Mining Surveillance Application Using a CubeSat Constellation

Authors:
A.K. Naudé, F.N. Lombard, L.H. van der Stokker

Co-Authors:
Dr H.W. Jordaan & Mr A. Barnard

Stellenbosch University Department of Electrical and Electronic Engineering, Western Cape, South Africa

19 November 2018

1. Introduction Mining Industry in South Africa

Minerals Council SA in 2017

- Nearly 465,000 people employed
- Represented 90 % of SAs mineral production
- \$8.8 bn contributed to employee earnings
- \$1.1 bn contributed to SA in taxes

Statistics obtained from: Minerals Council SA Facts and Figures [1]

1. Introduction — Problem Statement

“A particular concern during 2017 has been the number of accidents related to seismic activity and subsequent fall of ground incidents.” - Minerals Council SA Facts and Figures [1]

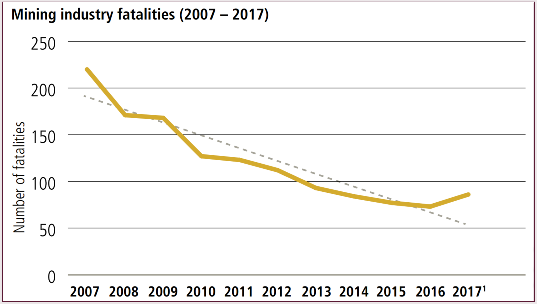


Figure 1: Mining Fatalities [1]

1. Introduction Problem Statement

Socio-economic and Environmental Impact of Mines

- Mining operations utilise large quantities of water
- Operations significantly impact water availability and quality
- Polluting the environment
- Deteriorating water infrastructure poses an additional future threat [2]

South African Human Rights Commission [2]

1. Introduction Current Risk Mitigation Strategies

- Ground movements are monitored using seismic sensors
- Data acquisition using seldom aeroplane flyovers
- Drones have been considered over manned flight
- MCSA works with environmental departments

1. Introduction

Proposed Solution

- Satellites capabilities extend beyond store-and-forward of data
  - Using imagery to monitor ground deformations and the environment
  - Increase mine sensor range
- Improve coverage frequency of active and inactive mines
- Improve the monitoring of mines and adjacent water sources across SA
- Early detection and management of disasters
- Build database for better predictions

1. Introduction UN Sustainable Development Goals

1. Good health and well being
2. Decent work and economic growth
3. Industry, innovation and infrastructure
4. Responsible consumption and production
5. Life on land
6. Life below water
7. Partnerships for the goals

2. Concept of Operations — Mission Objectives

1. Monitor irregular seismic activity near mines
2. Measure and detect ground deformations and movements in land surfaces
3. Analyse environmental effects of active and inactive mines
4. Relay seismic sensor data to the ground station

2. Concept of Operations — Mission Concept

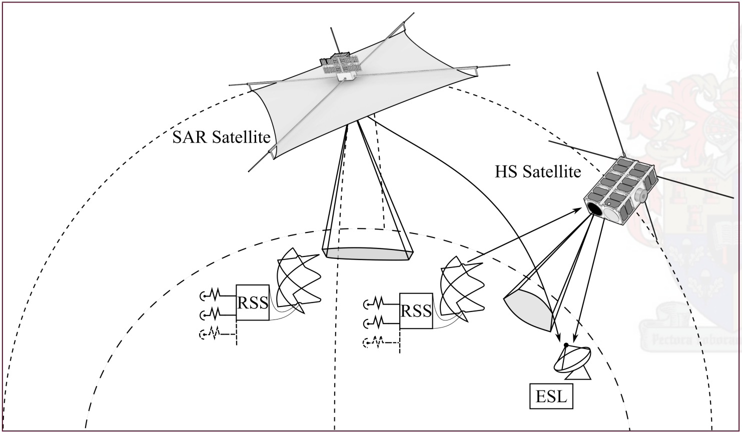


Figure 2: Mission Concept Visualisation

3. Space Segment Description

Overview

- TT&C link at 140 MHz up and 435 MHz down at 9600 bps
- SAR and HS 2.9 GHz data link at 2 Mbps
- Satellites will not require a large amount of propellant
- Both satellite types will be low in mass and volume
- At mission EOL satellites will de-orbit in less than 4 years
- Each satellite's estimated cost is $ 1.5 mil

