Doppler Navigation System for GPS - Denied Environments

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Abstract

Low Earth Orbit (LEO) satellites in the Amateur Radio Band can be used as signals of opportunity to provide a rough global position fix. By measuring the Doppler Shift of incoming signals with a software-defined radio, our developed algorithm determines a user's location in emergency situations.

Motivation

Resistance to Jamming & Spoofing

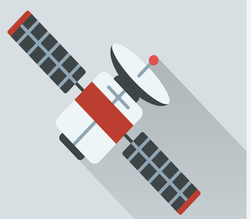
LEO satellites are unlikely to be successfully targeted by an enemy. They transmit on multiple frequencies, and are not traditionally used for navigation.

Low Cost & Lightweight

With a hardware implementation for under $50, and a weight under 2kg, the system is functional for backpacking, nautical and other stationary field survival applications.

Industry Trends

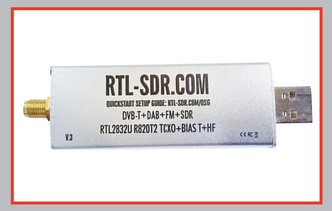
LEO satellites are often less expensive to build and launch than GEO or MEO counterparts. Large proposed constellations of LEO satellites could improve the coverage and accuracy of the system.



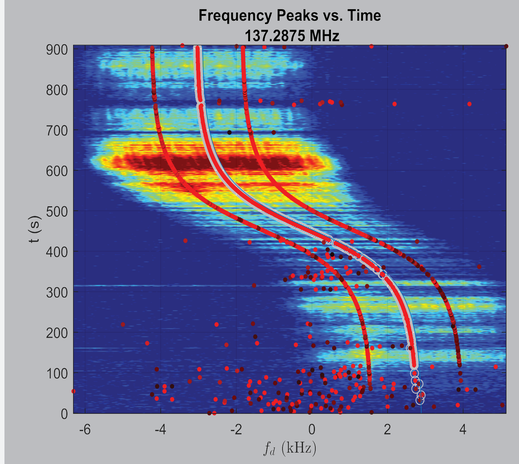
Methods

Hardware and Recording

The RTL-SDR is a software defined radio with a frequency range of 500 kHz - 1.7 GHz and 3.2 MHz of instantaneous bandwidth. The small dongle is programmably tuned to the center frequency of the desired transmitter as the satellite passes directly overhead. An omnidirectional dipole antenna was employed to eliminate the need for a rotator, and the bandpass filter effectively reduced major sources of terrestrial noise.



Measuring Doppler Shift

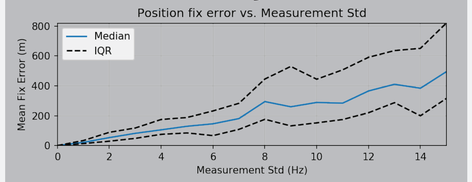


The transmitter carrier frequency is recovered using a modified version of the multiply-filter-divide algorithm. The incoming recording is processed in real time, and the strongest frequency peaks are stored with a corresponding confidence metric. Following outlier removal, the final frequency estimates, indicated with a white outline (left), reveal the frequency shift of the signal due to the Doppler effects of the satellite motion.

Optimization

Finding the location on Earth that corresponds to the smallest error in observed Doppler shift is computationally expensive due to the required orbital mechanics. The L-BFGS algorithm, a quasi-Newton algorithm, provides fast convergence to the global minimum of the cost function.

Error Analysis



Results

System Output

```
[23:42]  [Processor]  Processed:     data_frank/ORBCOMM FM108\data00129.mat        137.4600 MHz
[23:42]  [Processor]  Processed:     data_frank/ORBCOMM FM108\data00129.mat        137.7125 MHz
[23:42]  [Processor]  Added Folder:     data_frank/ORBCOMM FM108/
[23:42]  [Optimizer]  Added Folder:     data_frank/ORBCOMM FM108\137p4600\  115 points
[23:42]  [Optimizer]  Added Folder:     data_frank/ORBCOMM FM108\137p7125\  114 points

[23:42]  [Optimizer]  Lat:        43.8119 °N
[23:42]  [Optimizer]  Lat:       -99.2075 °E
[23:42]  [Optimizer]  SDR Error:    58.96 Hz
[23:42]  [Optimizer]  Final Error:  1.03 km

[23:42]  [Optimizer]  Satellite:        ORBCOMM FM108       ORBCOMM FM108
[23:42]  [Optimizer]  Expected:          137.4600 MHz        137.7125 MHz
[23:42]  [Optimizer]  Offset:                58.96 Hz            58.96 Hz
[23:42]  [Optimizer]  Mean of SR:          9.14e-01            9.20e-01
[23:42]  [Optimizer]  # Points:                 115                 114
```

Performance

Guaranteed Accuracy: 2km

Wait Time: <15 minutes of a suitable satellite pass

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DRAPER