



Flight Results from the nSight-1 QB50 CubeSat Mission

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nSight-1: The Story



- Built by SCS-Space in South Africa
- Late entry to QB50 nSight-1 project started in 2016
- Testbed for in-house developed
 "Gecko" Earth imager
- Short time-to-develop
 - Use COTS sub-systems where possible
 - Borrow from partners CubeSpace and Stellenbosch University
- ZA-AeroSat: Stellenbosch University CubeSat, built for QB50
- QB50 ADCS Units Delivered by Stellenbosch University and University of Surrey to QB50
- ADCS Hardware has since been commercialised by CubeSpace





nSight-1 Layout



nSight-1

- COTS EPS and Communications sub-systems
- Y-momentum ADCS (CubeSpace)
- ✤ QB50 FIPEX science unit
- Gecko Imager





ADCS Hardware





Deployable Magnetometer



Coarse sun sensors



ADCS Bundle: Size = 95 x 90 x 56 mm, Mass = 397 gram





ADCS Requirements

- FIPEX sensor pointing to RAM direction +/- 10 deg
- Attitude estimation accuracy +/- 2 deg
- Gecko Imager pointing to Earth

Sensors & Actuators	Туре	Range / FOV	Accuracy (RMS)	
Magnetometer	etometer 3-axis MagR ± 60 μT		< 40 nT	
Sun Sensor	2-axis CMOS	Hemisphere	< 0.2°	
Nadir Sensor 2-axis CMOS		± 45°	< 0.2°	
Coarse Sun	Coarse Sun6 Photodiodes		< 10°	
Rate Sensor	MEMS	± 85º/sec	< 0.05 deg/sec	
Momentum Pitch wheel	BDC Motor	± 1.7 milli-Nms	< 0.001 milli-Nms	
Magnetorquers	Ferro-magnetic rods & air coil	\pm 0.2 Am ²	< 0.0005 Am ² (remanence)	



SCS Gecko Imager



Gecko Earth Imager

- Modular design
- Compatible with CubeSats
- High-speed high-capacity mass data storage
- FPGA processor for real-time image processing
- High frame rate capability (for larger optics)

Characteristics				
Form factor	< 1U			
Mass	< 480 g			
GSD	31 m from ISS orbit			
Image Sensor	2.2 Megapixel RGB			
Storage	128 GB			
Rad. tolerance	Tested to 30 krad TID			
Space heritage	2017 !			







- XML file defines command and telemetry interface
- Generate flight software source code from XML interface definition
- Generate ground software source code (classes) and also user interface elements from XML interface definition
- Changes to interface occur only in one place (the XML markup) eliminates the possibility of "copy and paste" errors

<Ttcs CanSet="false" CanGet="true" CodeName="PositionLLH" DisplayName="Satellite Position (LLH)" Description="Satellite position in WGS-84 coordinate frame" Len="6" >

<Item CodeName="Latitude" DisplayName="Latitude" Description="WGS-84 Latitude angle " BitOffset="0"
BitLength="16" ValueType="SignedInteger" CalibrationUserToRaw="USERVAL*100.0"
CalibrationRawToUser="RAWVAL*0.01" MeasurementUnit="deg" />

</Ttcs>

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	V X Y F	PositionLL	H 🗌 🗹 151	30 Satellite Position (L	LH) Satellite position in WGS-84 coordinate	frame ADCS State	•	6 🔽	part of AdcsState	~	
	Bit Offse	Bit Len	Name (source code)	Display Name	Description	Value Type		Enumeration	Calibration (User to Raw)	Calibration (Raw to User)	Unit
	288	16	Latitude	Latitude	WGS-84 Latitude angle	SignedInteger	~		RAWVAL*0.01	USERVAL*100.0	deg
	304	16	Longitude	Longitude	Longitude angle	SignedInteger	~		RAWVAL*0.01	USERVAL*100.0	deg
	320	16	Altitude	Altitude	WGS-84 altitude	UnsignedInteger	~		RAWVAL*0.01	USERVAL*100.0	km

Satellite Position (LLH) 😵						
Latitude	-1 <mark>6</mark> .93	deg				
Longitude	23. <mark>4</mark> 0	deg				
Altitude	400.79	km				
Wheel Speed						
X Wheel Speed	rpm					
Y Wheel Speed	rpm					
Z Wheel Speed	0	rpm				



Deployed from the ISS









- Bdot Magnetic Control
 - Damp X/Z-body rates
 - Align Y-body axis with orbit normal
- Y-Thompson Spin Control
 - Set Y-body rate at -3 % sec
- Measures Y-rate with MEMS rate sensor or Rate Kalman Filter
- Magnetic moment is pulse width modulated by switching 3-axis magnetorquers