3. Space Segment Description SAR Satellite Design

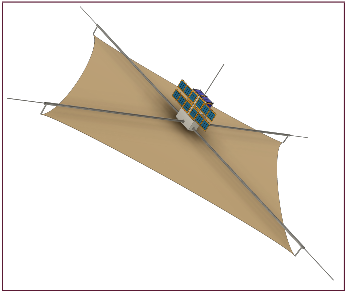


Figure 3: SAR Outside View

Figure 4: SAR Inside View

3. Space Segment Description HS Satellite Design

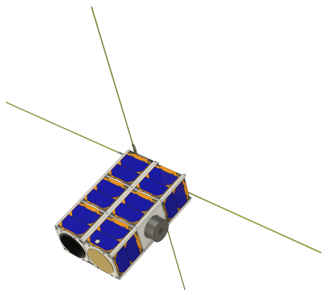


Figure 5: HS Outside View

Figure 6: HS Inside View

4. Orbit and Constellation

Orbital Parameters

- 10am/10pm for better HS imaging
- 6am/6pm for SAR; constant sun exposure
- 1 % Swath overlap nadir-pointing

Satellite Constellation Parameters

Satellite	Altitude	Inclination	Separation
HS	500 km	97.4°	5.1°
SAR	500 km	97.4°	13.5°

4. Orbit and Constellation — HR Coverage

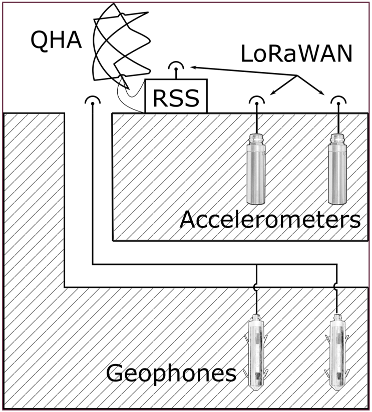
- HS max roll of 10° as GSD is not to exceed 30 m
- Effective swath of 88 km wherein a 38 km image can be captured
- SAR has a swath of 50 km; requires fewer satellites for the same coverage
- Each satellite can transmit up to 140 MB per pass (100 km and 15 km, respectively)

6 Day Constellation Means for Communication

Satellite	Elevation	Range	# Accesses	Access Time
HS	10.1°	1901 km	$\sim$ 325	182 331 s
SAR	10.2°	1912 km	$\sim$ 220	122 514 s

5. Implementation Plan

Ground Segment



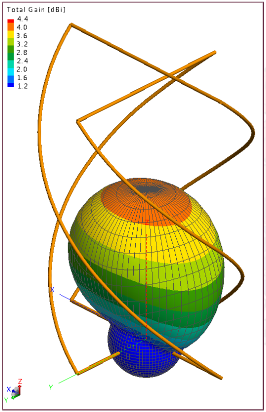


Figure 7: Remote Sensing Station Setup

5. Implementation Plan

Mission Risk

Severity (Insignificant → Catastrophic)

Probability (Rare → Near-certain)

	1	2	3	4	5
5	5	10	15	20	25
4	4	8	12	16	20
3	3	6	9	12	15
2	2	4	6	8	10
1	1	2	3	4	5

LEGEND	
	Low risk
	Medium risk
	High risk

Figure 8: Risk Table Severity Guide

Risk	Comms Failure	ADCS	Thruster	Debris	SAR	Funding	Launch	Interference
Score	15	10	6	6	6	6	4	2

Figure 9: Satellite Risk Analysis

6. Future Work

Possible Expansions

- Monitor ocean mining activities and effects
- Monitor fracking activities
- Collaborate with other countries
- Open source data
- Implement a more powerful HS imager
- Change modulation scheme
- SAR techniques to only scan points of interest to reduce data
- Increase number of GSs to improve data acquisition

7. References

Bibliography

[1] Minerals Council South Africa. (2017), Facts and Figures 2017, [Online]. Available: https://www.mineralscouncil.org.za/industry-news/publications/facts-and-figures (visited on 12/11/2018).

[2] South African Human Rights Commission. (2016), National Hearing on the Underlying Socio-economic Challenges of Mining-affected Communities in South Africa, [Online]. Available: https://www.sahrc.org.za/home/21/files/SAHRC%5C%20Mining%5C%20communities%5C%20report%5C%20FINAL.pdf (visited on 12/11/2018).

[3] Council for Geoscience. (2003), Selected Active Mines, [Online]. Available: http://www.geoscience.org.za/index.php/publication/downloadable-material (visited on 12/11/2018).

