HW4: "Concept" and "Concept of Operation (ConOps)"

Problem Statement: Present a solution to the problem of communicating from the depth of ocean to a satellite in Earth orbit. The systems should be able to achieve the following:

1. Survive and be operational for years under extreme pressure with no "service" calls/visits.
2. Be triggered reliably, whenever desired, from standoff commands from a ship or an autonomous underwater vehicle (AUV) in the vicinity of the deployment.
3. Rapidly transfer the data payload to satellite.

Alternate Approach (bonus): if triggering of the data transfer can be achieved via an aerial platform (plane or UAV) that can be sent to fly over the location of your system deployment, without involvement of a ship or AUV.

Key points to consider:

1. It shall transfer multiple gigabytes of data.
2. Type of data: full HD videos, Imagery and sonar data.
3. Depth of deployment: 2-4 kms below the water level.
4. Recipient of data: space-based satellite in Low Earth Orbit (550 km).
5. When to transfer data: whenever communication window opens up.
6. Assumption 1: Communication window opens if one or more satellite appears over location of deep ocean data acquisition and transfer system.
7. Assumption 2: satellites have inter-satellite communication links

"This page is only for reference. ConOps information is mentioned from next page"

1. Introduction

1.1. Project Description

1.1.1. ***Background***

There have been significant technological innovations in the field of long-distance communication and data exploration. With those, humans have been able to communicate from earth to space, sea level to highest place on the Earth (Mount Everest), etc., and has achieved high-speed data transmission rates. With these technical advancements, humans haven't found the right approach to communicate with the device located in the deep ocean. We are aiming to solve this problem and open new opportunities for ocean exploration. There has been some success seen by researchers at MIT, who were able to design a system that made this possible. This success can be our reference to developing the future of communication (link in appendix 8.2).

1.1.2. ***Assumptions and Constraints***

1.1.2.1. We will be working closely with experts from academia, wherever required.

1.1.2.2. This technology, once developed, will be first of its kind, and it might be tough to present references in some cases.

1.1.2.3. Data acquired, will be transferred to satellites in lower Earth orbits, 550 km, such as SpaceX's Starlink satellites.

1.1.2.4. It assumes that inter-satellite laser links are available. The satellites are capable of communicating and transferring data using these links.

1.1.2.5. Satellites are capable of receiving data and relaying to base station.

1.1.2.6. Other than primary mode of data transfer, we will be exploring options like on-demand data transfer to Unmanned Aerial Vehicles (UAV).

1.2. Overview of the Envisioned System

1.2.1. ***Overview***

Oceans have always been challenging to explore. As mentioned earlier, it is possible to transfer a large packet of data at high speed to and from space, but water as a medium of propagation provides a significant hindrance in sending and receiving data from the deep ocean. We are planning to design a system for deep ocean data acquisition and transfer. This device will be deployed 2-4 km below sea level. This system will be capable of transferring data to satellites placed in low Earth orbits. It will be capable of transferring data on demand and to in-range satellites. We are open to explore on-demand data transfer to UAVs.

1.2.2. ***System Scope***

1.2.2.1. The systems will acquire HD data and transfer raw data. There will not be any on-device processing of data. However, data encryption shall be considered.

1.2.2.2. It will have on-device storage to keep the data stored before transferring data.

1.2.2.3. As device will be deployed in the depth of ocean, it shall be capable of surviving attacks from powerful sea life like whales, sharks etc.

1.2.2.4. It shall deploy anti-theft mechanism to ensure data and system is protected from human borne threats.

1.2.2.5. While we are choosing the mode of communication for data transfer, we have to consider the attenuation capability of water as medium of propagation. It shall be capable of transferring data on-request as well if satellites are in range.

1.2.2.6. It shall not malfunction under high pressure, low temperature and no light conditions in deep ocean. Other factors like cyclone, earthquake, Tsunamis must be considered while designing.

1.2.2.7. In case, device is moved from its location of deployment or in general, based on exploration requirement, we shall be able to control the device remotely to realign its exploration area.

