Student Projects for Space Navigation and Guidance

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Two Group Projects

- Determination of a satellite orbit from telescope observations of a satellite.
- Position determination of a Global Positioning System (GPS) receiver from data on the web.

The Class

- This class: ENAE 441 *Space Navigation and Guidance* covers orbit determination, including estimation, and GPS
- Previous class: ENAE 404 *Space Flight Dynamics* covers basics of orbit and attitude mechanics
- Students have spent the semester mastering orbit determination techniques
- Differential correction (Newton's method) as a solution to nonlinear vector equations, including least squares for estimation

The Project and its Goals

- Group project is required of all students
- Ideally 4 students in a group
- Teach the concepts learned in class, but in a practical setting with real data, acquired the hard way
- Not as easy as a textbook, but ideas still work
- Verbal and written expression of what was done and what was learned

Observatory project

- University observatory near campus
- 2° field of view spotting scope for 14" Schmidt Cassegrain
- Keypad entry RA, dec
- Trees, haze
- Move quickly!

Students from 2001 class at the observatory;
James Clark, Troy Sookdeo, Brian Kujawa, Ben Lee, Neal Gupta
Photo from their report

Predict satellites from Heaven's Above

- http://heavens-above.com
- Given lon, lat, shows visible satellites that evening
- Star chart available with more precise data
- Details on satellite (TLE, etc.)
- Sometimes old elsets

Heavens Above

Daily predictions for brighter satellites | Home | Prev. PM | Next PM | Prev. AM | Next AM | Help |

Search Period Start: 12:00 Sunday, 20 July, 2003
Search Period End: 01:00 Monday, 21 July, 2003
Observer's Location: Big Sky Meadow Village (45.2680° N, 111.3010° W)
Local Time: Mountain Daylight Time (GMT - 6:00)
Limiting magnitude: 3.5

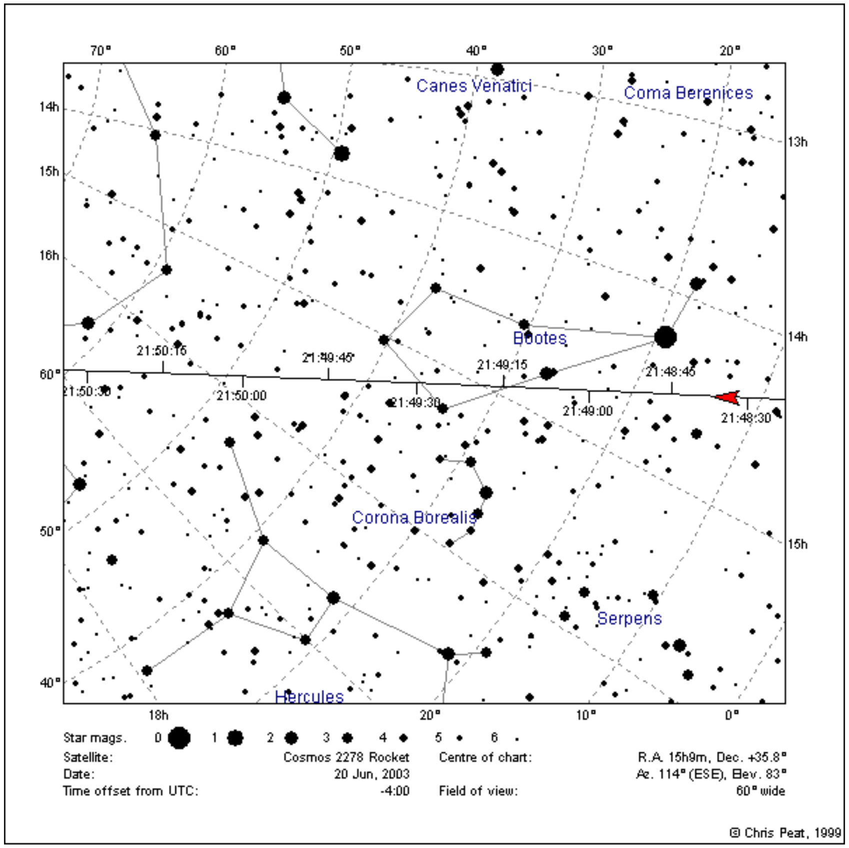
NEW! Click on the time of max. altitude to get a star chart and other pass details.

