Mission Requirements Document (MRD)

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Abstract

The NTNU SmallSat Mission will primarily be a science-oriented technology demonstrator. It will enable low-cost & high-performance hyperspectral imaging and autonomous onboard processing that fulfill science requirements in ocean color remote sensing and oceanography. NTNU SmallSat is prospected to be the first SmallSat developed at NTNU with launch planned for 2020. Furthermore, vision of a constellation of remote-sensing focused SmallSat will constitute a space-asset platform added to the multi-agent architecture of UAVs, USVs, AUVs and buoys that have similar ocean characterization objectives.

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01	Initial Document	Mariusz	09-05-2018

Abbreviations

ADCS	Attitude Determination & Control System
ASV	Autonomous Surface Vehicle
AUV	Autonomous Underwater Vehicle
COTS	Commercial-Off-The-Shelf
CONOPS	Concept of Operations
EO	Earth Observation
GCS	Ground Control System
GSD	Ground Sampling Distance
HSI	Hyperspectral Imager
ISS	International Space Station
KSAT	Kongsberg Satellite Services
LEO	Low-Earth-Orbit
LEOP	Launch and Early Orbit Phase
LTAN	Local Time of Ascending Node
MAR	Mission Analysis Report
MRD	Mission Requirements Document
NIR	Near-Infrared
NTNU	Norwegian University of Science and Technology
P-POD	Poly-Picosatellite Orbital Deployer
RAAN	Right-Ascension of Ascending Node
SAR	Synthetic-Aperture Radar
S/C	Spacecraft
SDR	Systems Design Report
SNR	Signal-to-Noise Ratio
SRD	Systems Requirements Document
SSA	Space Situational Awareness
SSO	Sun-Synchronous Orbit
ToA	Top-of-Atmosphere
TLE	Two-Line Elements
TT&C	Telemetry, Tracking & Command
UAV	Unmanned Aerial Vehicle
UHF	Ultra-High-Frequency
USV	Unmanned Surface Vehicle
VIS	Visible

Contents

1 Overview

1.1 Purpose

The Mission Requirements Document (MRD) is the initial step in systems engineering of the NTNU `SmallSat` mission, defines the mission design framework to be completed in Phase A, and serves as foundation for documentation in MAR, SRD and SDR in respective chronological order.

1.2 Scope

This document includes concise information on the Phase 0 mission design and covers: mission objectives, mission requirements (functional and operational) and constraints, science requirements, payload & data requirements and mission phases.

1.3 Summary

Table 1 summarizes the conceptual mission.

Table 1: NTNU `SmallSat` Mission Concept

General	**Definition**
Objective	Ocean color/oceanography
Subject	Coast of Norway
Target Location (baseline)	Lat: 63.867608 °, Lon: 8.663644 ° (Mausund, Norway)
Orbit	
Type	10:00 AM/10:00 PM SSO
Altitude	500 km
# Satellites	1
Revisits to Target per Sat	3
Launch	Q1 2020
Launch (mission #2)	Q3 2020
Payload	
Type	Pushbroom Hyperspectral Imager
Spectral Range	400-800 nm
Spectral Resolution	<10 nm
Ground Sampling Distance	<100 m
Operating Modes	High Res; Medium Res
Autonomy	
Data Processing	Onboard geometric, radiometric, spectral and spatial processing
Downlinked Data Products	Level 2 and 4 (Levels 0, 1a, 1b and 3 upon request)
Operations	Uplink and downlink to Ground Station, tasks determined by mission control
Communications	
Bands	S-band (downlink)+UHF (uplink) or only S-band (uplink+downlink)
Ground Stations	NTNU, KSAT (Svalbard)

2 Mission Objectives

1. **To provide and support ocean color mapping through a Hyperspectral Imager (HSI) payload, autonomously processed data, and on-demand autonomous communications in a concert of robotic agents at the Norwegian coast.**

2. To collect ocean color data and to detect and characterize spatial extent of algal blooms, measure primary productivity using emittance from fluorescence-generating micro-organisms, and other substances resulting from aquatic habitats and pollution to support environmental monitoring, climate research and marine resource management.

