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IGOOS MISSION SCIENCE TRADE STUDY

In this trade study, the mission science will be under observation. Multiple data types will be evaluated to determine what type of data will be collected by the scientific payload. The main objective of the IGOOS mission science payload is to obtain locations and observations of volcanic activity on the Galilean moon, Io. Secondary objectives are to determine the forces acting behind the located volcanic activity.

Data maps are the best way to solve this problem, to locate volcanic activity on Io from a remote sensing perspective without ground measurements. Due to the beginning stage of the design process and theoretical nature of the problem, cost is assumed negligible due to the range of possible solutions. The solution data must have at least one high resolution data type, preferably from the electromagnetic (EM) spectrum. This constraint is due to the fact that it is easier to visually see and confirm processes occurring on a surface rather than detecting magnetic fields and needing to assume that it is volcanic activity without confirmation. In addition, due to the deep space nature of the IGOOS mission, it would be best to have the data collected with med-low power instrumentation.

Specific data alternatives for this problem are the EM spectrum, gravity measurements, and magnetic measurements. This comes from the Earth's many instruments in the EM spectrum currently imaging and monitoring volcanoes. In addition to the EM data there is research that gravity and magnetic changes can be seen due to the changes in subsurface mass in active volcanoes [1], so these data types are also considered as alternatives.

Specifically for the EM spectrum, 4 data alternatives are found currently in use on Earth. They are the visible (VIS), infra-red (IR), microwave (MW), and ultraviolet (UV) wavelengths. The visible allows for visual confirmation of ash clouds, and the erupting volcano and lava flow. IR is used to quantify heat radiation, lava flow, and ash clouds. Synthetic Aperture Radar (SAR) is used for quantifying surface deformation and detecting areas of lava flow. UV quantifies SO_2 concentrations as well as volcanic gas [2].

Around Earth, there are many different instrumentation that have been previously sent into orbit for observations, are currently in a mission, or are planned for a future mission. Each solution already has instrumentation that is on an active or planned satellite mission. For each solution one instrument was chosen from the Observing Systems Capability Analysis and Review Tool (OSCAR) [3] and was found on a currently active or future satellite. Selection was based on how closely it then fulfilled the mission goal for the specific alternative. The reasoning behind a current or future mission is so that the technology would be compatible and relevant in a future building and launch date.

For this trade study, the alternatives have been evaluated in 2 parts. The evaluation criterion for the EM, magnet and gravity data have been chosen to be heritage, mass, power usage and mission success. The evaluation criteria for the alternatives found on the EM spectrum have been chosen to be heritage, mass, power usage, mission success, resolution and SNR. Heritage determines the history of hardware, software and procedures that are reused for a new mission to enable a capability or reduce overall mission risk [4]. As there haven't been many missions to Io, it is best to have a strong heritage to especially reduce risk. Mass, though is not currently important, it is beneficial to have a reasonable satellite weight for size and launch parameters. Power usage is important to keep low due to limited resources around Io for power. Mission success is if the data is collected, will it be able to fulfill the mission objective individually or will it need additional data to accurately and reliably locate volcanic activity. Resolution is significant so that volcanic activity can be seen in detail so that potential processes behind the activity can be researched.

Signal to Noise Ratio (SNR) is important because the received signal should have minimal noise to best the data.

The weighting for the first set of criterion has heritage at 35%, mass at 15% power usage at 20%, and mission success at 30%. Heritage is ranked highest due to the risk factor in a deep space mission and having not working instrumentation would be unproductive. Mission success is ranked lower for the fact that there is a significant leaning towards the EM instrumentation without any specific constraints on the mission. For sensitivity, the values that would be changing would be reducing heritage and focusing more on mission success, as successfully completing the mission is key. This would help determine instrumentation that would not be useful for adding to the scientific payload. The complete table can be seen below in Table 1.

Table 1: Weighting and criterion table for EM, magnet and gravity instrumentation solutions on a scale of 1-3.

	Weighting	1	2	3
Mass	*15%*	High (>200kg)	(<200kg)	Low (≤10kg)
Power Use	*20%*	Significant power consumption (>500W)	Fair amount of power (>100W)	Uses very little power (≤100W)
Mission Success	*30%*	Needs additional data and processing	Succeeds with another data	Succeeds individually
Heritage	*35%*	Simulations	R&D	Strong

The weighting for the second set of criterion puts heritage at 20%, mass 10%, power 10%, mission success 25%, resolution 20%, and SNR at 15%. Mass, power, and resolution, while important, aren't constrained and so have lower importance in the current selection. Heritage, mission success and resolution all deal with fulfilling the mission objective and thus are placed higher. The full set of criteria can be seen below in Table 2.

Table 2: Weighting and criterion for EM instrumentation solutions on a scale of 1-3.