1.2.2.8. It shall be capable of capturing high quality videos, images, and sonar data.

1.2.2.9. Power requirement can be challenging for operation in dark deep oceans.

1.2.2.10. Deployment and Disposal strategy.

1.2.2.11. All the calculations should be done in SI units.

2. Concept

An underwater data acquisition system which captures data from the deep ocean and relays to different recipient like satellites, AUVs and UAVs.

3. Description of Envisioned System

3.1. Needs, Goals and Objectives

3.1.1. ***Needs:*** Oceans are largely unexplored and are expected to have key role in human's survival in future.

3.1.2. ***Goals:*** Solve the problem of data transmission from depth of the Ocean.

3.1.3. ***Objective:*** Transfer large amount of data at high speed and take steps towards dominance in ocean exploration.

3.2. Overview of System and Key Elements

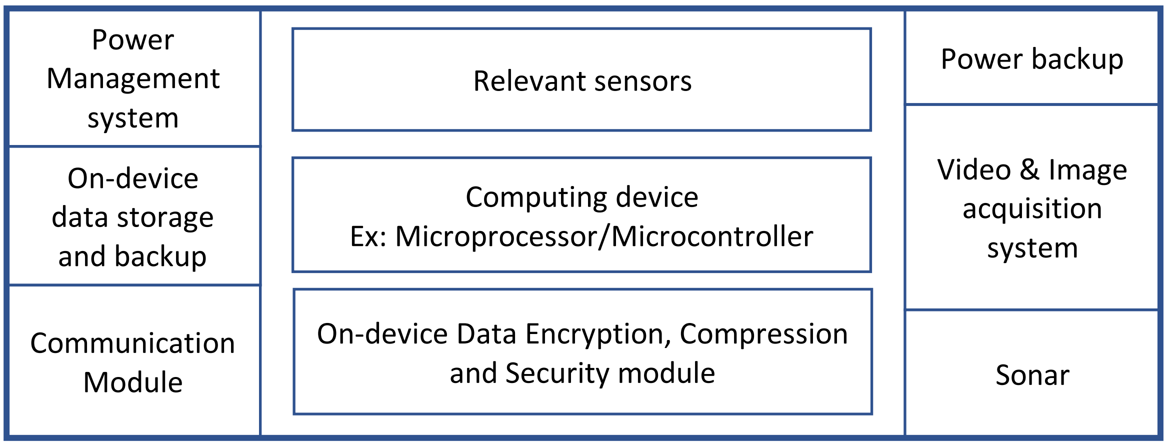


Figure 1: System Overview

3.2.1. ***Very High level working of the system***

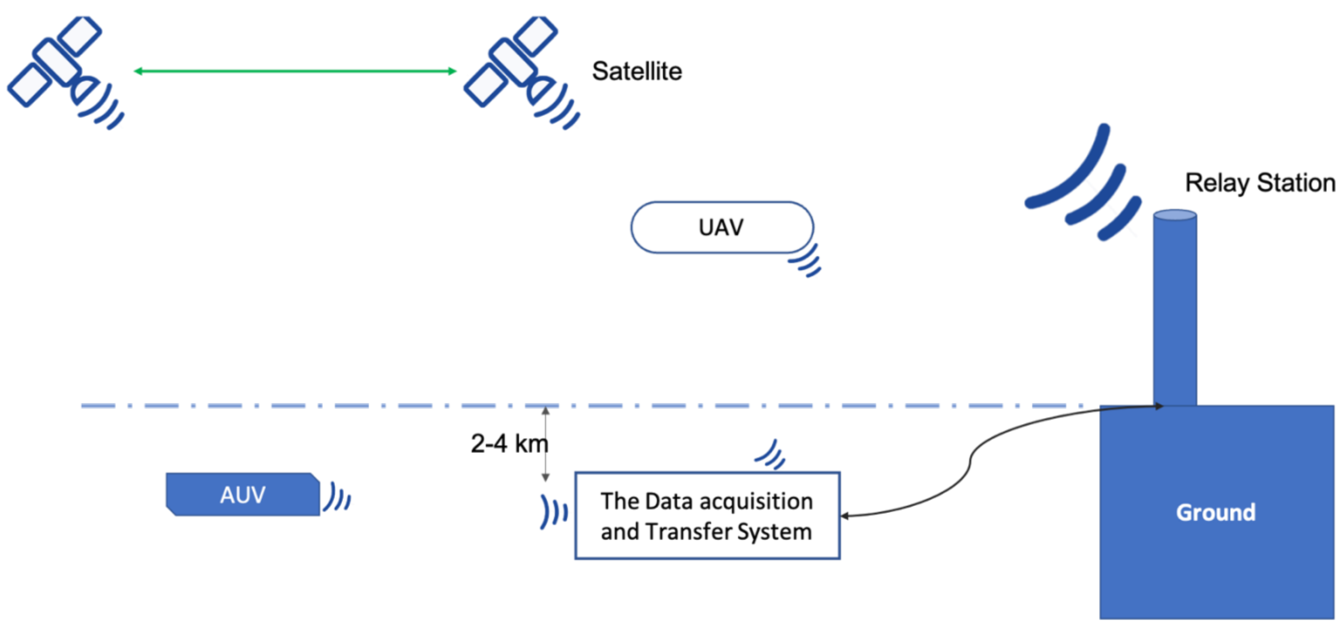


Figure 2: Very High-Level working of the system

3.3. Stakeholder Identification

Stakeholder can be divided into 2 broad categories. These are

3.3.1. ***Internal stakeholders:***

S.No.	Team/Member	Role	Engagement
1	Top Management	Driving forces for the project.	From Day 0
2	Logistics	Responsible for transport of device from base location to location of deployment. They will play major role in transportation during development.	Development, High during deployment
3	Program Management	Responsible for monitoring overall timeline and delivery.	High during development
4	Data Management	Responsible for data retrieval and storage. They will be responsible for onboard diagnostics of the systems through remote connection in case of failure.	Development, deployment & operations
5	Research and Development	They will use the data received from data Management team to draw meaningful conclusions. Includes team who will be part of development deployment of device.	Development, deployment & operations
6	Other functional teams	Testing, validation, trainers etc.	Development, deployment & operations

3.3.2. ***External stakeholders:***

S.No.	Team/Member	Role	Engagement
1	Sponsors	Financial support and their high hope of success. It might be government or other institutions.	
2	Government	They will be concerned about the legal and cross-country pacts for ocean explorations. They will want to be updated about the results.	Starts during project approval.
3	Suppliers and contractors	They will be responsible for supply of parts and other services throughout the project life cycle.	Starts during project approval.
4	Academia	They will provide research support as needed.	Starts during project ideation
5	Political diaspora	Other than the people part of the government will be closely monitoring.	High after project approval.
6	Environmentalists	They will be concerned about impact on life in the ocean, pollution caused by deployment and disposal of the unit.	To be factored during ideation.
7	Other focus groups	To be identified	