3. Develop robust framework for rapid systems engineering for a pipeline of spacecraft that may optimize project development in academia and industry.

4. Build strong competence and strengthen the prospect of nano- and micro-satellite systems as supporting intelligent agents in integrated autonomous robotic systems dedicated to marine and maritime applications in Norway and internationally, these being applicable to communications and remote sensing (altimetry, SAR, radiometry etc.).

5. Describe scientific methodology that will be adopted for the research, and coordinate the project plans with other ongoing research activities at NTNU and other research institutions and companies.

Furthermore, it is emphasized that this mission is developed by PhD students, researchers, Master's students and professors, hence it shall be of academic nature and include objectives to emanate publishable results in the respective domains of control theory, artificial intelligence, electrical engineering, aerospace engineering, marine technology, biology and remote sensing.

3 Mission Requirements & Constraints

The Level-0 mission statement flows down to success criteria and consequently to the functional and operational requirements. The success criteria are operational in nature and are distinctive in whether they may be considered a minimum or full success. Mission requirements have to reach fulfillment of full success criteria. System requirements follows from mission non-functional requirements and will be defined in SRD.

3.1 Mission Success Criteria

Req. ID	**Success Criteria**	Min	Full
M-0-001	S/C shall successfully launch, deploy, detumble and initialize operations (LEOP and commissioning) in LEO	✓	
M-0-002	Mission control shall identify S/C, generate TLE and estimate its initial state upon deployment from P-POD with max ± 30% deviation allowed to nominal orbit	✓	
M-0-003	Shall observe Case 2 water area in Norwegian coast of $\leq 70 \times 70$ km^2 at view angle $\leq 70°$ with respect to Nadir	✓	
M-0-004	Should observe Case 2 water area in Norwegian coast of $\leq 200 \times 200$ km^2 at view angle $\leq 20°$ with respect to Nadir		✓
M-0-005	Shall pass target at least 1 pass per day	✓	
M-0-006	Should pass target at least 3 passes per day in Spring time		✓
M-0-007	Shall, under cloudless or cloud gap conditions, take at least 3 image of target area with ≤ 20 bands in VIS-NIR spectral range that contains a detectable water-leaving signature to be ground truthed	✓	
M-0-008	Should, under cloudless or cloud gap conditions, take at least 30 images of target area with ≤ 100 bands in VIS-NIR spectral range that contains detectable water-leaving signatures to be ground truthed		✓
M-0-009	Shall downlink at least spatially compressed data in raw format	✓	
M-0-010	Shall enable flexible mission planning & scheduling and subsystem updates through uplinked data	✓	
M-0-011	3 onboard processed image and TT&C data shall be downlinked for direct interpretation	✓	
M-0-012	10 onboard processed images and TT&C data shall be downlinked for direct interpretation		✓
M-0-013	Shall communicate to ground and downlink house-keeping telemetry data for at least 1 pass per day	✓	
M-0-014	Should communicate to ground and downlink house-keeping telemetry data for each available pass per day		✓
M-0-015	Shall be operational for at least 6 months with daily mission updates during peak-season	✓	
M-0-016	Should be operational for at least 3 years with daily mission updates during peak-season		✓

