P42

Development and Testing of a Multi-Modal Sensor Suite to Observe Ice in the Marginal Ice Zone (MIZ) of Antarctica

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MARiS Marine and Antarctic Research for Innovation and Sustainability

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I. Background

Antarctic sea ice is crucial for cooling the Earth, absorbing CO_2 [3], and supporting marine ecosystems. Changes in sea ice affect heat absorption, ocean mixing, and phytoplankton growth, with potential ecosystem impacts [1]. Unlike the Arctic, Antarctic sea ice is poorly characterised as limited in situ data hampers understanding of these dynamics [1].

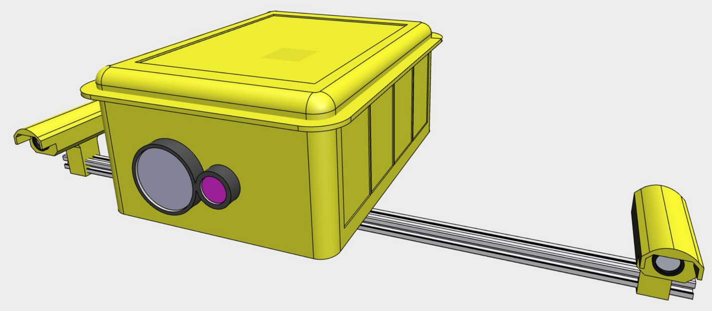
Due to the inaccessibility of the region and thus lack of in-situ data, current mathematical models describing the formation and deconstruction of ice floes in the Marginal Ice Zone (MIZ) of Antarctica have been shown to be inaccurate [7]. Although satellite imaging holds the advantage of increased coverage without having to endure the harsh Antarctic climate, these methods still depend on in-situ ground truth data for validation [7]. Additionally certain parameters cannot be collected through satellite imaging and thus the need for in-situ data collection methods remains.

The previously mentioned mathematical models depend on multiple parameters, such as thickness, shape, density of the ice floes. However, to date, few datasets contain these required parameters pertaining to the same ice floe at the same instant in time [7].

II. Objectives

The goal of this project is to develop a multimodal sensor suite according to the following specifications:

Specifications	Description
Complete parameter coverage	It is critical that the sensor suite be capable of extracting the various parameters needed by the researchers. These include: wave data, ice thickness, ice shape, ice floe density and ice temperature.
Time synchronization	To minimize the error in the data collected by the sensor suite is imperative that the various sensors onboard are meticulously time synchronized
Weatherproofing	The intended deployment context of the sensor suite is onboard the S.A. Agulhas II. Thus, it is required that the sensor house the internal electronics in a waterproof and insulated enclosure to ensure longevity. The sensor suite must also be capable of autonomous operation without human intervention.



3D Visualization of Sensor Suite

III. Design Methodology

Sensor Selection:
The project began by identifying which sensors would best meet the research requirements. A literature review revealed the key parameters that needed to be recorded and showed which sensors had already been successful in polar research. It became clear that a well-designed sensor suite should strike a balance between complementary and redundant sensors: complementary sensors provide diverse data types, while redundant improve overall accuracy, reliability, and robustness.
Based on these findings, three primary sensors—LiDAR, a stereo camera, and a thermal camera—were chosen to fulfil the project objectives with both complementary and redundant qualities. Subsequent testing compared different models of each sensor, evaluating factors such as range, resolution, and how well each sensor integrated with the broader suite.

Time Synchronization:
To synchronize sensor data capture with minimal time offset, a hardware trigger system was implemented. However, unlike the stereo and thermal cameras—which record data in discrete frames—a solid-state LiDAR outputs a continuous flow of 3D points, making it impossible to trigger in the same way. The workaround was to use a modified LiDAR driver that raises a flag at the start of each scan cycle, triggering the other two sensors at that instant.
Additionally, to further improve synchronization, a Precision Time Protocol (PTP) is used over Ethernet to align all sensors' internal clocks. In PTP, a master clock sends timing signals to other devices, which measure the signal travel time and adjust their clocks to match the master. This ensures that all sensors remain synchronized accurately.

