

## **Augmented Coral Reef Monitoring using a Stationary Reef Monitoring System**

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### **Abstract**

Coral reef monitoring is a reliable tool to assess the effect of climate change as corals are sensitive to increases in water temperatures between 30°C to 35°C resulting in bleaching - a whitening process when the corals lose their colour and the reefs begin to die. Existing satellite based monitoring products facilitate coral bleaching monitoring over large spatial scales, but their use in predicting local scale stress that influences the bleaching severity across reefs is limited. In this paper, we describe a Stationary Reef Monitoring System (SRMS) that monitors the time evolution of coral reefs through the photography of nearby coral clusters. Simultaneously, the SRMS measures and records environmental parameters such as temperature, solar irradiance (PAR), and salinity in the waters surrounding the coral colonies. When deployed in the sea, the SRMS detected a 0.1 – 0.4 °C variability in temperature between the in situ and satellite datasets. The SRMS eliminates the need for physical/visual verification of coral health by a diver, but by using colour photography along with the environmental conditions to determine the bleaching thresholds specific to the reefs. By this approach, one can determine the stress thresholds and identify the vulnerable and resilient reefs so as to prioritize conservation efforts.

**Key words:** Coral reef, Monitoring, Data acquisition, Autonomous systems

## 1. Introduction

Coral reefs all over the world have suffered in the last 3-4 decades and continue to do so, due to a host of factors as diverse as bleaching, pollution, coastal development, sea-level changes, increase in sea surface temperature (SST), over-exploitation of mineral and organic resources, and tourism pressure (Aronson et al. 2003; Hughes et al. 2010; Heery et al. 2018). The UN report on Coral Reef Monitoring estimates that 70 percent of the Earth's coral reefs are threatened with 20 percent having already been destroyed with no hope for recovery, 24 percent are under imminent risk of collapse, and an additional 26 percent are at risk due to longer-term threats (Manfrino, 2017). Continuous monitoring of coral reefs has become an essential component of reef management practice in view of the ongoing climate trajectories in synergy with anthropogenic pressure. The earliest monitoring strategy developed in the 1990s and still in use is that of the Global Coral Reef Monitoring Network (GCRMN), which uses SCUBA diver-mediated underwater surveys over standard lengths (transects) in a reef (English et al. 1997; Hill and Wilkinson, 2003). However, it is difficult to evolve a mitigative or a conservation measure only with diver-based monitoring data. Data on the physicochemical variables and their liaison with the observed variation in the reef variables is crucial for devising strategies to mitigate the climate change effects.

There are three known approaches in coral reef monitoring. In the traditional monitoring practice, an experienced diver and buddy with a camera, survey the coral reef beds in a straight line transect, halting at locations along the transect to image any corals affected by bleaching or disease (Abrar et al. 2019; Rizal et al. 2020). This conventional approach is labour-intensive, and time-consuming with additional time to resurface, change air tanks, and resume the mission (Lam et al. 2006). Given the high cost and strenuous human effort involved, one-time monitoring in a month is considered adequate in the current monitoring protocols. Moreover, diver-based surveys are error-prone and provide only basic information about the distribution of different reef communities and the relative changes in their diversity and abundance at spatial and temporal scales (Urbina-Barreto et al. 2021). Besides, diver-based surveys are critical during stress events like bleaching, disease outbreaks, storms, and cyclones to assess the extent of the damage. However, it is difficult to ascertain the environmental thresholds leading to the decline in the coral population using diver-based surveys and data.

Satellite-based monitoring products such as coral reef watch (CRW) are used to monitor coral reefs at a large geographic scale, especially coral bleaching - a stress response characterized by the loss of symbiotic algae from the coral tissues (Liu et al. 2014; Heron et al. 2016). These products are aided by new satellites, sensors, and algorithms and provide high-resolution data on Sea surface temperature (SST) on a global scale. Besides SST, other environmental parameters such as Photosynthetically

Active Radiation (PAR) and low salinity also cause coral bleaching, which is least considered in these satellite-based products (Buchheim, 1998, Lesser et al. 2011). Recently, sensors have been used to collect in-situ data on selected environmental variables like temperature and PAR for an extended time to validate the satellite data (Manzello et al. 2019; Colin and Johnston, 2020). However, there is little autonomy in such monitoring systems, and it involves manual retrieval of data from the respective sensors after a prolonged time interval. Given these limitations, it is essential to improve the monitoring capability of reef monitoring systems to provide data in real-time, which in turn will help prompt actions by reef managers.