3.4. Interfaces

3.4.1. ***Users and Operators: Expected Interactions***

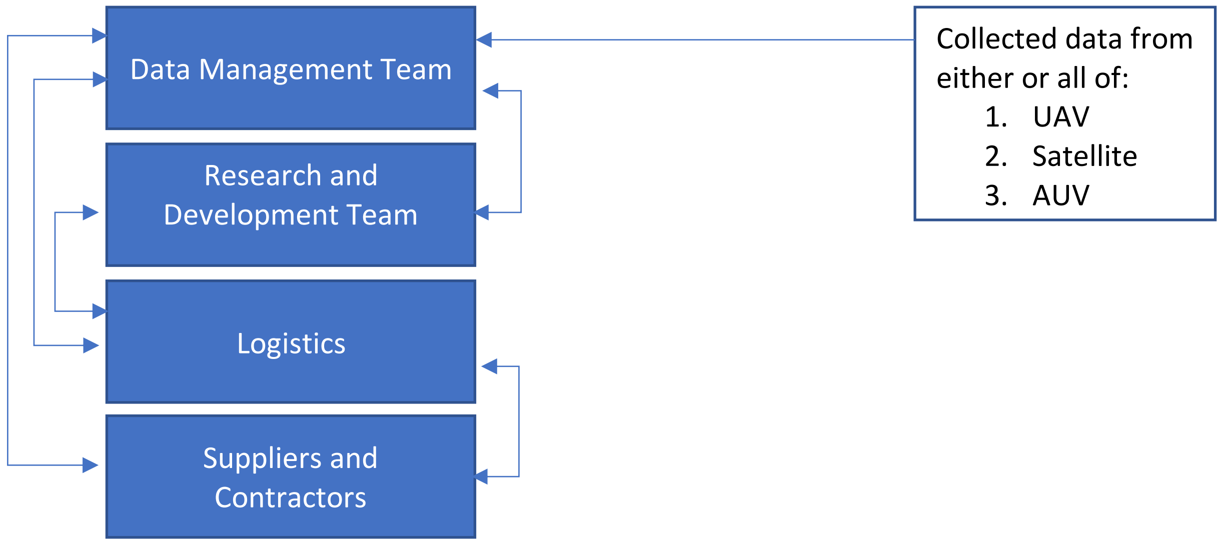
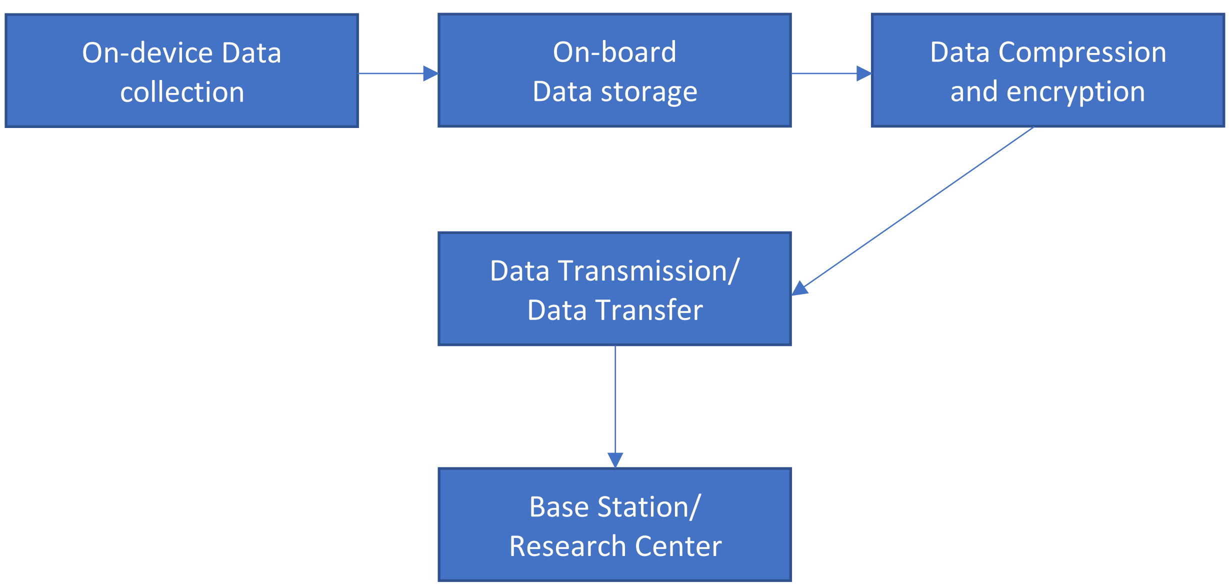


Figure 3: Data Usage and Management related interactions

Above interactions will be explained in relevant sections in this document. Blocks connected with arrow are expected to interact and streamline the activities.

3.4.2. ***Interfaces when system is functional***

The core of this system is data collection and there must be highest priority on data security.



Note: Above flow diagram is tentative and can be modified to best suited conditions for loss less capture and transfer of the data.