	Weighting	1	2	3
Mass	*10%*	High (>200kg)	(<200kg)	Low (<10kg)
Power Use	*10%*	Significant power consumption (>500W)	Fair amount of power (>100W)	Uses very little power (<=100W)
Mission Success	*20%*	Needs additional data and processing	Succeeds with another data	Succeeds individually
Resolution	*20%*	Low (>50m)	Medium (<50m)	High (<5m)
SNR	*10%*	Low (10-15dB)	(16-24dB)	High (25-40+dB)
Heritage	*20%*	Simulations	R&D	Strong

For completing the analysis of the different data types, the following instruments were selected from OSCAR and detailed below in Table 3. Based on the main goals of the instrument, their specifications, the final decision matrices can be filled out and evaluated.

Table 3: Detailing of different instruments selected for the trade study. Most information came from OSCAR [3].

Data	Instrument	Full Name	Heritage	Mass (kg)	Power (W)	Resolution	Radiometric Resolution
Visible	OLI	Operational Lander Imager	Strong	450	375	30m	26-39 dB [5]
IR	SLSTR	Sea and Land Surface Temperature Radiometer	Strong	150	100	.5 km	NETD<50Mk [6]
UV	GEMS	Geostationary Environmental Monitoring Spectrometer	Simulations	110	<100	5km	1500:1 [7]
MW	COSI	Corea SAR Instrument	Strong	520	600	1m	NESZ ≤17dB [8]
Magnet	GGAK-E/FM-E	GGAK-E/Magnetometer instrument	Flown on operational programme	3	3	N/A	N/A
Gravity	LR	Laser Reflectors	Flown on R&D satellite	48	0	N/A	N/A
EM	ETM+	Enhanced Thematic Mapper +	Flown on operational programme	441	590	30	37-37

Table 4: Decision matrix for EM, magnet and gravity measurements. Blue shaded area shows the best option, EM instrumentation. See Table 10 in Appendix A for detailed uncertainty/sensitivity calculations.

	Weight	EM	Magnet	Gravity
Heritage	35%	3	2	2
Mass	15%	1	3	2
Power consumption	20%	1	3	3
Mission Success	30%	3	1	1
Total	100%	2.3	2.05	1.9
		77%	68%	63%

Table 5: Weighting alternatives and results for Table 4. Grey shaded areas show changes in weighting from the original, option C. Blue highlighted areas show the best option.

Different Weighting Options		A	B	C	D	E
Weighting	**Heritage**	25%	30%	35%	40%	40%
	Mass	15%	15%	15%	15%	15%
	Power consumption	20%	20%	20%	20%	15%
	Mission Success	40%	35%	30%	25%	30%
Data Results	**EM**	2.30	2.30	2.30	2.30	2.40
	MAG	1.95	2.00	2.05	2.10	2.00
	GRAV	1.80	1.85	1.90	1.95	1.85

From Table 5, it can be seen that changing the weighting from mission success to heritage only changes magnet and gravity results, as the same value is the same in both these categories for the EM instrument. This means that unless the weighting is shifted from the heritage and mission success to the mass and power, the EM instrument will be the best option. This is makes sense for now as there is no power or mass constraints so it's of lower importance. For a broad overview, these results work, until more constraints and details are determined.

Table 6: Decision matrix for EM data types. Blue shaded area shows the best option, IR data. See Table 13 in Appendix A for detailed uncertainty/sensitivity calculations.

	Weight	VIS	IR	MW	UV
Heritage	20%	3	3	3	1
Mass	10%	1	2	1	2
Power consumption	10%	2	3	1	3
Mission Success	20%	2	3	2	2
Resolution	25%	2	1	3	1
SNR	15%	3	3	2	3
Total	100%	2.25	2.4	2.25	1.8
		75%	80%	75%	60%

Table 7: Weighting alternatives and results for Table 6. Grey shaded areas are changes from the original, option A. Highlighted blue show the best option dependent on the weighting.

Different Weighting Options		A	B	C	D	E	F
Weighting	**Heritage**	20%	20%	20%	15%	20%	15%
	Mass	10%	10%	10%	10%	5%	5%
	Power consumption	10%	10%	10%	10%	5%	5%
	Mission Success	20%	20%	15%	15%	25%	25%
	Resolution	25%	30%	35%	35%	25%	20%
	SNR	15%	10%	10%	15%	20%	30%
Data Results	**VIS**	2.25	2.20	2.20	2.20	2.35	2.40
	IR	2.40	2.30	2.20	2.20	2.45	2.55
	MW	2.25	2.30	2.35	2.30	2.35	2.25
	UV	1.80	1.70	1.65	1.75	1.80	2.00

From Table 7 it can be seen that IR or MW data can be a better choice for the mission due to the weighting sensitivity. This is because IR and MW data generally score higher than visible in the heavier weighted criteria seen in Table 6. In the results, however, visible data can be just as good as or better than MW seen in options A, E and F. Lastly, UV is not the best choice no matter the weightings. This is mainly due to the resolution and weaker heritage that it has. Depending on more specifications, UV may be a better option for a low mass and power budget or may be more critical to mission success than realized.