To overcome the limitations of diver-based and satellite-based monitoring, research scientists have developed Autonomous Robot Vehicles (ARV) carrying cameras and sensors as payloads (Huvenne et al. 2017; Avila et al. 2021). A low-flying reef ARV cruising at 0.5 m/s covers a 1 km line transect in a mere ~ half hour while recording video images of corals along a transect. This approach fulfills all the functions executed by the human diver and buddy combination while offering additional benefits of video imaging, data gathering, and the autonomy of a robot vehicle.

In this study, we present a new approach, the stationary reef monitoring system (SRMS) – an automated prototype system, as an alternative to the existing coral reef monitoring methods that are aimed at monitoring the bleaching response among coral colonies and the environmental conditions leading to the bleaching events. As the name suggests, the SRMS remains stationary at a fixed location and records an image of a coral cluster while simultaneously recording Temperature, PAR, and salinity in waters surrounding the corals at pre-set time intervals (~ every 2 h). This paper provides a detailed description of the design of mechanical and electronic modules and the interconnections between different modules of SRMS. Moving forward, we have included a comparison between the SRMS and MODIS satellite datasets to highlight the potential of SRMS to provide sea truth data for the existing and next-generation environmental satellite sensors.

## **2. Architecture of SRMS**

The structure of SRMS can be described as three interconnected modules connected on a mooring line held taut at one end with a dead weight that rests on the seabed and the other end of the taut line attached to the Data Transmission Unit (DTU) – a floating metal framework on which sits an array of solar panels for charging onboard batteries (Fig. 1). The DTU transmits averaged in situ data to a land base station.

The underwater unit comprises the sensor Data Recording Unit (DRU) and the image acquisition unit (IAU) interfaced with a camera that photographs the coral clusters below it. Synchronization

between the three units is crucial for long-term deployment. The system when not in measurement mode is switched off in order to save every watt of power possible. The block diagram shown in Fig.2 depicts the connections between DRU, IAU, and DTU.

### **2.1.Sensor Data Recording Unit (DRU)**

The data recording unit was designed from an existing technology of Autonomous Vertical profiler (AVP) [Desa et al. 2012] developed at the Marine Instrumentation Division, CSIR-National Institute of Oceanography. The AVP profiles the water column with mounted in-situ sensors with the help of a thruster and control system to hover at a pre-defined depth. To meet the requirement of monitoring the CTD, chlorophyll, turbidity, PAR, and dissolved oxygen at one spot of the coral reefs of Lakshadweep Island, the AVP is modified to be point moored at one location (Fig 3).

The DRU consists of a PIC microcontroller stack responsible for executing a mission to; (i) start the data recording, (ii) trigger the image acquisition system, (iii) obtain the GPS positions, and (iv) control the power to other systems. The DRU is enclosed within a water-tight enclosure containing a lithium polymer (LiPo) battery bank with a battery management system to charge it using the solar panels and supplies power to all three units. As shown in Fig.1 the mooring line is kept vertical with the help of an intermediate buoy close to the DRU.

The sensors are interfaced to the hardware (ARM-based module with serial ports) of the DRU, and it was programmed to record the data every two hours for three minutes. The sensor data was acquired every second during the three-minute time window. The sensor data includes Dissolved Oxygen, Chlorophyll, Turbidity, PAR, and CTD. The GPS and GPRS modules are switched on only at the time of image acquisition and transmission. The timings are controlled using a Real Time Clock (RTC), which interrupts the PIC controller every hour. After wakeup, the controller checks if it is time to take an image or time to record the data, otherwise it goes back to sleep. At the time of data recording, the DRU starts the sensors and records the data into its memory card. At the time of image acquisition, the DRU switch on the IAU, GPS, and GPRS module and transfers the sensor data files to IAU. The flow chart of the overall process is shown in Fig 4.

### **2.2. Image Acquisition Unit (IAU)**

The IAU consists of a single board computer (beagle bone black), a camera (Logitech HD C910, 1080p), and RTC. The RTC is used to maintain the time for the beagle bone black and keep track of the image names. Once powered on by DRU, the IAU starts the camera for capturing images. The acquired image is saved in two resolutions. The lower resolution image of approximately 50KB file size is used for transmission, and the higher resolution image with ~250KB file size is saved in the

solid-state disk. After image acquisition, the IAU requests for the DRU data files and transmits the pictures and the data files through the GPRS modem. The structure for holding the camera is designed in such way, that angle of view can be adjusted by changing the slot position of the rigid connection between the two perpendicular metallic pipes (Fig. 5).