3.2 Mission Functional Requirements

Req. ID	Definition
M-1-001	Shall achieve LEOP plus commissioning in less than 2 weeks with full mission operations support in less than 3 weeks
M-1-002	Detection and identification of scientific matter in mesoscale target area shall happen in at least in 1 out of 72 orbits in spring and summer season with less than 10 % false positive signatures
M-1-003	Target area shall be any area with mesoscale size of at least 70×70 km^2 along the coast of Norway that will include the point at Lat: 63.867608 ° and Lon: 8.663644 ° and be imaged between 08:00 AM and 13:00 PM in spring and summer season
M-1-004	50 % of target area image shall be without brightness saturation due to sun-glare
M-1-005	S/C payload shall have spectral range of at least 400-800 nm (VIS-NIR) and spectral resolution of $\leq$ 10 nm
M-1-006	Images of target area with positive signatures shall have spatial resolution of $\Delta x \leq 100$ m, ≥ 20 spectral bands at $\leq$ 10 nm resolution, and mapping knowledge error of $\leq \pm 10$ m
M-1-007	Remote sensing images with positive signatures shall have $\leq 100 \times 100$ m^2 spatial resolution, i.e. $\Delta x \leq 100$ and $\Delta y \leq 100$ m and GSD ≤ 100 m
M-1-008	Faintest detectable ToA signature in the range of 400-600 nm range shall be at SNR of 200:1 for algorithm detection
M-1-009	Angle between initial target area point and Nadir, e.g. view zenith angle or sensing axis-target angle, shall not exceed 70°
M-1-010	Shall enable automated on-board geometric (situational awareness) processing/calibration; radiometric processing/calibration; spectral compression; and spatial compression in the respective order
M-1-011	Shall fuse overlapping fields of view in order to enhance the image resolution by a factor of at least 1/3 and mean SNR of at least $\sqrt{2}$
M-1-012	Shall have on-board radiometric and geometric calibration resulting in $\leq$ 15% radiometric uncertainty and $\leq$ 10 % geometric uncertainty
M-1-013	Target area shall be viewed with a total of 3 observable passes
M-1-014	Shall downlink at least 3 images per day and perform 3 full and nominal imaging operations per day when signatures are detectable
M-1-015	At least raw data with ancillary information, including radiometric and geometric calibration coefficients and geo-referencing parameters (Level 1a) shall be downlinked
M-1-016	At least spectrally and spatio-temporally compressed data that are geometrically plus radiometrically calibrated onboard (Level 2 & Level 4) shall be downlinked
M-1-017	S/C shall have absolute pointing knowledge of $36''/0.01°$ ($2\ \sigma$) and absolute pointing accuracy of $360''/0.1°$ ($2\ \sigma$)
M-1-018	S/C shall slew in 3-axis prior to image acquisition such that S/C points maximum +60° with respect to Nadir and in direction of orbit-track with settling time $\leq$ 1 min and drift error $\leq 0.01°$
M-1-019	S/C shall slew in 3-axis in opposite direction of orbit-track with maximum slew rate of $1°/s$ in image acquisition mode during $\leq$ 1 min and drift error $\leq 0.01°$
M-1-020	Response time of downlinked image with positive signature to in-situ validation in target area shall be less than 2 hrs
M-1-021	Spectral band selection and data bases on radiometric, geometric and atmospheric models shall be uplinked in maximum 3 orbits prior to the observations are made
M-1-022	Shall be inserted in a SSO configuration at altitude of 450-600 km with allowance of ± 23% deviation from nominal inclination angle
M-1-023	Shall be launched at 9:00-11:00 am or 8:00-10:00 pm LTAN with allowance of ± 10% deviation from nominal RAAN angle
M-1-024	Shall uplink data on mission planning & task execution with data size at max. 50 Mb
M-1-025	Shall downlink Level 2 or Level 4 data with data size at max. 300 Mb
M-1-026	Should downlink data of > 300 Mb size in 3 consecutive orbits
M-1-027	Downlink data rate shall be at least 0.8 Mb/s at frequency between 2.60 to 3.95 GHz (S-band) and conform with the national frequency usage requirements
M-1-028	S/C shall be of a CubeSat design standard and adhere to the launcher requirements
M-1-029	Launch window for S/C should be maximum 2 months prior to spring season, specifically before or in March 2020
M-1-030	Launch window for S/C shall be maximum 2 months prior to summer season, specifically before or in June 2020

3.3 Mission Non-Functional Requirements

Listed here are the mission operational requirements, autonomy requirements, ground segment requirements and mission data acquisition, storage and dissemination requirements. These describe *how* the mission shall operate and how users interact with it to meet their specific needs.

