Smartphone Video Guidance Sensor for Small Satellites

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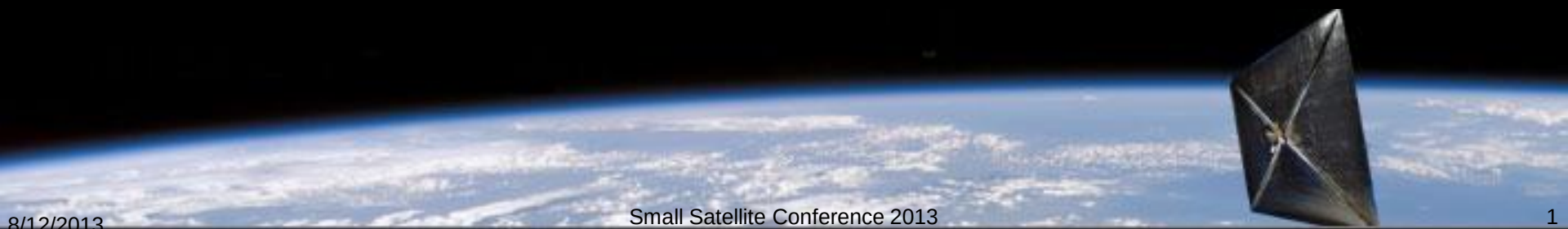
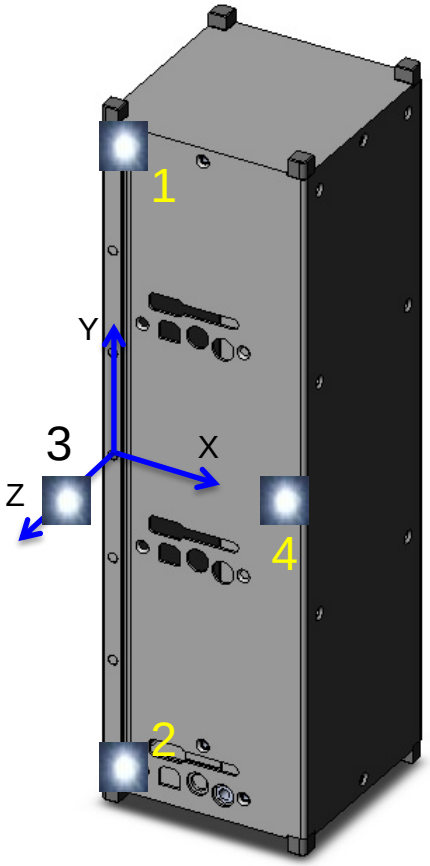


SVGS Overview/Concept

- Smartphone Video Guidance Sensor (SVGS) is a low mass, low cost COTS implementation of the MSFC-developed Advanced Video Guidance Sensor AR&C sensor
- Designed for cubesats and small satellites
- Based on an Android smartphone platform
- Captures images using the smartphone camera and flash and analyzes the pattern of the illuminated retroreflectors on the target spacecraft using photogrammetry techniques to determine the range and relative orientation (6-DOF state)
- Enables multi-spacecraft formation flying using cubesats or other small satellites
- Initial development began as a project in FY12

SVGS Concept of Operations

Target Spacecraft (3U CubeSat)