Weatherproofing
A modified Pelican case was chosen to house the sensor suite due to its durability, IP67 waterproof rating, and polypropylene construction, which provides better insulation than metal. To address condensation inside the enclosure—which can damage components and fog up lenses—a silicon heating pad will be placed at the base of the enclosure, ensuring even heat distribution, keeping the suite above its dew point, and helping sensors stay within their intended temperature ranges. Silica gel packets will also be included to absorb excess moisture.
Finally, to prevent water and ice buildup on the lenses, spinning deflection lenses will be installed in front of all sensors. These lenses rotate at 3000rpm, effectively flinging off any water or ice and enabling the sensors to operate autonomously in adverse conditions.

IV. Sensor Suite Design

Livox Avia [LiDAR]
LiDAR provides highly accurate 3D reconstructions of ice floes from a distance. The Livox Avia model was selected because its unique rosette-shaped scanning pattern produces a focal point with a higher point density than other LiDARs, enabling finer surface detail capture. This pattern also complements the unidirectional setup of the sensor suite.

FLIR Boson 640 [Thermal Camera]
A thermal camera will be used to measure the temperature differences that drive sea ice formation and melting. Because ice and water exhibit distinct temperature profiles, this camera also aids in segmenting imagery into ice and water regions. The chosen model has a 640×512 resolution—larger than many thermal cameras—providing a broader field of view and simplifying data fusion with other sensors. It also supports hardware triggering, which helps maintain synchronization across the entire sensor suite.

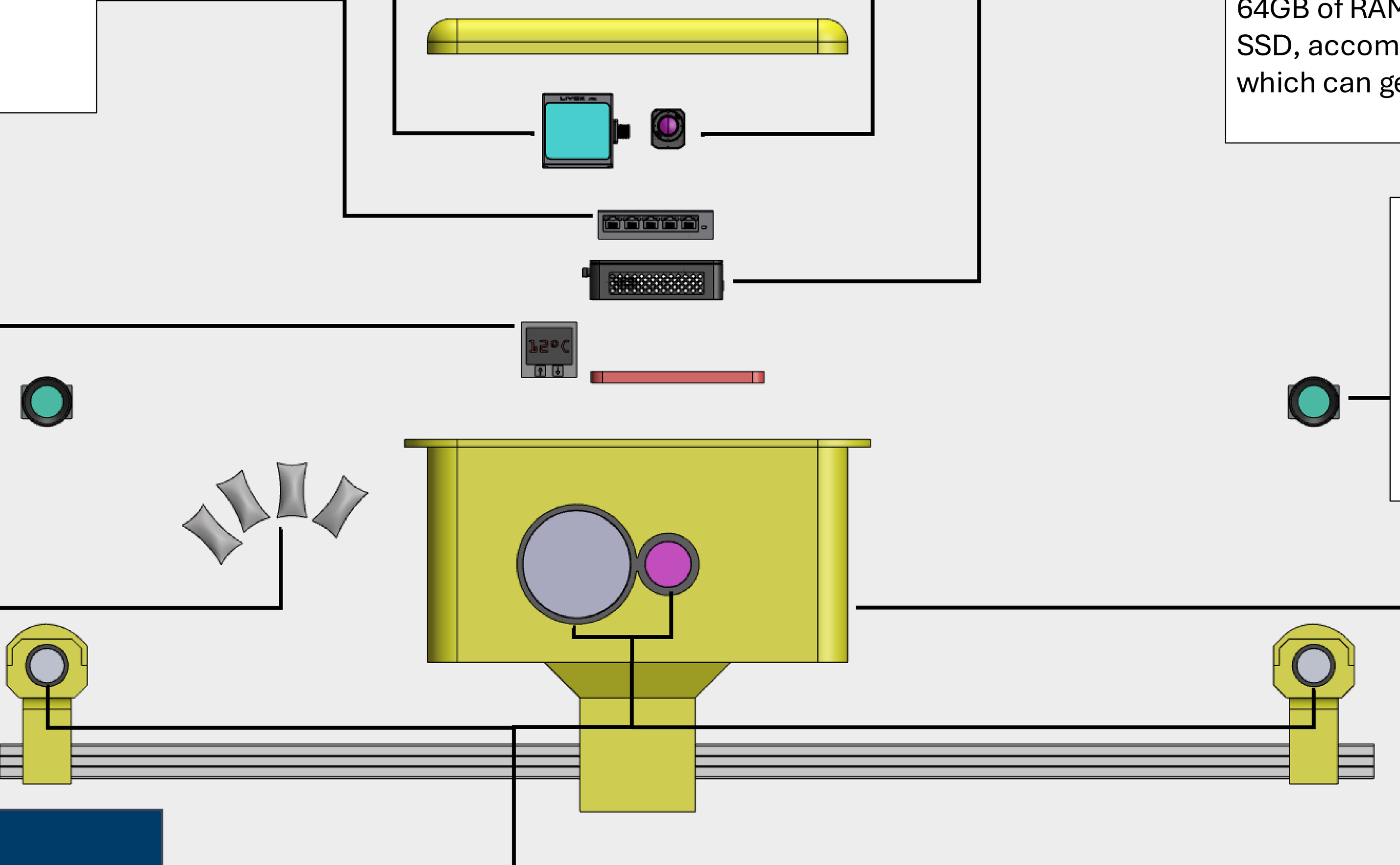
Ethernet Switch
Many of the devices included in the suite communicate through ethernet. As such, where clock synchronization is necessary, devices will be synchronized using the Precision Time protocol [PTP]. This will ensure that the clocks of the devices on the network are aligned.