ID	Definition
M-2-001	Shall nominally map nominal target area each day without any apriori task commands on target location from Ground by slewing along-track with respect to Nadir, i.e. along in-track-Nadir (2-axis) plane and not pointing towards a target
M-2-002	Target location coordinates shall be uploaded from Ground based on visual inspection, in-situ assets other satellite data (e.g. MODIS, MERIS, Sentinel-3) within 24 hrs
M-2-003	Should point to and perform image acquisition of target areas where there is highest probability of detection off the coast of Norway
M-2-004	Shall perform imaging when conditions are cloudless or with cloud gaps, have solar zenith angle of $\leq 75°$ and wind ground speeds of < 12 m/s
M-2-005	Corrections for atmospheric distortions, water particles, aerosols, turbidity, clouds shall be enabled by utilizing $750 - 800$ nm (NIR) bands
M-2-006	Shall achieve GSD ≤ 100 m through 3-axis controlled slew maneuver to achieve effective image resolution of ≤ 100 m through post-processing algorithms
M-2-007	S/C shall be able to uplink and downlink from/to at least 2 ground stations being in Trondheim, Norway, and Longyearbyen, Svalbard
M-2-008	Mission planning & scheduling and pointing maneuvers shall be updated on-board through uplinked data in the same pass with lead time of minimum 5 min to the observations are made
M-2-009	Image acquisition and onboard processing of dataset shall happen during 2 min
M-2-010	Mean contact time during uplink and downlink of one image shall be 4 min and 5 min, respectively, and happen during same pass as observations
M-2-011	Ground shall have at least 1 available operator each day from 7:00 AM to 4:00 PM (UTC+1)
M-2-012	Downlinked and ground processed data should be available to other robotic agents, these being UAVs, USVs and AUVs, with response time of maximum 30 min to investigate positive signature detection(s) in target area
M-2-013	A shared model shall be updated on a data and model server between S/C, UAV, USV and AUV and other EO satellites and linked to payload data, navigational data and task execution and planning
M-2-014	Level 2 data shall consist of geometrically and radiometrically calibrated and geo-referenced hyperspectral images with up to 100 spectral bands and ≤ 10 nm resolution that have Gaussian average for each band
M-2-015	Level 4 data shall consist of target location and at least radiometrically calibrated hyperspectral images with up to 20 spectral bands and ≤ 5 nm resolution that have Gaussian average for each band
M-2-016	Mission shall support off/on payload operations during off-demand and NTNU shall have full uplink authority of model & camera updates to payload
M-2-017	Shall use on-board databases of on apriori-known reference spectral bands to detect, atmospheric models and environmental parameters for calibration and compression and enable payload to operate in different high-resolution and medium-resolution modes
M-2-018	S/C shall communicate to ground and downlink house-keeping telemetry data of up to 100 kb for at least 1 pass per day
M-2-019	Onboard databases on atmospheric models, solar angle conditions, weather models, sea state, target coordinates and usable spectral bands shall all enable payload to operate in unique modes according to the database used (e.g. gain tuning, exposure time, binning operations, and spectral compression).
M-2-020	Finer-scale images at *mm*-level resolution for identical parts of target area given positive detection(s) shall be provided by either UAVs, USVs and AUVs or all
M-2-021	Sub-surface water samples and in-situ measurements from identical parts of target area given positive detection(s) shall be provided manually or by either USVs, AUVs and buoys or all to give ground truth