### 2.3. Mission Software

A predefined mission is stored on the memory card attached to the PIC microcontroller with the file name 'Mission.txt'. The mission file contains the commands recognized by the PIC for configuring the time for recording data and acquiring images. The main command \$Profile:04:08:12 has parameters for maximum up to three times of image acquisition (\$Profile:time1:time2:time3). For only two images per day, the user can specify only two parameters in the same command followed by a carriage return. In case the file doesn't exist, or any error occurs while opening the file, the PIC controller will power on the IAU at a default hard coded time of 4, 8, and 12 hours GMT. There are many other commands which are parts of the mission for the debug purpose, for example, *StartLog* used to initiate an Image capture manually, *InitTime*, used to initialize the RTC to GPS time, etc (Table 1). The mission file can be transferred to the SD card during setup. Through the web server at the base station, the user can modify the mission remotely. Point to point over Ethernet (PPoE) was used to establish an internet connection to the single-board computer. PPoE obtains the IP address for the device over GPRS and allows the user to access the internet as if it is connected to Ethernet. The images and the data files are uploaded to a server running at our lab using file transfer protocol.

### 2.4. Data Transmission Unit (DTU)

The DTU is part of the floating structure on the surface of the water (Fig. 6). It consists of a GPRS Modem, GPS, and solar panels for charging the batteries inside the DRU. The DTU is designed in such a way that the center of gravity (CG) of the DTU system lies below the center of buoyancy (CB) in one line. A lead weight under the metal frame as shown in figure 6(a) provides stability to the whole system. In the case of high-energy waves, even if the DTU topples, it will come back to its designed equilibrium condition. Fig.6 (b) shows the deployed system in the sea with the help of a small boat.

## 3. Deployment and operation of SRMS at sea

The SRMS was deployed on the reef slope of Agatti Island, UT of Lakshadweep between 5<sup>th</sup> and 12<sup>th</sup> May 2016 in the wake of the global El Nino event (Fig 7). The SRMS was lowered from a dive boat to a depth of 15 m and the entire system was attached to a mooring line which was made taut by dead weights at one end and surface floats at the other end. The image acquisition unit was fixed at a height of 1 m from the reef floor with the camera positioned facing a patch of coral colonies and set to

take three pictures in a day at fixed time intervals. The DRU was positioned above the IAU and configured to record and internally log the data continuously at every two hours intervals for three minutes. The water temperature ( $^{\circ}\text{C}$ ) and PAR values ( $\mu\text{mol m}^{-2}\text{s}^{-1}$ ) were recorded up to two decimal points using an SBE 49 FastCAT CTD sensor and Satlantic PAR sensor, respectively. A series of well-resolved images of coral clusters with supporting time series sensor data over the period of deployment period was acquired and transmitted using DTU three times a day to a web server, which could be accessed through a website.

## **4. Results**

### **4.1. SRMS data and analysis**

The daily average data recorded by all the sensors integrated with SRMS were summarized in Table 2. The average in situ water temperature was  $31.1 \pm 0.13$   $^{\circ}\text{C}$  (Mean  $\pm$  SD) and the daily temperature range was consistently high ( $\geq 31^{\circ}\text{C}$ ) during the monitoring period. The in situ PAR ranged between 427.93 and 591.93  $\mu\text{mol m}^{-2}\text{s}^{-1}$  with a daytime average of  $513.9 \pm 54.7$   $\mu\text{mol m}^{-2}\text{s}^{-1}$ . The turbidity values ranged between 0.12 to 0.37 NTU, characteristic of many tropical reefs. The average dissolved oxygen recorded at the deployment site was  $6.9 \pm 0.1$   $\text{mg L}^{-1}$  and the dissolved oxygen levels were  $>6.5$   $\text{mg L}^{-1}$  during the entire duration of the deployment. The average salinity of the seawater was  $35.3 \pm 0.09$  PSU and it ranged between 35.2 and 35.5 PSU during the monitoring period. The images of the coral cluster recorded during the experimental operation were provided in Fig 8. The period of deployment was too short to notice any visible changes in the coral cluster. However, the important point is the development of a tool and technique to acquire images and data that allow the researcher to monitor the health of coral colonies remotely.