Intel NUC13ANKi50000 NUC 13
The Intel NUC serves as the sensor suite's primary processing unit, gathering data from all sensors and running their drivers. Its onboard clock acts as the master clock, synchronizing other clocks in the system. It's equipped with 64GB of RAM for potential real-time processing needs and includes a 4TB SSD, accommodating the high data output from the three main sensors, which can generate over 1GB of data in just a few seconds.

Heating System
Although cold temperatures often benefit some electronics, Antarctica's extreme -20ºC environment necessitates a heating system to keep sensors within their specified operating range and to prevent damaging condensation. The solution chosen is a thin silicon heating pad situated at the base of the sensor suite, controlled by a PID unit. This setup ensures the electronics remain at proper temperatures while mitigating condensation.

DMK33GX264e [Stereo Camera Pair]
Like LiDAR, the stereo camera pair can produce 3D reconstructions; however, stereo cameras can capture ocean waves—an essential factor in sea ice formation and decay. Because colour data isn't necessary, monochrome cameras were chosen to conserve storage space. They also support hardware triggering for precise synchronization with the rest of the sensor suite.

Silica Gel Packets
To further prevent the formation of condensation, silica packets will be distributed throughout the sensor suite to absorb any additional moisture.



Pelican Case Enclosure
A Pelican Case was chosen to protect the sensor suite's delicate electronics. Its robust construction, IP67 rating, and superior insulation make it ideal for withstanding the harsh, wet, and cold conditions in which data will be collected.

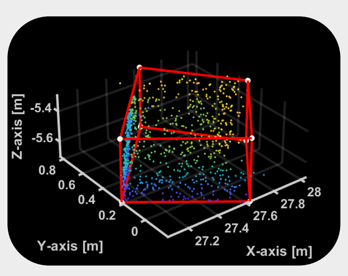
Spinning Deflection Lenses
To enable continuous data collection, spinning deflection lenses rotating at around 3000rpm are mounted in front of the sensors to prevent water and ice buildup. For the thermal camera, a germanium lens is specifically required to ensure its view remains unobstructed.

V. Preliminary Results

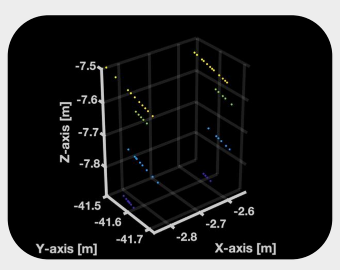
At this stage of the project, the primary results to report on are those obtained during the *sensor selection* stage. Here various sensors were tested respect to their ability to obtain measurements at ranges up to 40m as this is the expected operating ranges from the S.A. Agulhas II.
LiDAR: For these tests, the performance of a solid-state LiDAR (Livox Avia) was compared against a mechanical LiDAR (Ouster OS2) with regards to their ability to form a 3D reconstruction of a box at a range of 40m. The results showed that due to the rosette scanning pattern of the Livox Avia, successive scans were able to produce a far denser point cloud than the OS2's repetitive scanning pattern which failed to establish a point cloud dense enough to decern the target box.