Y-Wheel Mode (3-Axis stabilised)



Extended Kalman Filter

- Full state estimation from vector measurements
- Model vectors in ORC frame (sun, nadir, B-field)

Y-momentum wheel controller

- X-product Magnetic controller to manage Y-wheel momentum at -1 milli-Nms and damp roll & yaw:
- PD controller for Y-wheel to control body pitch axis









Detumbling result as measured by the MEMS Y-Rate sensor, fully detumbled in less than 1 hour 02/06/2017





- Pre-launch calibration
 - Determine its bias and sensitivity (gain) calibration coefficients per axis
 - ✓ Use Helmholz coil and accurate reference magnetometer
 - Determine the magnetometer's temperature sensitivity
 - ✓ Especially for Magneto-restrictive and –inductive types

$$\mathbf{B}_{cal}(k) = \mathbf{G}_{cal}[\mathbf{B}_{raw}(k) - \mathbf{O}_{cal}]$$



Post-launch calibration

- Sample a WOD file with raw magnetometer measurements every 10 sec for at least an orbit, while tumbling around all axes
- Compare the measurement vector magnitude with the time corresponding IGRF vector magnitude
 - Use an EKF^[*] for attitude-independent estimation of the bias vector and gain matrix best-fit calibration parameters
- Will also compensate for alignment errors (cross-coupling between axes

[*] J.L. Crassidis, K-L Lai & R.R. Harman, *Real-Time Attitude-Independent Three-Axis Magnetometer Calibration*, AIAA Journal of Guidance Control and Dynamics, Vol.28, No.1, 2005, pp.115-120. Magnetometer Calibration Result



S space



ADCS stabilization





Stabilization result as estimated by the Magnetometer EKF 21/06/2017 @ 01:25:10 to 04:34:40



ADCS stabilization





Stabilization result as estimated by the Magnetometer EKF 21/06/2017 @ 01:25:10 to 04:34:40



ADCS stabilization





Y-Wheel speed during attitude stabilization 21/06/2017 @ 01:25:10 to 04:34:40





- > The sun sensor works reliably, except for occasional reflections when it gives a measurement error
- > The nadir sensor is slightly out of focus and the reflections from the panel opening cause measurement errors



Y-Wheel control In-flight performance

SPACE



Y-Wheel momentum control over 2 week period estimated by the Magnetometer and Sun EKF 25/06/2017 to 09/07/2017



Attitude Stability Over Time





- EPS ground watchdog reset 28 July 2017 operator negligence
- ✤ Magnetometer lock-up 13 to 25 Aug 2017 transmitter EM interference
- OBC Reset 28 Oct 2017 Unexplained, possible SD card failure
- Stable (zero roll, pitch and yaw) attitude for >90% of mission duration
- Performing science operations since 23 Jun 2017







30 sec Beacon 2 watt transmitter disturbance on magnetometer measurements 01/06/2017