8. Back-Up Slides

GSD Pointing Off-Nadir

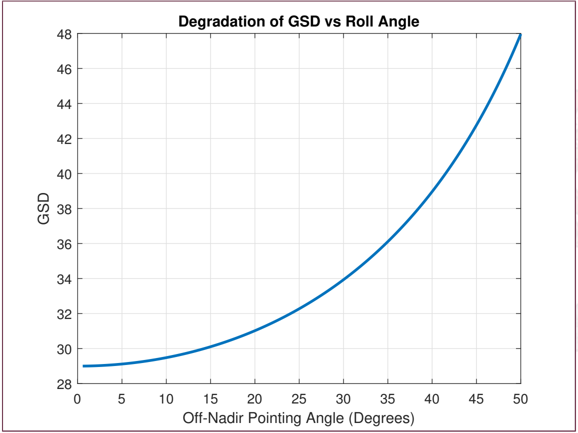


Figure 10: Imager GSD vs Roll Angle

8. Back-Up Slides Significant SA Mining Locations

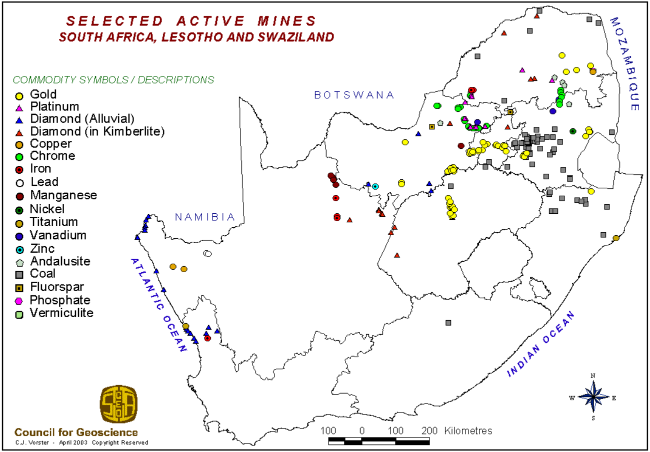


Figure 11: SA Mining Locations [3]

8. Back-Up Slides HS Coalmine Coverage

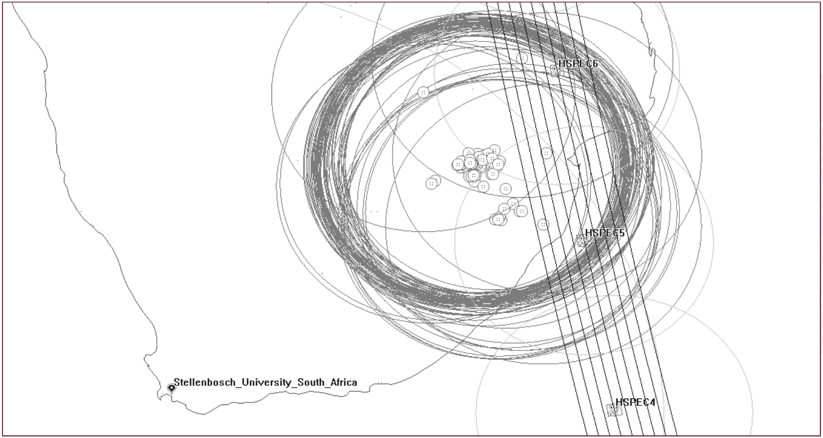


Figure 12: HS Constellation Pass over SA Coal Mines; Their Sensors are Indicated as Targets with Circles around Them