M-2-022	Should support UAV, USV and AUV field campaigns through path-planning corrections and updates on geo-referenced target area coordinates
M-2-023	Shall accommodate distribution of Level 2 and Level 4 data to a maximum of 15 users
M-2-024	Shall accommodate distribution of Level 0 and Level 1a data for operational and payload performance characterization purposes for up to 5 users
M-2-025	Lifetime of NTNU SmallSat mission shall be at least 6 months and S/C shall de-orbit within 25 years
M-2-026	Shall have capability of being in idle mode while not imaging, thus only harvesting solar power in this mode while not in eclipse

3.4 Mission Constraints

ID	Definition
C-001	Must adhere to at least 6 months of from delivery to launcher to the launch itself
C-002	Must adhere to frequency regulations set by the respective government where operations take place and frequency allocation determined
C-003	Must adhere to policy on SSA for tracking of Space Debris in LEO, thus enable de-orbit upon end-of-life within < 25 years
C-004	Project budget shall be within ≤ 13 MNOK for two missions
C-005	NTNU will partner with a third-party to do systems design, integration and testing and potentially launch, hence authority on results and operations needs to be negotiated
C-006	Launch shall happen in Q1-Q2 2020 with second mission in Q3-Q4 2020
C-007	Payload development needs calibration, characterization and testing prior to integration on S/C bus
C-008	Mission is a case study for PhD and Professor research initiatives hence needs to be rigorously developed in terms of achieving publishable results
C-009	First mission needs a team of at least 10 people under its development from Phase A to Phase E, where 5 people are fully committed
C-010	S/C will piggyback on a launcher, hence the desired orbit is not guaranteed
C-011	Cloudy conditions are expected in Norway, hence results may not be satisfactory in terms of hyperspectral imaging up in northern latitudes

4 Science Requirements

S-001	Detect algae and phytoplankton in Case 1 and Case 2 waters with Chlorophyll-a (Chl-a) concentrations of at least 1 mg/m^3 (see Table 2 for relevant biology)
S-002	Enable <100 m spatial resolution and high spectral resolution of at least 10 nm to characterize useful signatures
S-003	Detect color of other matter such as biology, color-distorted organic matter, oil spills and river plumes
S-004	Distinguish harmful and non-harmful species cooperatively from space observations (inferral) and in-situ measurements (validation)
S-005	Enable remote sensing corrections for atmosphere, aerosols, air bubbles, sun-glint, water turbidity, diffracted second order light, water vapor, landscape distortions
S-006	In-situ validation of remote sensing data will be necessary by methods of using USVs, AUVs or manual sample collection
S-007	Space remote sensing shall be coordinated with NTNU AUV field campaigns in Svalbard, Trondheim and Frøya
S-008	Positive detections of relevant signatures from space are to be investigated closer by UAV, USV or AUV with high response
S-009	Observations shall be available in Spring/Summer time from March to July when biology is most abundant and likelihood of detection is highest

One of the main phytoplankton classes that are common in Norwegian ocean are a) Diatoms; b) Prymnesiophytes; c) Raphidophytes/Dictyochophytes; d) and Cyanophytes aka Cyanobacteria [?]. Algae/plankton classes and species to look for in Norway/Scandianvia are listed in Table 2.

Table 2: Available biology in Norway/Scandinavia [?]

Class	Color	Location	Season
Diatoms	Green/yellow	S to Mid-West Norway	Mar-Jun
Prymnesiophytes	Golden/brown	All Norway	Apr-Jul
Raphidophytes/Dictyochophytes	Golden/brown	South-West Norway	Apr-May
Cyanophytes	Reddish	Baltic/Skagerrak/South Norway	Jul-Sep
Species (red = TOXIC)	Color	Location	Season
Skeletonema costatum	Golden/brown	Skagerrak	May-Jun
Chaetoceros convolutus	Golden/brown	Rogaland-Helgeland	Mar-Apr
Prymnesium parvum	Golden	Hylsfjord in Ryfylke	Jul-Aug
Chrysochromulina polylepis	Brown	S, SE, W and Mid-Norway, Oster/Sørfjord	Apr-Jul
P. papilliferum	Golden	Hylsfjord in Ryfylke	Jul-Aug
Heterosigma akashiwo	Reddish	Osterfjord/Sørfjord	Apr-May
Karenia mikimotoi	Golden/brown	Skagerrak/Baltic	Apr-Aug
Karlodinium veneficum	Golden/brown	Skagerrak/Baltic	Apr-Aug
Emiliania huyxlei	Milky/brown	Along all Norwegian Coast	Apr-Sep
Pseudochatonella	Golden/brown	Baltic	Apr-Aug