Camera Flash Light Source

Illuminated Targets

Chaser Spacecraft

Smartphone

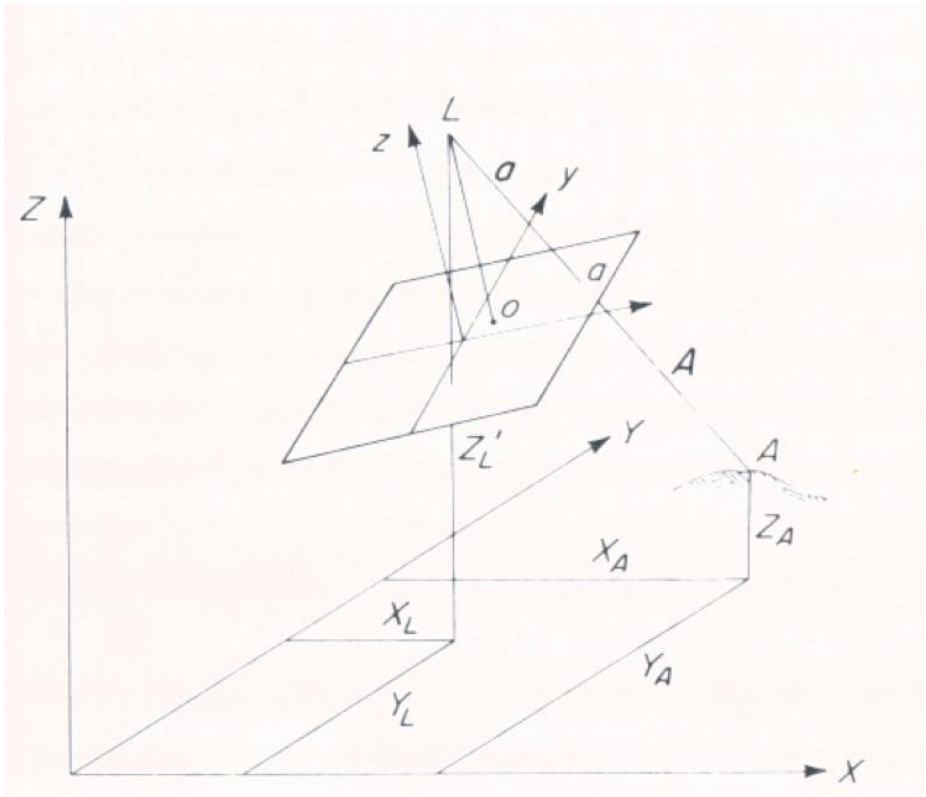
Image

Image Processing & SVGS Algorithms

6-DOF State

GN&C

Collinearity Formulation



$$\boldsymbol{v_A} = \begin{bmatrix} X_A - X_L \\ Y_A - Y_L \\ Z_A - Z_L \end{bmatrix}$$

$$\boldsymbol{v_a} = \begin{bmatrix} x_a - x_0 \\ y_a - y_0 \\ -f \end{bmatrix}$$

$$v_a = kMv_A$$

$$x = f\frac{m_{11}(X - X_L) + m_{12}(Y - Y_L) + m_{13}(Z - Z_L)}{m_{31}(X - X_L) + m_{32}(Y - Y_L) + m_{33}(Z - Z_L)} + x_0$$

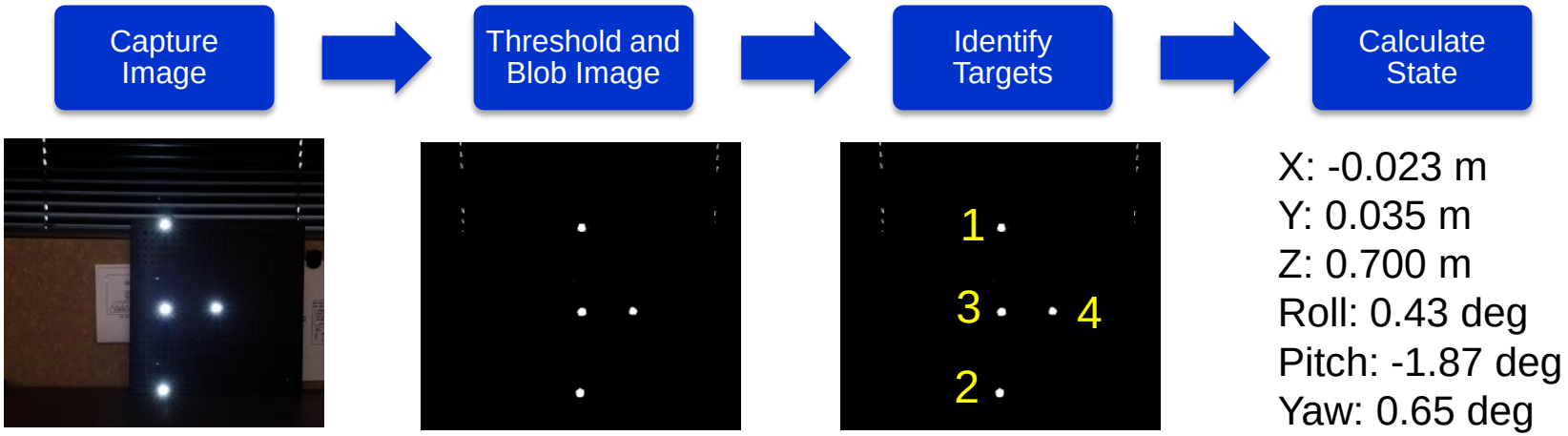
$$y = f\frac{m_{21}(X - X_L) + m_{22}(Y - Y_L) + m_{23}(Z - Z_L)}{m_{31}(X - X_L) + m_{32}(Y - Y_L) + m_{33}(Z - Z_L)} + y_0$$

$$Az = \tan^{-1}\left(\frac{x - x_0}{f}\right)$$

$$El = \sin^{-1}\left(\frac{y - y_0}{\sqrt{(x - x_0)^2 + (y - y_0)^2 + f^2}}\right)$$

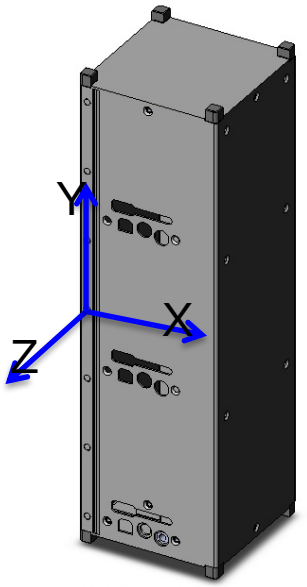
SVGS Software Overview

- **Image processing algorithms coded in native C++ code for increased performance**
- **All other software developed in Android java**