Satellite		Starts			Max. Altitude			Ends		
Name	Mag	Time	Alt.	Az.	Time	Alt.	Az.	Time	Alt.	Az.
Okean O Rocket	2.8	21:38:00	10°	SSE	21:42:24	80°	ENE	21:46:53	10°	N
ISS	-0.2	22:13:50	10°	SSW	22:16:47	39°	SE	22:19:44	10°	ENE
Envisat	2.9	22:42:22	18°	SSE	22:46:17	83°	ENE	22:51:29	10°	NNW
UARS	3.0	23:24:31	10°	NW	23:28:38	70°	NE	23:30:06	39°	ESE
Cosmos 1980 Rocket	3.3	23:41:36	20°	SSW	23:45:39	88°	N	23:51:17	10°	NNE
ISS	0.8	23:49:53	10°	W	23:52:52	39°	NNW	23:55:51	10°	NE

Developed and maintained by Chris Peat, Heavens-Above GmbH
Please read the updated FAQ before sending e-mail.

Hosted by DLR/GSOC

Starchart from Heaven's Above



- Clicking on “Max Altitude” (elevation) time brings up star chart
- Sky track with 30 second ticks
- Click to center, read RA/dec at bottom

Making Observations

- Students arrange for observatory time
- Prepared with information about several satellites
- Data 1 minute apart, several minutes between satellites
- Jobs: Secretary, keypad, observer, flashlight
- Practice; first satellite is usually a lost cause
- Weather must be reasonably clear

Observation data and processing

- As satellite comes nearest the crosshairs, time is recorded
- Fractional estimate of how close it came
- Not always exact: old elements, etc.
- Gauss angles-only orbit determination
- Orbit estimation
- Several satellites for good luck

COBE observations
Seven observations in one pass
November 6, 2000

Predicted Time (EST)	Observed Time (EST)	Right Ascension	Declination	Offset (0-10)
17:31:30	17:31:29	21:48:00	-16.3°	1
17:32:30	17:32:30	21:41:00	-2.0°	0
17:33:30	17:33:30	21:31:45	19.3°	0
17:34:30	17:34:30	21:14:00	46.9°	3
17:35:30	17:35:29	20:28:00	71.9°	3
17:36:30	17:36:30	15:01:00	84.6°	2
17:37:30	17:37:30	11:03:00	76.1°	0

COBE Cartesian processed

Parameter	X (km)	Y (km)	Z (km)	Vx (km/s)	Vy (km/s)	Vz (km/s)
Actual	3528.320	-4313.871	4654.938	-4.1033	2.658	5.564
Initial Orbit Determination	3522.654	-4309.333	4646.863	-4.048	2.631	5.499
Full Estimation	3533.316	-4319.816	4659.711	-4.143	2.676	5.636
Standard Deviation	14.524	12.545	20.598	0.144	0.086	0.189
Difference estimated-actual	4.996	-5.945	4.773	-0.040	0.018	0.072
Time adjusted estimation	3515.942	-4303.236	4632.720	-3.983	2.586	5.404
Time adjusted standard deviation	4.921	4.234	6.954	0.049	0.029	0.064
Difference time adjsted-actual	-12.378	10.635	-22.218	-3.983	-0.072	-0.160

Positions within a few km, velocities tens m/s

COBE Elements

Convert the previous Cartesian results to elements:

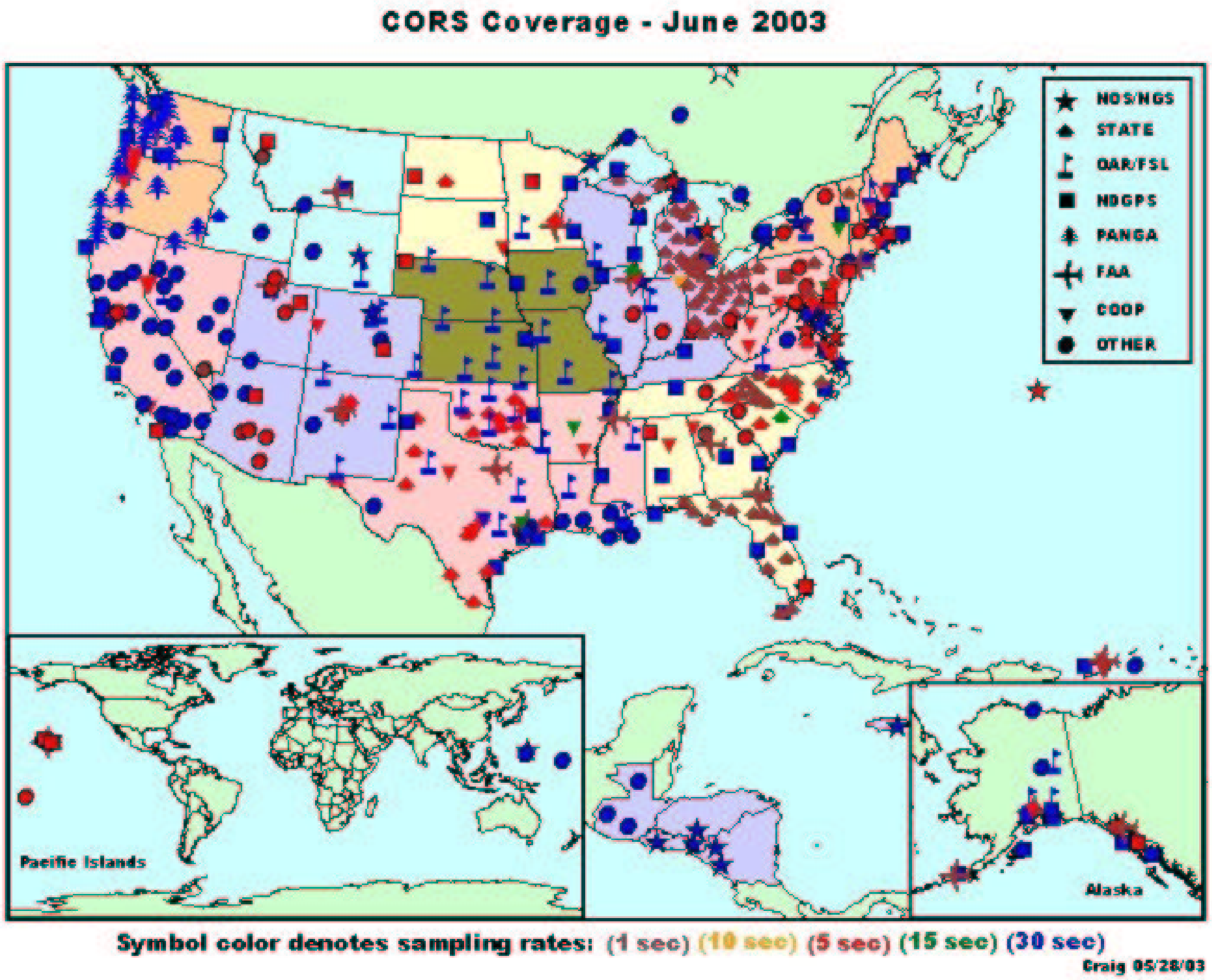
Parameter	a (km)	e	i	RAAN	Arg. perigee	Mean anomaly	Mean arg. latitude
Actual	7264.91	0.00100	98.900	-43.204	163.259	-122.706	40.553
Gauss IOD	7062.92	0.02625	98.870	-43.256	-142.214	-177.231	40.555
State estimate	7441.31	0.02300	98.916	-43.192	37.549	2.768	40.317
Time + state estimate	6822.07	0.06052	98.895	-43.253	-141.282	-178.103	40.615

- Agreement for inclination, RAAN are good (green)
- Semimajor axis could be better (yellow)
- Near circular orbit, eccentricity and elements based on perigee are bad (red)
- but mean argument of latitude, sum of mean anomaly and argument of perigee, is very consistent