Explanation to each module:

a. **On-Board Data Collection:** The system will employ sensors and devices to capture data in form of high-quality images and videos. It shall also collect sonar data. Its function will be limited to raw data collection and it will not do any data filtering or processing.
b. **On-board Data Storage:** Data collected through data collection interfaces will be transferred to on-board storage. Data backup strategy to be considered to prevent data loss.
c. **Data Compression and Encryption module:** Not necessarily an interface. This shall protect data in case of theft and other unintended human interventions.
d. **Data Transfer/Transmission:** These will factor 3 major recipients; Satellites, UAV and AUV. It should factor the cases in which if data transfer was interrupted because of any reason, it should receive the status from next data transfer request or at the opening of next data window and start the transmission accordingly.
e. **Base Station/Research Center:** These will be receiving the data from various recipients. They can trigger manual data request as well.

3.5. Modes of Operations

3.5.1. *Development*

This mode represents the entire development process for the system. This can be further divided based on feature maturity. Device should be rigorously tested for scenarios mentioned in sections “Operational Scenario and Use cases”. During this phase of operation all the cross functional team are expected to work together to finalize the concepts, develop, perform testing and validate the entire system to attain final maturity for deployment.

This is highly critical stage and device must meet the agreed requirements between the cross functional teams.

3.5.2. *Deployment*

During this phase, Research and Development team will work together with logistics team to ensure deployment at mutually agreed location.

3.5.3. *Functional*

Once deployed, the system will enter into functional mode of operation. In this stage it is expected to collect and transmit data to recipients whenever data transfer window opens. This includes data transfer on-request from the recipients.

During this phase, cases may arise where data transfer was not completed because of various reasons. Requirement should be captured to address such scenarios. Details can be found in "Operational Scenarios and Use Cases" section.

3.5.4. ***Standby***

This mode is specifically for case where system has used all the on-board storage memory and is no longer receiving data transfer request or hasn't encountered any opening on data transfer window. Details can be found in "Operational Scenarios and Use Cases" section. System should continuously transmit "Standby Mode" signal which will captured by base stations.

Aim should be to avoid entering into this mode as it doesn't serve mission requirement. "Standby Imminent" warning can be triggered at some levels before reaching a state of full memory. Team to work out the threshold.

3.5.5. ***Disposal***

Once system completes its agreed life cycle, disposal of different components of system must be planned. This should keep in mind the impact on environment and medium in which it is disposed. Aim should be to reuse the parts, possibly after recycling. Therefore, 3R (reduce, reuse, recycle) must be considered while writing the requirements.

3.6. Proposed Capabilities

Matric: Level 1 represents lowest level of expertise.

Level 3: Undergraduate level expertise and skills.

Level 5: Represents highest level of expertise requirements. Expected degree: PhD. Significant experience in that field.

S.No.	***Type***	***Level***
1	Materials Engineer	***Level 5***, *Level 4, Level 3*
2	Oceanography expert	***Level 5***, *Level 4, Level 3*
3	Radar and Antenna expert	***Level 5,*** *Level 4, Level 3*
4	Memory devices expert	***Level 5,*** *Level 4, Level 3*
5	Video and image acquisition device expert	***Level 5,*** *Level 4, Level 3*
6	Data security	***Level 5,*** *Level 4, Level 3*
7	Database manager	***Level 5***
8	Data management support roles	*Level 4, Level 3, Level 2*
9	Mechanical engineer	***Level 5,*** *Level 4, Level 3*
10	Power supply expert	***Level 5,*** *Level 4, Level 3*
11	Embedded systems experts	***Level 5,*** *Level 4, Level 3*
12	Program manager	***Level 4*** *with experience.*
13	Logistics	***Level 4,*** *Level 3, Level 2, Level 1*
14	And other…	

Above table represents, skill level required for the project. In this, Level in **Bold** is expected to lead the team. As the project is one of its kind, all the skills levels are expected to have experience with their sub-systems or roles.

4. Physical Environment

4.1. Integration

4.1.1. All the subsystems will be integrated at room temperature (25 deg C).

4.1.2. Integration will happen at company premises.

4.2. Testing

4.2.1. Testing will be performed for all the use cases.

4.2.2. Two types of testing will be performed – simulated and real environment.

4.2.3. Testing cases should consider all the operation environment challenges and the operational, deployment, maintenance use cases.