Stereo Camera: A pair of DMK33GX264e monochrome cameras were already available to the project as these cameras had already been used in Antarctic research aboard the S.A. Agulhas II. The researcher who conducted these experiments stated that the cameras were well suited for the sensor suite. Consequently, the experiments conducted prioritised determining the optimal configuration of the stereo pair in terms of distance between the two cameras (the baseline) and which lens to use. The results showed that for ranges around 20m, the larger baseline (80cm) significantly outperformed the smaller baseline (20cm) in its ability to create a 3D reconstruction from a stereoscopic image.

Thermal Camera: For the thermal camera, a FLIR Boson 640 thermal camera was selected. High quality thermal cameras are difficult to acquire in South Africa as the USA, who are one of the primary producers, have strict export laws due to the weaponizable nature of thermal imaging technology. Thus, a FLIR Boson 640 was selected as it was already available to the project. This camera was tested with regards to its ability to make temperature readings at increasing distances. To accomplish this, blocks of dry ice were placed at increasing distances from the thermal camera. It was found that although temperature disparities were clearly visible at both 5m and 40m, the further the dry ice was from the thermal camera, the closer the temperature readings were to atmospheric temperatures. This is expected behaviour as accurate long range temperature measurements are a non-trivial problem that isn't easily overcome.

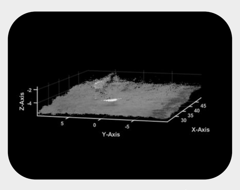


Livox Avia @ 40m



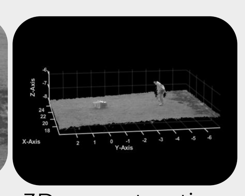
Ouster OS2 @ 40m

Base image \w 20cm baseline



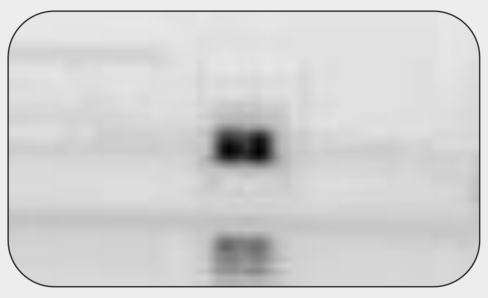
3D reconstruction \w 20cm baseline

Base image \w 80cm baseline



3D reconstruction \w 80cm baseline

Thermal image of dry ice @ 5m



Thermal image of dry ice @ 40m

VI. Preliminary Results

This project is far from complete, listed below is the up coming work that needs to be completed:

- **Construction of spinning deflection lenses:** The exact implementation of these lenses still needs to be finalised. This involves deciding on whether they should be developed in-house or should premade components should be bought. Some other important considerations are how will these lenses impact sensor performance as well as impact the waterproofing of the sensor suite enclosure. Secondly, a standard glass lens cannot be used for the thermal camera as most glass appears opaque to thermal cameras. Thus, the feasibility of using a germanium pane needs to be investigated.
- **Assembly of sensor suite hardware and system integration:** The various components of the sensor suite need to be assembled. Especially the heating systems and moisture prevention systems. Verification processes need to be undertaken to ensure that the system can operate safely and autonomously in the Antarctic climate.
- **System-wide calibration:** For the purposes sensor fusion, a calibration method needs to be developed that can calibrate all three primary systems of the sensor suite simultaneously. The purpose of this calibration is to document the various intrinsic properties sensors as well as the extrinsic properties such as the sensors' orientation with respect to each other. This information is critical in overlaying the data types, allowing for successful sensor fusion.
- **In-situ testing:** Lastly, the sensor suite needs to tested in its intended operating environment, namely, mounted to the hull of the S.A Agulhas II.

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Acknowledgements

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