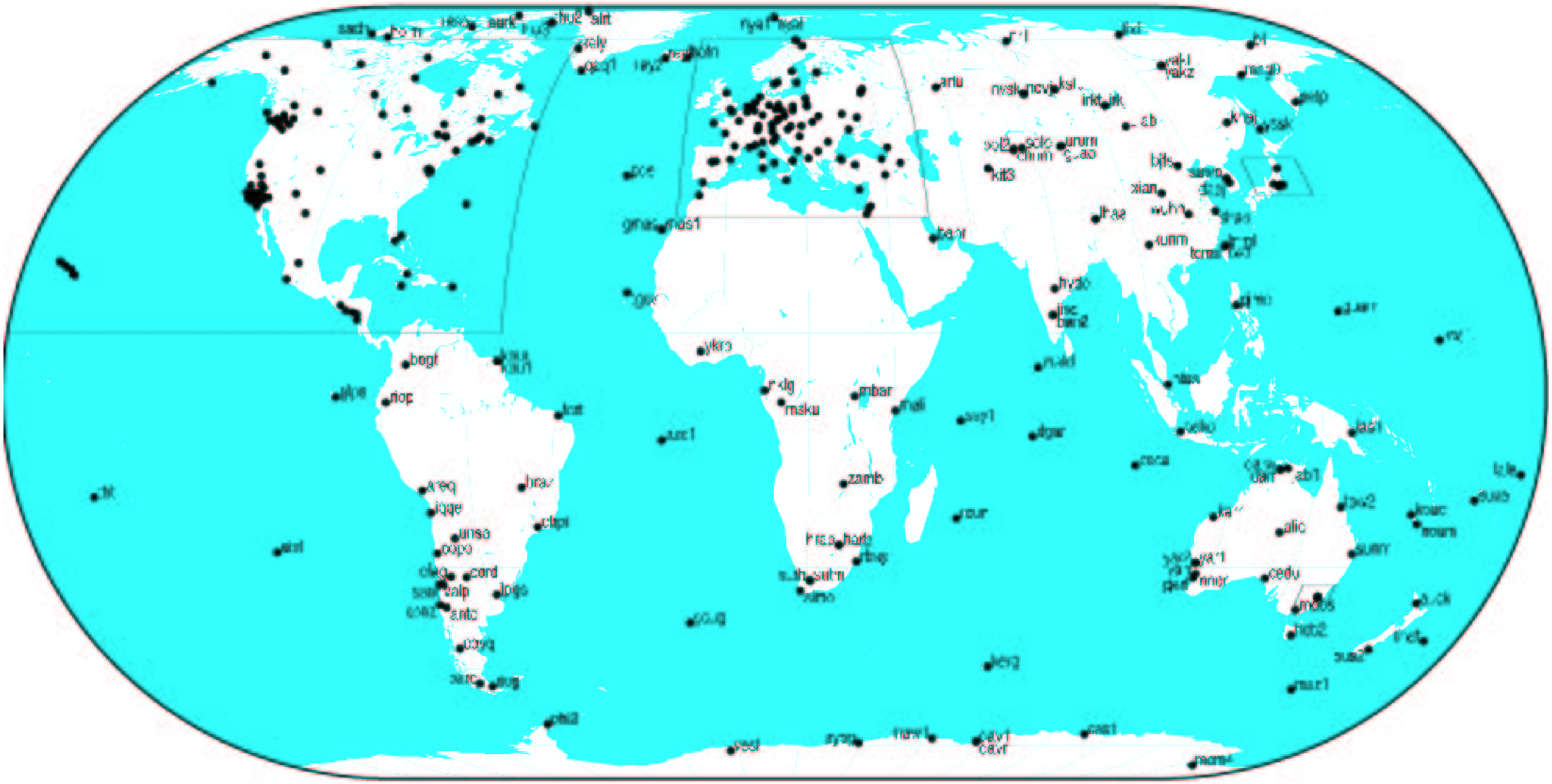
GPS Project

- Two web sites with GPS receiver data:
  - CORS *Continuously Operated Reference Stations* *http://www.ngs.noaa.gov/CORS*
  - IGS *International GPS Service* *http://igscb.jpl.nasa.gov/*
- Data is in industry-standard RINEX format
- Not as much fun as hands-on data acquisition, but plenty challenging nonetheless