From Tables 4 and 6, the best recommended alternative to fit the mission needs would be EM data, and more specifically the IR and MW data alternatives. Though visible data scored just as high as MW, visible had a lower resolution than MW, thus MW data was able to fulfill the high resolution selection criteria. This is so that with data fusion techniques, the image data can be combined to create a high resolution image containing the data that is needed. From Table 7, it could be decided that MW data could be specifically chosen without IR data due to the sensitivity of the weightings. This alternative would need to be revisited again with more definite constraints, but is a possibility.

Going through this trade study, some significant trade studies that would need to be addressed were discovered. The first trade study would be if it is more beneficial to send a lander to determine seismic activity on Io's surface rather than studying volcanoes from satellite data. This is due to the fact that here on Earth a combination of ground and satellite data are being used to determine volcanic processes. A second trade study could be done on the type of scanning mechanism for the instrumentation specifically for the imagery. Finally, a trade study could also be done with a riskier option and looking into having a neural network or automated detection system aboard the satellite that can determine and monitor volcanic activity based on the received data and make data maps to send back to the scientists for research. This would limit the need for scientists to send pointing instructions to the satellite for closer observations [11, 12].

Though the recommended alternative of IR and MW data is reasonable, a trade study going further in depth into what this trade study covered is necessary. This would go into specifically choosing the right wavelengths (such as what band to cover for MW data) for the data collection and choosing what specifically will be looked for in the data produced by the satellite to find volcanic activity. Taking into consideration resolution based on the orbit also chosen and field view will also be important further on in the data instrument development.

Data Sources Used

[1] https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2017TC004806

[2] https://www.mdpi.com/2072-4292/11/13/1528/htm

[3] https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20100040532.pdf

[4] https://www.wmo-sat.info/oscar/instruments/

[5] https://www.researchgate.net/publication/273519384_Landsat-8_Operational_Land_Imager_OLI_Radiometric_Performance_On-Orbit

[6] https://sentinel.esa.int/web/sentinel/technical-guides/sentinel-3-slstr/instrument/specifications

[7] https://geo-cape.larc.nasa.gov/docs/AUG2009MEST/2009-GEMS-jkim.pdf

[8] https://ieeexplore.ieee.org/document/5652759

[9] https://solarsystem.nasa.gov/moons/jupiter-moons/io/in-depth/

[10] https://www.sciencedirect.com/science/article/pii/S2095268616301951

[11] https://www.sciencedaily.com/releases/2018/06/180628171415.htm

[12] https://www.gemsys.ca/subscribe-to-quantum-e-news/quantum-v1-winter-2002/mt-etna-errupts-again-and-magnetometers-are-a-key-part-of-the-picture/

Appendix A: Weighted uncertainty and sensitivity ranges.

Table 8: EM, magnet and gravity weighting uncertainty ranges

	Min	Max
Heritage	25%	40%
Mass	10%	15%
Power consumption	10%	20%
Mission Success	25%	50%

Table 9: Min and Max weights applied to Table 4

	Min			Max		
Heritage	0.75	0.5	0.5	1.2	0.8	0.8
Mass	0.1	0.3	0.2	0.15	0.45	0.3
Power consumption	0.1	0.3	0.3	0.2	0.6	0.6
Mission Success	0.75	0.25	0.25	1.5	0.5	0.5

Table 10: Resulting min/max averages and final sensitivity (Avg Min-Avg Max) in weighting.

	Avg Min	Avg Max	Sensitivity	
Heritage	0.583333	0.933333	0.35	12%
Mass	0.2	0.3	0.1	3%
Power consumption	0.233333	0.466667	0.233333	8%
Mission Success	0.416667	0.833333	0.416667	14%

Table 11: EM data types weighting uncertainty ranges.

	min	max
Heritage	10%	40%
Mass	5%	10%
Power consumption	0%	10%
Mission Success	20%	40%
Resolution	15%	40%
SNR	20%	40%

Table 12: Min and Max weight applied to Table 6.

	Min				Max			
Heritage	0.3	0.3	0.3	0.1	1.2	1.2	1.2	0.4
Mass	0.05	0.1	0.05	0.1	0.1	0.2	0.1	0.2
Power consumption	0.1	0.15	0.05	0.15	0.2	0.3	0.1	0.3
Mission Success	0.4	0.6	0.4	0.4	0.8	1.2	0.8	0.8
Resolution	0.3	0.15	0.45	0.15	0.8	0.4	1.2	0.4
SNR	0.6	0.6	0.4	0.6	1.2	1.2	0.8	1.2

Table 13: Final min/max averages and final sensitivity (Avg Min-Avg Max) in weighting for EM data types

	Avg Min	Avg Max	Sensitivity	
Heritage	0.25	1	0.75	25%
Mass	0.075	0.15	0.075	3%
Power consumption	0.1125	0.225	0.1125	4%
Mission Success	0.45	0.9	0.45	15%
Resolution	0.2625	0.7	0.4375	15%
SNR	0.55	1.1	0.55	18%

*Note: I wasn't able to specifically find how to do sensitivity analysis calculations, but this is a basic start/ rough estimate of what I would expect.