5 Payload Requirements

ID	Definition
P-001	Payload shall be a push-broom hyperspectral imager (HSI) with spectral range of 400-800 nm (VIS-NIR) and spectral resolution of $\leq$ 10 nm and be integrated with FPGA on PCB for onboard processing
P-002	Camera exposure time shall be set between 15-60 frames per second (FPS)
P-003	Payload housing shall, in order, have a front lens, entrance slit, collimator lens, grating and detector lens in the form factor of less than 3U volume
P-004	Faintest detectable ToA signature for on-board algorithm detection shall be at least SNR of 200:1 in the range of 400-600 nm range and at least SNR of 50:1 in the 600-800 nm range
P-005	Onboard processing shall consist of automated geometric (situational awareness) processing/calibration; radiometric processing/calibration; spectral compression; and spatial compression in the respective order and have feedback loop to the navigational and control & task execution data from ADCS
P-006	Corrections for atmospheric distortions, water particles, aerosols, turbidity, clouds shall be enabled by utilizing $750 - 800$ nm (NIR) bands
P-007	Four imaging modes shall be enabled: 1) high-resolution with 100 spectral bands; 2) medium-resolution with 100 spectral bands; 2) high-resolution with 20 spectral bands; 3) medium-resolution with 20 spectral bands
P-008	On-board deconvolution algorithms shall enable overlapping fields of view to be fused in order to enhance the image resolution by a factor of at least 1/3 and mean SNR of at least $\sqrt{2}$
P-009	Level 2 data transmitted to ground shall consist of geometrically and radiometrically calibrated and geo-referenced hyperspectral images with up to 100 spectral bands and $\leq$ 10 nm resolution that have Gaussian average for each band
P-010	Level 4 data transmitted to ground shall consist of target location and at least radiometrically calibrated hyperspectral images with up to 20 spectral bands and $\leq$ 5 nm resolution that have Gaussian average for each band
P-011	Payload operations shall be enabled to be switched on/off during off-demand
P-012	NTNU shall have full authority and control to payload
P-013	Available storage size for payload data (TT&C plus images) shall be at least 10 GB on payload image processing board
P-014	Payload shall operate in unique modes according to the database used (e.g. gain tuning, exposure time, binning operations, and spectral compression)
P-015	Payload shall operate in nominal temperature range of -30 to $+70°C$, and 0 to $+30°C$ in imaging mode
P-016	Payload shall enable on-board radiometric and geometric calibration resulting in $\leq$ 15% radiometric uncertainty and $\leq$ 10 % geometric uncertainty
P-017	Payload shall work at medium to full processing power during two phases 1) image acquisition and 2) image processing during main target acquisition, and be idle during other phases
P-018	Non-mission-baseline payload operations shall be at low or medium intensity for imaging and data processing