CORS: 387 sites, US & Possesions

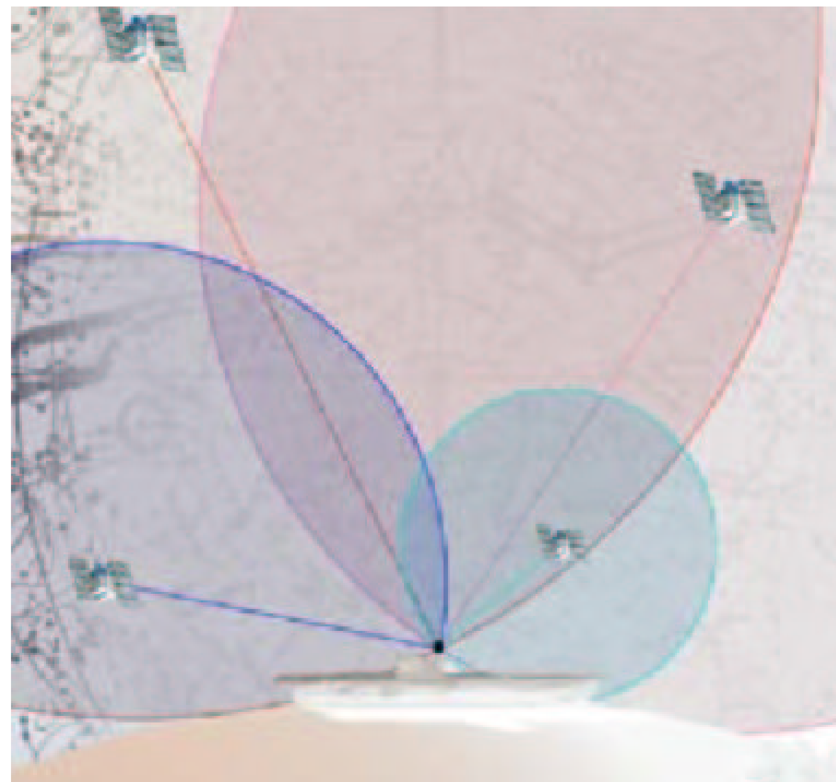


IGS: 359 International Sites



Position determination with GPS

- *Upside-down orbit determination*: satellite orbit known, but not observer's position
- Trilateration; minimum of 4 satellites (solve for receiver clock bias)



National Air & Space Museum web site

Solving position equations

- Simultaneous solution of 4 equations (one for each satellite)
- 4 unknowns (three position + clock bias)
- Linearized equations, iterate to converge to solution
- Any starting position is OK: center of earth
- Differential correction: add rows to Jacobian matrix A

Interpreting Data

- Two RINEX files,
  - OBS (.03o) with receiver data
  - NAV (.03n) with SV (GPS sats) ephemeris
- Algorithms for computing ITRF position at any desired time from NAV data
- Code pseudoranges from OBS data
- Reading file: compressed gzip, zip, or compress, some browsers do a bad job
- Finding fields and interpreting columns correctly

THTI: Papeete, Tahiti receiver data

- On 2003-06-06 12:30:00 GPS, there were signals received from 8 GPS satellites
- Process
  - 4 lowest PRN#s: 6, 9, 10, 17
  - then full 8 for one time
  - then 8 for three times (24 points, one minute period, 30 second data interval)

THTI Position determination

Parameter (km)	4 PRN Determination	8 PRN Estimation	8 PRN Standard Deviation	Actual	Difference
ITRF x	-5246.263	-5246.318	0.056	-5246.412	0.0945
ITRF y	-3077.204	-3077.258	0.044	-3077.276	0.0187
ITRF z	-1913.791	-1913.823	0.022	-1913.825	0.0018
Clock bias ct	34.013	34.058	0.043		
				distance (m)	96.31

Accuracy of results

- All sites tried show 50-100m error; student experiences similar
- Error not in a notable direction (e.g. up)
- Ionospheric correction only helps a tiny bit
- Adding more data does not help, not random noise
- Still a mystery

Experiences

- Observatory last three fall semesters, GPS last fall; both will be repeated
- Students take project seriously, and do an excellent job in the investigation
- Written and oral reports leave something to be desired
- I have started working with them during the semester on the reports so they understand how to write/present research papers