### **4.2. Intercomparison between SRMS and Satellite data sets**

The in situ temperature data recorded by SRMS was compared with satellite dataset products to assess the advantage of SRMS in determining the thermal bleaching thresholds of corals. The statistical significance of the variation observed between the in situ and satellite dataset was analyzed using Paired T-test in the statistical software SPSS V.28. The in situ temperature recorded by SRMS was compared with NOAA's Coral Reef Watch (CRW) daily global 5km SST product, CoralTemp (Version - 3.1), which is commonly used for monitoring and documenting the global coral bleaching events (Liu et al. 2018; Couch et al. 2017). The SST dataset of CRW uses night-time only data to reduce the anomaly caused by solar heating during the day (Strong et al. 2011). Therefore, the in situ data recorded only during the nighttime was used for comparison. The differences between the satellite datasets and in situ data were quantified with Root Mean Square Error (RMSE), Mean bias, and Paired

T-test. The in situ temperature recorded by the SRMS was consistently higher by 0.1 - 0.4 °C than the CRW data with the RMSE and Mean bias of 0.25 °C and 0.22 °C respectively. The observed variation between the in situ and CRW temperature data, though small in magnitude, was statistically significant (Paired t-test,  $t(8) = 4.3$ ;  $p = 0.002 < 0.05$ ) (Fig 9).

## **5. Discussion**

### **5.1. SCUBA Diver vs SRMS**

SRMS is a sophisticated, autonomous, near real-time system that monitors the corals and environmental conditions parallelly through an integrated network of cameras and sensors and it is suitable for long-term monitoring. The SRMS presents and communicates high-resolution in situ data along with color images of the coral clusters that would augment the existing satellite and diver-based monitoring practices. Diver-based surveys are central to the globally coordinated coral reef monitoring networks such as the Global Coral Reef Monitoring Network (GCRMN) which monitors the status and trends of coral reefs at a large spatial and temporal scale (Nocerino et al. 2020; Chennu et al. 2017). Though the data generated by diver-based surveys provides useful and communicable information, it is not sufficient to understand nuances of reef health, such as the recovery potential of corals, biological diversity composition, and functional, geochemical, physical processes concurrently interacting to support coral reef ecosystem health (Obura et al. 2019). Therefore, there is a demand for integrated, interdisciplinary data combined with an increasing capability to generate such data sets with modern tools and technology for sustained observations. The SRMS described in this study is one such tool that would provide researchers, reef managers, and conservationists unprecedented access to the reef environment without the need for SCUBA diving. The SRMS helps in better understanding the condition and processes influencing the health of coral reefs by providing data on coral health and its surrounding environment in near real-time to the scientists, resource managers, and policymakers in making science-based management decisions.

### **5.2. Satellite datasets vs SRMS**

The SRMS detected a significant variation of 0.1 - 0.4 °C in temperature between the in situ and satellite datasets. Since the frequency of bleaching events has increased in recent times, monitoring the bleaching thresholds, extent, and severity of coral bleaching and the recovery potential of corals has become an essential practice in reef management (Sully et al. 2019). Bleaching, a condition where the corals lose their zooxanthellae, and hence the pigmentation, is a prominent response to environmental stress, notably a rise in ambient temperature above the threshold of tolerance (Lesser, 2011). The CoralTemp (Version - 3.1) product of the NOAA's Coral Reef Watch (CRW) program

documents bleaching on wider geographical scales and, possibly, predicts it (Liu et al. 2014). While satellite datasets largely focus on thermal stress, it fails to address the local scale conditions such as shading or circulation, particularly at the subsurface, which might influence the in situ temperature and result in differential bleaching response among the reef communities across the spatial scale. A unique feature of SRMS is its use in capturing these fine-scale differences in the environmental conditions which cannot be detected by the satellite datasets. Also, SRMS aids in overcoming the limitations of satellite datasets by filling data gaps caused due to cloud cover. Thus, while satellite-based products cover wider areas, their usefulness can be strengthened by resorting to sustained, automated observations at specific sites in a reef using SRMS.