4.3. Operational environment

4.3.1. It will be deployed at 2-4 km below the sea level.

4.3.2. Sudden change in temperature and pressure can be expected.

4.3.3. Device must survive the impacts due to high or low tides generated due to motion of the earth and moon.

4.3.4. Device will be in environment which is prone to underwater disturbance caused due to earthquake, seismic plate shift, tsunami etc.

4.3.5. It will be placed in ocean and hence, will be in contact of highly corrosive salty water.

4.3.6. It will be working in absence of light as light travel only up to 200m below sea level.

4.3.7. It will face extremely high pressure and very cold temperature.

4.3.8. High speed ocean currents

4.3.9. It will be prone to attack from large marine life like whales, shark etc.

5. Support Environment

1. Satellites to collect the data from the "System". These satellites are capable of transferring data to other satellites through interlinked laser network.
2. Other ways of data collection are through UAVs and AUVs.
3. System may receive on-demand data transfer request through any of the above-mentioned mediums.
4. "System" will be monitored by design team. They will plan periodic maintenance visit at the location of deployment. Period of maintenance visits to be finalized.
5. Software upgrades can be done in two ways – Over the air or during the maintenance visits.

6. System shall be capable of automatically detect hazard and take actions.
7. Device will be powered through renewable source of energy. Technology used by Microsoft in their underwater data center can be referred as a starting point. Link: https://natick.research.microsoft.com/

6. *Operational Scenarios, Use Cases, and Reference Mission*

6.1. Reference Missions

6.1.1. Microsoft Underwater Datacenter: *https://natick.research.microsoft.com/*

6.1.2. *NOAA Ocean Exploration Technology demonstration 2021: https://oceanexplorer.noaa.gov/okeanos/explorations/ex2102/features/welcome.html*

6.1.3. Samudrayaan Mission, India *https://en.wikipedia.org/wiki/Deep_Ocean_mission*

6.2. Nominal Conditions

6.2.1. ***Deployment operations***

DRM-0100: The system will be carried in closed vessel such that it will prevent any major direct interaction with the outside environment.
DRM-0101: The System will go through 3 level of deployment activities.
DRM-0102: In the first level, it will be packed inside a closed vessel inside the assembly premises and made ready for pickup for transport to deployment location.
DRM-0102: In the second level, it will be loaded into the carrier (logistics team to work with R&D team to finalize).
DRM-0103: In the last level, it will be deployed into the ocean.
DRM-0104: Deployment will happen in close monitoring of experts and hence, logistics shall be arranged accordingly.
DRM-0105: all the subsystems must pass through functional checklist before packing the system in the vessel.
DRM-0106: if the deployment location is far away from the base location: a pre-deployment station shall be established. The system will undergo another round of testing before deployment.

6.2.2. ***Functional operations***

DRM-0201: There are three types of recipients.
DRM-0202: It will be integrated with ground stations which will act as data transmission station for satellites. Details in section: data transfer through ground stations.
DRM-0202: First and default recipient is Satellite. System should be capable of automatically detecting them.

DRM-0203: Second level of recipient is AUVs. Data transfer will happen on-demand.
DRM-0204: Third level of recipient is UAVs. Data transfer will happen on-demand.
DRM-0205: As mentioned above data transfer initiation can happen in 2 ways, on-demand and if system detects that data transfer window has opened.
DRM-0206: Data transfer window will be considered open if System detects recipient satellite in transmission range.
DRM-0207: Data transfer window will be considered closed if system detects the recipient satellite has gone out of transmission range.
DRM-0208: The system should transfer data in blocks. It should keep track of how many blocks of data has been transmitted.
DRM-0209: If there is any interruption during data transfer, system should keep the track of last block which was transmitted.
DRM-210: once connection is re-established after interruption stage, only data which was not transmitted should be transmitted.
DRM-211: The system will not delete the data unless it gets confirmation of data received when next communication window opens or it receives on demand delete or transfer request.
DRM-212: In case on-demand data request is triggered from AUVs or UAVs, upon verification of authentic recipient, it will transmit the data.