8. Back-Up Slides

HS Area Coverage

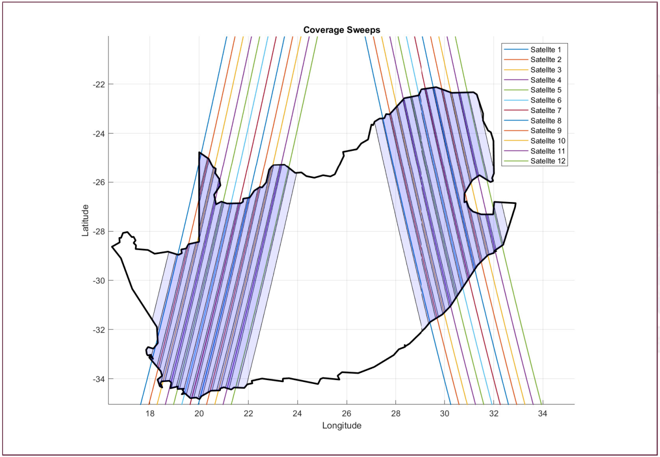


Figure 13: HS Constellation Swath Area Coverage

8. Back-Up Slides STK Constellation Visualised

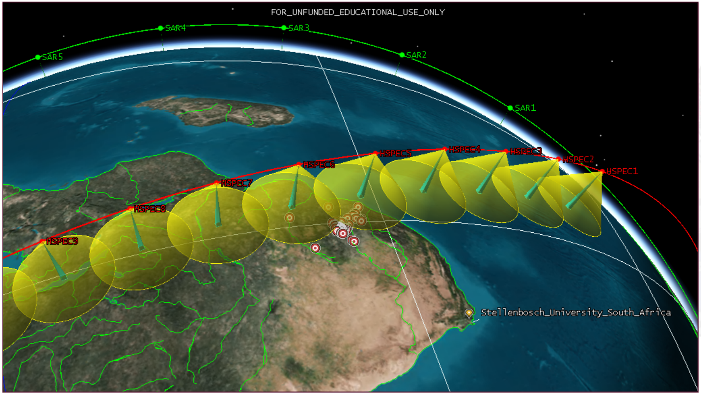


Figure 14: 3D View of the HS Satellites Communicating with the RSSs

8. Back-Up Slides — Cost Budget

Component	Amount	Cost (USD)	Total (USD)
General			
Launch as priced per 1U	120	80 000	9 600 000
Structure and Mechanism	20	10 000	200 000
Cube Space CubeADCS	20	49 850	997 000
Cube Space Reaction Wheels	60	6 000	360 000
ISIS 1U Solar Panels	276	2 900	800 400
Busek BmP-220 Plasma Thruster	20	50 000	1 000 000
OBDH with Mass Data Storage	20	11 000	220 000
CPUT TT&C UHF/VHF Transceiver	20	~ 4 500	~ 90 000
EPS and Battery Pack	20	22 550	445 000
General Components Total			**13 848 400**

Component	Amount	Cost (USD)	Total (USD)
HS Satellite Only			
CPUT S-Band Transmitter and Patch	12	~ 12 000	~ 144 000
Crossed Dipole Antennas	12	4 000	48 000
SCS Space Chameleon HS Imager	12	200 000	2 400 000
Totals HS Only			**2 592 000**
SAR Satellite Only			
High Power EXA Solar Panels	32	15 600	499 200
Commissioning Monopole Antenna	8	1 000	8 000
Crossed Dipole Antennas	8	4 000	32 000
SAR Combined Payload (Estimate)	8	1 000 000	8 000 000
Boom Deployment System	*8*	N/A	N/A
Deployment Booms	*32*	N/A	N/A
Copper-coated polymer membranes	*8*	N/A	N/A
SRI-CIRES Payload	*8*	N/A	N/A
Totals SAR Only			**8 539 200**
Mission Total (Total Cost + 25% Margin)			**31 224 500**

Figure 15: Estimated Cost

8. Back-Up Slides

Link Budget

			Data Link			TT&C and RSS Data Relay			
Item	**Sym.**	**Units**	**HS**	**SAR**	**RSS**	**HS UP**	**HS Down**	**SAR Up**	**SAR Down**
Frequency	f	MHz	2900	2900	140	140	435	140	435
Tx Power	P_T	W	1	6	1	1	2	1	2
Tx Power	P_T	dBW	0	7.8	0	0	3	0	3
Tx Antenna Beamwidth	θ_t	°	60	5	101	16.7	91	16.7	N/A
Peak Tx Antenna Gain	G_T	dBi	7	36	4	12	3.2	12	0
Tx Antenna Pointing Loss	L_P	dB	3	35.8	0	0	3.6	0	0
Free Space Losses	L_{FS}	dB	166.3	166.3	131.4	140	149.8	140	149.8
Peak Rx Antenna Gain	G_R	dBi	46.5	46.5	2.4	2.4	30	0	30
Rx Antenna Beamwidth	θ_r	°	0.8	0.8	148	148	5.4	N/A	5.4
Rx Antenna Pointing Loss	L_P	dB	4.6	4.6	2.8	2.8	0.1	0	0.1
Data Rate	R	kbps	2000	2000	9.6	9.6	9.6	9.6	9.6
Required CNR	C/N_0	dB-Hz	73.5	73.5	50.3	50.3	50.3	50.3	50.3
CNR	C/N_0	dB-Hz	89.9	126.7	72.9	80.6	91.5	81	88.3
Required Eb/N0	E_b/N_0	dB	10.5	10.5	10.5	10.5	10.5	10.5	10.5
System Noise Losses	L_S	dB-K	21.3	21.3	27.9	27.9	23.4	27.9	23.4

Figure 16: Link Budget

8. Back-Up Slides

Power Budget

Component	Maximum Power (~W)	Duty Cycle	Orbit Average Power (~W)
Common			
ADCS	0.85	100%	0.85
Reaction Wheels (x2 at full speed)	3	20%	0.6
OBDH (Without comms)	1	100%	1
TT&C Communications	7.22	8%	0.58
Plasma Thruster	7.5	< 1%	0.075
Total for Common Components	**19.57**	**15.87%**	**3.11**
HS Satellite Only			
Data Downlink	5	8%	0.4
HS Imager (Imaging Mode)	3.5	10%	0.35
HS Imager (Read-Out Mode)	2.5	50%	1.25
Total for HS Satellite	**30.57**	**16.7%**	**5.11**
SAR Satellite Only			
Data Downlink	10	8%	0.8
SAR	192	10%	19.2
Total SAR Satellite	**221.57**	**10.43%**	**23.11**

Figure 17: Power Budget