6 Concept of Operations (CONOPS)

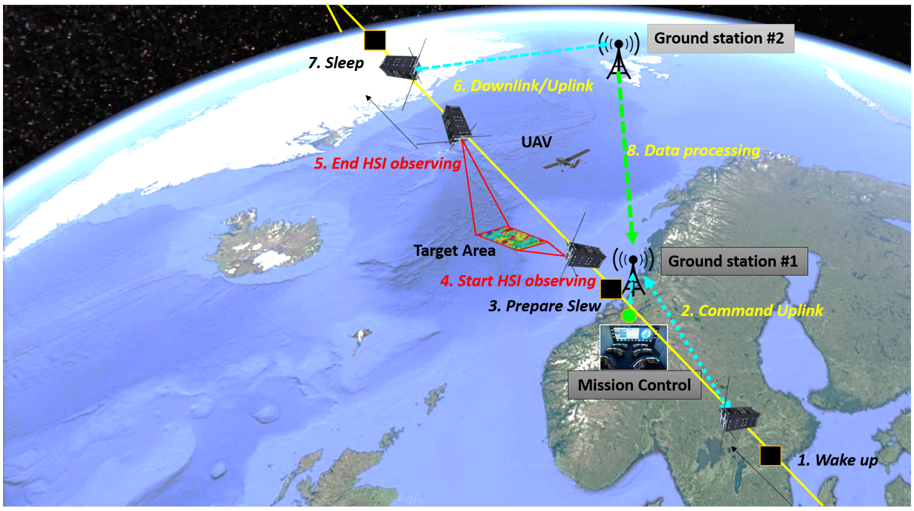

Figure 1: Concept of operations for `SmallSat` in retrograde near-polar orbit.

Operations of the `SmallSat` , as shown overall in Fig. 1, shall enable uplink, imaging, data processing and downlink to happen in one single pass. The mission operational modes are described as follows:

1. Idle: The `SmallSat` will spend most of its time in idle mode, where upon illumination it is harvesting solar energy.

2. Upload: The `SmallSat` is scheduled to initialize operations in due time before it passes the target area. In preparation for the observation phase, if available, a nearby ground control station (GCS) uploads tasks and updates to the mission planning & scheduling of the `SmallSat` . This may be changes in target area size and location, atmospheric variables, solar zenith angle, viewing zenith angle, ground sampling distance, cloud coverage observations and forecasts, camera gain setting and tuning, and data results from observations made by other assets (UAVs, USVs, etc.) to be used for calibration, or spectral and spatial signatures and other information on which target features to search for and report back on. [1]

3. Preparations: The `SmallSat` activates mission-specific attitude control in order to be ready, pointing the sensing axis towards the target at a specific viewing zenith angle before actuation for spacecraft to move in opposite direction once it is aligned for imaging with settling time less than 1 min.

4. Start observation: The `SmallSat` starts recording line scans from the HSI, while under slewing motion to scan slowly over the target area in order to maximize the spatial resolution along surface track by achieving GSD less than the payload's spatial resolution. With near-real-time geo-referenced data input, the images are fused in deconvolution filter or super-resolution/image fusion techniques. The `SmallSat` stores the consecutive data which later undergo data analysis and compression algorithms onboard. Figure 1 illustrates the pushbroom HSI sweeping the target area, showing the need for attitude control and slewing motion. It also illustrates the complementary data captured by a for example UAV at the target area.

5. End observation, and data processing: After the target area is scanned, the `SmallSat` starts geometric, radiometric, spectral and spatio-temporal processing and automated analysis of the data cube in search of positive signatures that match a-priori reference data or unexpected signatures that are new to the model.

6. Download and idle: Depending on the location of the next GCS that can communicate with the `SmallSat`, the `SmallSat` might directly downlink the results of its tasks, or go to idle-mode before scheduled to wake up and initialize for communications at a later stage.

7. Other: imaging operations that are off-baseline image acquisitions of other target areas, i.e. larger targets and image size(s), other target locations, other data products, ground-space calibration, and on-orbit calibration,

[1] For example, a USV or UAV might tactically emit gas to form an artificial cloud of the size of at least one pixel at a suitable location and time such that it can be used to calibrate the satellite's HSI in space, time and spectrum.

6.1 Mission Phases

Mission phases may be summarized in the following Table 3, assuming 20° viewing angle for HSI observations, 500 km altitude and 9:00 AM LTAN SSO configuration.