Data acquisition operations
DRM-213: It will continuously capture data in form of images, HD videos, sonar and other data from sensors.
DRM-214: It will save the data on device before transmitting the data to recipient.
DRM-215: It will transfer the data on first in first out basis.
DRM-216: Stored and transmitted data should be encrypted.

6.2.3. *Data transfer through ground stations*
DRM-217: The system will be integrated with ground stations through underwater ethernet cables.
DRM-218: Data saved on-device will be transferred to ground stations periodically.
DRM-219: once data window opens, data will be pushed to satellites.
DRM-220: AUV and UAV can collect data from both the locations, ground stations and going near the location of deployment.

6.2.4. *Maintenance operations*
DRM-224: The System will undergo periodic maintenance by experts.
DRM-225: There should be a team in place to perform the activities. The team will include experts from all the relevant teams.

6.2.5. *Disposal operations*
DRM-221: In case, the system reaches its lifecycle it shall be brought back to ground station and disposed.

DRM-222: Overall disposal process should keep in consideration the 3R principle (Reduce, Recycle, Reuse).
DRM-223: It should have minimal impact on the environment due to disposal.

6.3. Off-Nominal Conditions

6.3.1. *Standby operations*

DRM-301: It will go into standby mode if on-device memory is full.
DRM-302: Standby mode can be triggered manually from base station in case data monitoring is not required.
DRM-303: Device will trigger "Standby Imminent" warning if data memory is reaching a particular threshold. These specs will be decided by relevant team during detailed design.
DRM-304: In standby imminent mode, it should switch to record only high priority data.

6.3.2. *Hazard Detected Operations*

DRM-401: In case, the system is displaced due to any situation it should be able to detect and retrace back to area of exploration.
DRM-402: Device can be controlled manually from base station via different means including ship, AUV or UAV.
DRM-403: It should detect threat from attacks from marine life and change its course if required.
DRM-404: In case of breach attempt, it should trigger a breach warning to ground relay stations. Data will be locked for higher level of authorization.

7. Impact Consideration

7.1. Environmental Impact

The system uses renewable source of energy to power up the device. Other impact to be analyzed.

7.2. Organizational Impact

System once operational will be first of its kind exploration mission. This will bring our organization to a position of dominance in ocean exploration. However, being a new technology, it will require hiring of experts from different fields. It will also trigger a need to train the team members on big data handling. Capacity of our data centers has to be reassessed and may need to scale up significantly. It will also require setting up ground relay stations and hire operators for that.

7.3. Scientific Impact

This project will open new horizons of understanding of the ocean. The data collected and the study may lead to new revelations. We will be in position to understand marine life closely. It will also provide a lot of information to explore the impact of climate change.

8. Risks and Potential Issues

8.1. Technical and Operational Risk

1. The tech which we have envisioned is fairly new and there are very little references available.
2. This makes very challenging to actually predict the budget and expected timeline for delivery of the project.
3. Setting up new infrastructure will also bring challenges in operations with it.
4. Retraining staffs will be challenging as very less data will be available at initial stages of the project.
5. Simulating the test environment is also challenging affairs.

8.2. Political Risk

There are two types of risk in this category:

1. As this will be long term project, political instability can cause serious damage to our movement.
2. Device may go beyond agreed international waters which may attract opposition from foreign government.

9. Appendix

9.1. Abbreviations

UAV: Unmanned Aerial Vehicle
AUV: Autonomous underwater vehicle

9.2. Links

9.2.1. Microsoft Underwater Datacenter: https://natick.research.microsoft.com/
9.2.2. *NOAA Ocean Exploration Technology demonstration 2021:* https://oceanexplorer.noaa.gov/okeanos/explorations/ex2102/features/welcome.html
9.2.3. Samudrayaan Mission, India https://en.wikipedia.org/wiki/Deep_Ocean_mission
9.2.4. MIT: Wireless communication breaks through water-air barrier https://news.mit.edu/2018/wireless-communication-through-water-air-0822
9.2.5. Micro-float UW: https://www.pmec.us/research-projects/microfloat