Satellite Health







Ground Station Automation



CubeMCS - CubeSat TT&C Client				— П X				
Cround Station	Continger - M Disconnect			Connected to hus the 1992	Orbit			
Satellite nSight	• Settings • Conconnect		Last Beacon Received : -	Next Pass AOS 12:54:44 (01:10:43)	Local time: Tuesday, Tuesda	av 05 December 2017 11:44:00	UTC: Tuesday, 05 Dece	ember 2017 09·44·00
TTR/C Database	Pass Automation				-	- ACCELLANT T		
Automate Overpass Actions					·		nSight	
							Part RIP	
Synchronise TLEs								
Refresh File List								
Upload command schedule								
🔿 🏪 😼	1 🗣 😫 💥 🖶 🎼	B						
File Type Counter Size Check	sum ^ File Type Counter	Destination File Name Downloaded Tota	l size		1	Pass	table	
Remote		s salactar	tor dow	nload	Satellite	Start (UTC) 2017-12-05 10:54:44 201	End (UTC) Duration Max elev 7-12-05 10:55:59 00:01:15 2.1718297	/(deg) Visible 598130 True
TimLog 8 8 1 409164 6897	Payload			moad,	2 nSight 3 nSight	2017-12-06 00:13:50 201 2017-12-06 01:49:44 201	7-12-06 00:22:24 00:08:34 21.164076 7-12-06 01:58:42 00:08:58 26.853815	991957 False 579611 False
Payload2 0 16060 4BEE TimLog 1 3 382 1 1 782	Payload1 18 Payload1 35	C:\nsight_log_files\Payload1 61440 222 C:\nsight_log_files\Payload1 0 222	3224 1 10 10 0 10 0	~~	4 nSight 5 nSight	2017-12-06 03:28:40 201 2017-12-06 05:08:06 201	7-12-06 03:33:59 00:05:19 5.5369488 7-12-06 05:10:18 00:02:12 2.5126232	461675 True 391287 True
	Payload1 36 Payload1 37		nt progre	SS	6 nSight 7 nSight	2017-12-06 06:43:30 201 2017-12-06 08:18:58 201	7-12-06 06:50:18 00:06:48 8.8585823 7-12-06 08:28:25 00:09:27 56.942692	547096 True 027397 True
Payload2 10 16060 489D	Payload1 38	C:\nsight_log_files\Payload1 0 222			er 42726 🗢 Orbit par	ameters: Load from file Use	database Lock Start tracking	429943 True
Payload1 1 2228224 2C2E Payload2 2 32332 C5F3	Payload1 39 Payload1 24	C:\nsight_log_files\Payload1 0 222 C:\nsight_log_files\Payload1 2228224 222	3224 3224		ion		Orbit simulation	Auto-track
Payload2 3 16060 CB4F	Payload1 21	C:\nsight_log_files\Payload1 2228224 222	3224		2017-11-16 06:43:06 UTC	Set to AOS Multiplier 1.0	Simulate time Stop motion	
Payload2 4 16060 836E Payload2 5 16060 81E2	Fayload2 9	C: \nsignt_log_nies \Payload2 16060 160			m			
Payload2 6 16060 FB5E Payload2 7 16060 E57C					er Icom IC-9100	✓ Reverse dop	bler Synchronise time	Record overpass
Payload2 8 16060 41E8					Band UHF receive	 Frequency 	135.9000 🜩 MHz	Only in sun
Payload2 9 16060 ABBA Payload2 11 16060 9D88					Band VHF transmit	 Frequency 	145.9625 🜩 MHz Power 20.0 🜩 W	
TimLog 9 3826 BBEA					ction	An	renna control	
TimLog 10 11410 3B7C					roller Rotator	~	Stop Calibrate Park	
TImLog 11 124 7935 TImLog 12 2511544 2084								
TImLog 14 3790 CA45						RSSI history		
Payload 1 / 2228224 C.3AF Payload 1 8 6684672 AC7D						-80		
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					-	-85		
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	2017-12-05 11:20:52 : Downlo 2017-12-05 11:21:46 : Block d	ading from Payload 1.18 - 0 / 2228224 (C:\nsight_log_files\F ownload successful. Downloaded 20480 bytes.	'ayload1_18_20170929_094948BIN)					
	2017-12-05 11:21:46 : Downld 2017-12-05 11:22:40 : Block d 2017 12 05 11:22:40 : Downld	ading from Payload I. 18 - 20480 / 2228224 (C: hsight_log_t ownload successful. Downloaded 20480 bytes.	les (Payload I_18_20170929_094948BIN)			-95		
	2017-12-05 11:22:40 : Downlo 2017-12-05 11:23:49 : Block o 2017-12:05 11:23:49 : Downlo	ownload successful. Downloaded 20480 bytes. ading from Payload 118 - 61440 / 222824 (C:\nsight_log_f	iles\Pavload1_18_20170929_094948_BIN)			-100		
	2017-12-05 11:24:47 : Excepti	on during pass automation : Timeout waiting for TC response	See exception log for details					
-	,					-105		
Comms Log					*	-110		
>> 11:24:16.100 01 02 77 01 02 14 00					^ 0° 45° 9			
>> 11:24:32.726 01 02 78 01 02 FF FF FF >> 11:24:37.758 01 02 78 01 02 FF FF FF	FF							
					✓ AOS in	01:09:48 (2.4° @ HWS)	201	7-12-05 09:44:00 UTC
P nsight_log_files	Simple Tracker (42726 🖬 Cub	eMCS - CubeSat 🔶 AnyDesk					🔨 🗘 🛑 🔲 🖉 💭 🗮	d <mark>x</mark> 11:43 💭



nSight-1 Imaging





California, USA



More Imaging





Eastern Cape, South Africa



Even More Imaging





East London, South Africa



JPG vs. RAW





Mecca, Saudi Arabia



Multiple Overlapping Images





Vredefort Crater, South Africa



Conclusions



nSight-1 is healthy and fully operational Remarkably stable and reliable ADCS requirements for QB50 and imaging mission has been satisfied, and ADCS performance verified

Delivering daily science data to QB50 Imaging electronics proven, and serves as benchmark for CubeSat imagers – also forms the basis for more capable imagers – for CubeSats and also larger satellites Serves as an example of what can be done in a 2U CubeSat

Testament to growing maturity of South African space sector – majority of components manufactured locally

Salar de Uyuni, Bolivia