trajectory · Altimeter-aided INS Position RMSE: 27,226 m · SOP-aided INS (Radio SLAM) Position RMSE: 43.27 m · True SOP position · Initial SOP position estimate · Initial SOP estimate uncertainty · Final SOP position estimate · Final SOP estimate uncertainty

20 km

Radio SLAM error (n=6, m=0) · Radio SLAM ±3σ (n=6, m=0) · Radio SLAM error (n=2, m=4) · Radio SLAM ±3σ (n=2, m=4) · Altimeter-INS ±3σ

Heading (deg) · Pitch (deg) · Roll (deg) · North (m) · East (m) · Down (m)

n = # of known towers; m = # of unknown towers

Radio SLAM error (m=2, m=4) · Radio SLAM ±3σ (m=2, m=4) · Measurements available

Error · ±3σ · East [m] · North [m] · Velocity [m/s] · Clock bias difference [s] · Clock drift difference [s]

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