SVGS Prototype System Specs

- **Platform specs (based on unmodified Galaxy Nexus)**
  - Mass – 150 g
  - Size – 13.55 x 6.79 x 0.95 cm
  - Processor – Dual core @ 1.2 GHz
  - Camera resolution – up to 2592 x 1944 px
  - Operating time – ~2 hours (on OEM battery)



- **Sensor specs**
  - State vector accuracy

	Range (m)	
	0-10	**10-30**
X, Y Position Error (m)	< 0.35	< 1.8
Z Position Error (m)	< 0.13	< 0.51
RPY Attitude Error (deg)	< 2	< 3.5

  - Sensor range – 0-45 meters (depends on target pattern spacing)
  - State output rate – 5 Hz @ 1920 x 1080 px image resolution

- **Targets**
  - Nominal -12.7 mm corner cube reflectors (4), in a modified AVGS target pattern (half-cross shape), fit in form factor of 3U Cubesat
  - Choice of targets is flexible but may affect sensor range

Test Setup

Corner Cube Target

Sensor Mount

Target Mount

- **Two COTS smartphones tested – HTC Amaze 4G and Samsung Galaxy Nexus**

Test Results

Amaze 4G

Mean State Error

Range (m)	Position (m)			Attitude (deg)		
	X	Y	Z	Roll	Pitch	Yaw
1	0.07	0.03	0.02	1.0	0.9	0.3
2	0.07	0.04	0.01	0.9	0.6	0.3
3	0.06	0.05	0.03	0.7	0.5	0.3
4	0.07	0.06	0.04	0.5	0.4	0.3
6.5	0.05	0.10	0.07	1.1	0.5	0.7

State Error Standard Deviation

Range (m)	Position (m)			Attitude (deg)		
	X	Y	Z	Roll	Pitch	Yaw
1	0.016	0.022	0.013	0.47	0.52	0.29
2	0.016	0.016	0.009	0.37	0.40	0.14
3	0.028	0.024	0.014	0.43	0.37	0.18
4	0.033	0.028	0.018	0.35	0.32	0.19
6.5	0.037	0.048	0.030	0.44	0.40	0.25

Galaxy Nexus

Mean State Error

Range (m)	Position (m)			Attitude (deg)		
	X	Y	Z	Roll	Pitch	Yaw
5	0.05	0.08	0.07	0.6	0.9	2.0
10	0.10	0.16	0.13	0.7	1.0	1.8
15	0.26	0.30	0.18	0.9	1.2	1.9
20	0.41	0.50	0.23	1.3	1.6	2.0
30	1.12	1.53	0.47	2.2	3.0	1.2

State Error Standard Deviation

Range (m)	Position (m)			Attitude (deg)		
	X	Y	Z	Roll	Pitch	Yaw
5	0.037	0.038	0.039	0.39	0.24	0.04
10	0.077	0.098	0.076	0.50	0.24	0.06
15	0.188	0.193	0.116	0.72	0.36	0.11
20	0.269	0.382	0.140	0.99	0.30	0.13
30	0.744	0.887	0.352	1.50	0.72	0.26

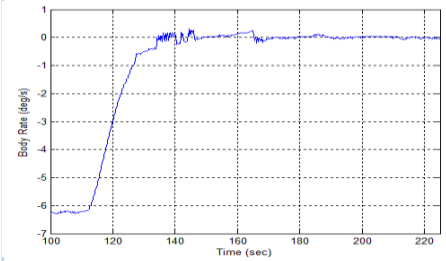
SVGS Future Work

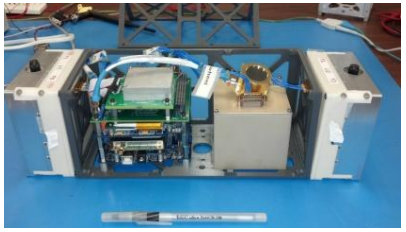
- Increase capabilities of SVGS to work with different target types
- Further miniaturize and remove unnecessary hardware components
- Develop calibration routines for deployment on any Android smartphone

MSFC Cubesat Development Efforts

FY12 CIF – CubeSat ACS

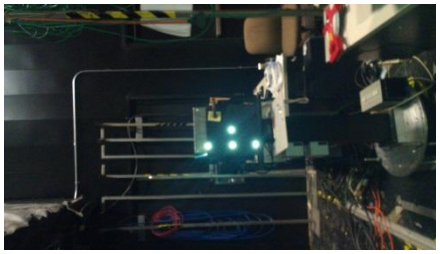
Demonstrated CubeSat attitude control system with MEMS rate gyros, sun sensor, reaction wheels, & micro propulsion system





FY12 CIF – Smartphone Video Guidance Sensor

Smartphone version of Advanced Video Guidance Sensor contains camera, flash, software and processor all in one small, COTS package for 6DOF state estimation of target vehicle



FY13 MSFC TIP – CubeSat Prox Ops

Autonomously rendezvous a CubeSat prototype with another CubeSat or FASTSAT mock-up in MSFC's Flight Robotics Lab ("The Flat Floor")

Technical Objectives

1. Integration and demo of miniature sensor and actuator suite for AR&C
2. Demo of cubesat proxops and formation flying with other small spacecraft