Table 3: Mission Phases in Orbit 1 Concept

Segment	Description	Start (UTC)	Duration (s)
Phase 0	Pre-mission operations orbit	08:07:00	5400
Phase 1-1	Initialize	09:37:00	15
Phase 1-2	Comms. to Trondheim	09:37:15	125
Phase 1-3	Prepare slewing	09:39:20	115
Phase 1-4	HSI operations	09:41:15	54
Phase 1-5	Data processing	09:42:09	74
Phase 1-6	Point to Svalbard	09:43:25	20
Phase 1-7	Comms. to Svalbard	09:43:45	270
Phase 1-8	Idle (harvest)	09:48:15	605
Phase 1-9	Idle (eclipse)	09:59:20	2207
Phase 1-10	Idle (harvest)	10:36:07	2245
Phase 2	Next operations (Phase 2-1 to Phase 2-7)	11:13:42	383

6.2 Mission Operational System Modes Requirements (in Order)

MOS-001	Prior to 07:00 AM the S/C shall be in Idle Mode and not communicating, where it is only harvesting solar energy, regulating and managing house-keeping data
MOS-002	S/C shall initialize for 15 seconds at ca. 09:37 once it closes in on Ground Station (NTNU), getting ready to downlink TT&C data
MOS-003	Ground system (NTNU) shall point its antenna towards estimated track of satellite with receiver ON
MOS-004	S/C shall transmit TT&C data to the Ground receiver
MOS-005	Ground (NTNU) shall uplink data on mission planning & scheduling (target and timeliness), atmospheric data, task execution and updated FPGA logic for imaging and pointing/slewing operations during 125 seconds
MOS-006	S/C shall incorporate mission planning & scheduling (target and timeliness), calibration variables, atmospheric databases, payload camera adjustments, updated data processing scheme and pointing profiles to initialize slew maneuver and payload functionality
MOS-007	S/C shall turn on the payload and, through sensor fusion on orbit knowledge and location and size of target, actuate its reaction wheels and perform slewing to a reference viewing zenith angle during 20 s
MOS-008	S/C shall actuate reaction wheels again and slew in opposite direction of in-track direction as it approaches the target area with settling time being 40 s
MOS-009	At viewing zenith angle of 20° the S/C shall turn on imaging mode
MOS-010	S/C shall perform deconvolution/super-resolution/image fusion during image acquisition for each frame while being fed in with attitude and situational awareness parameters for calibration & motion blur correction
MOS-011	S/C have imaging mode turned on while slewing for 54 seconds
MOS-012	Once imaging finishes at viewing angle of $-20°$, the camera will stop capturing & storing images and the magnetorquers will dump the slew maneuver momentum due to reaction wheels
MOS-013	Onboard processing shall start after imaging is done with radiometric, geometric, spectral and spatial processing for 74 seconds
MOS-014	S/C shall commence pointing to Ground Station (Svalbard), and Ground Station (Svalbard) shall point its antenna towards the track of S/C, while S/C finishes up data processing during 20 seconds
MOS-015	S/C shall downlink imaging data and TT&C to Ground Station (Svalbard) during 270 seconds
MOS-016	S/C shall be in harvesting Idle Mode for 605 seconds after downlink finishes/ground contact is lost
MOS-017	S/C shall be in non-harvesting Idle Mode for 2207 seconds in eclipse
MOS-018	S/C shall be in in harvesting Idle Mode for 2245 seconds after re-entering sunlight from the Sun-Earth terminator
MOS-019	S/C shall perform MOS-002 to MOS-0015 again with a new target or revisiting the previous target with cross-track pointing profiles, that is up to 65° viewing zenith angle

References

[1] G. Johnsen, M. A. Moline, L. H. Pettersson, J. Pinckney, D. V. Pozdnayakov, E. S. Egeland, and O. M. Schofield, *Optical monitoring of phytoplankton bloom pigment signatures.* Cambridge University Press, 2011, ch. 14, pp. 538–606.