### **5.3. AUV/ROV vs SRMS**

Autonomous underwater vehicles (AUVs) and Remotely Operated vehicles (ROVs) are increasingly used in monitoring coral reefs including exploration of deeper habitats, monitoring the effect of invasive species, assessing the structural complexity and biodiversity of reefs (Ling et al. 2016; Ferrari et al. 2016; James et al. 2017). The AUVs and ROVs can monitor large areas in a short span of time and can be customized to operate in a wide range of environments ranging from mesophotic ecosystems to shallow reef environments. This makes them suitable to detect spatial changes in the reefs whereas the SRMS is more useful for detecting fine temporal changes. Moreover, the endurance of AUVs and ROVs are low compared to stationary monitoring systems like SRMS and hence the application of AUV/ROV in the long-term monitoring of coral reefs is limited. In general, AUVs used in reef surveys have a typical endurance of 4-8 hours (Desa et. al. 2009; Llewellyn et al. 2015). Whereas, the endurance of SRMS is not limited by energy as it uses solar power to recharge the batteries which allows the SRMS to monitor the reefs for an extended period of time. The batteries of SRMS last for approximately 6 months with transmission of three images per day without solar charging. Unlike AUVs/ROVs, SRMS cannot be used to monitor large reef areas. Instead, SRMS are meant for collecting more details from a small reef area that will help in understanding the nuances of reef health and their environmental thresholds. Though AUV surveys can have higher spatial coverage, their use in long-term monitoring is limited since they cannot capture the time evolution of stress responses like bleaching and diseases. Continuous monitoring, atleast at weekly intervals, is essential to detect the onset of bleaching and recovery of corals (Manikandan et al. 2017). Thus, the SRMS in-short is a monitoring system capable of providing an early warning that can help the researchers to decide on when to start the survey to study the stress events in the reef. So, SRMS is a unique stationary monitoring tool and it can't be compared with other monitoring tools like ARV which can cover large spatial areas. Alternatively, deployment of multiple SRMS in a network can provide discrete spatial coverage.



#### **5.4. UAVs vs SRMS**

Unmanned aerial systems (UAS) are used in recent times to monitor coral bleaching over large, remote, inaccessible habitats (Levy et al. 2018). UAS employs a combination of technologies such as hyperspectral imagery and photogrammetry to produce high-resolution maps of the coral reefs. UAS monitoring can reveal the spatial dynamics in coral bleaching between and within the reefs, but have limitations in identifying the environmental factors causing such variations in bleaching response. Besides, the accuracy of the data collected by UAS is also influenced by wave action, wind, and reflectance of water making benthic classifications challenging. A majority of studies combine UAS surveys with in situ monitoring for geo referencing and generating accurate results with a reasonable degree of error (Roman et. al. 2021). Autonomous systems like SRMS offer a suitable platform to acquire in situ environmental data such as temperature, PAR, and salinity that would explain the spatial dynamics in bleaching patterns within and between reefs. As with the standard monitoring practices, combining the UAS survey with SRMS has the potential to improve the efficiency and accuracy of the bleaching monitoring and benthic classifications.

#### **5.5. Other autonomous systems**

A system called Underwater Monitoring Wireless Sensor Network (UMWSN) was used for reef monitoring (Kawabata et al. 2014). The network consists of movable and stationary underwater sensor nodes. The stationary nodes described in the papers consist of the camera system which is hanging in the water column and needs active stabilization. It demands higher energy for their operations and requires frequent battery replacements. Bilodeau et. al. (2022) designed a low-cost long-term camera trap for standalone image acquisition which is processed post the recovery of the system and does not transmit images in near real-time. Boom et. al. (2012) report a camera system which records images of marine fishes for a long time but lack to transmit the images integrated with environmental data surrounding the reef. Given these limitations, SRMS offers a simplified system that can function using renewable energy for a long period of time without the need for frequent replacement of the batteries. It transmits the images along with the important environmental data needed to monitor the reef. SRMS can easily be integrated into any underwater sensor network.

### **6. Conclusion and scope for future development**

The SRMS is a simple yet sophisticated tool to provide a visual glimpse of corals insitu and important parameters required for monitoring the health of the coral reefs. The SRMS can be easily deployed at multiple locations in the coral reefs for monitoring bleaching events and capture the nuances of site specific differences in the bleaching response among the coral colonies. Multiple

monitoring systems can be connected to a single DTU for data transmission. The potential of SRMS to provide accurate sea truth data for calibrating satellite sensors of ocean colour, and SST is an important spin-off of this development. The proof of concept of the SRMS prototype for in situ monitoring of threatened coral reefs was demonstrated over a deployment period of 8 days. The deployment time can be extended to three months easily with the existing battery bank, however, cleaning of camera lenses for biofouling or algal growth need to be automated. During this study, the SRMS was deployed near shore where the GSM signals were available for the transmission of data. However, deployment at offshore and remote reefs requires a radio link between the SRMS and a land-based station. The DTU is equipped with a Radio modem working with a frequency of 1.2 GHz and a line of sight range of two km. The SRMS is a prototype that could be made into a useful commercial product easily. Also, an integrated reef monitoring practice that combines SRMS with other reef monitoring tools can provide high quality data and significantly enhance the way the reefs are being monitored.

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**Availability of Data:** The data pertaining to this study will be made available upon request to the Director, CSIR-National Institute of Oceanography, at [director@nio.org](mailto:director@nio.org).

#### **Declaration of competing Interest**

The authors declare that they have no competing financial interest or personal relationships that could have appear to influence the work reported in this manuscript.

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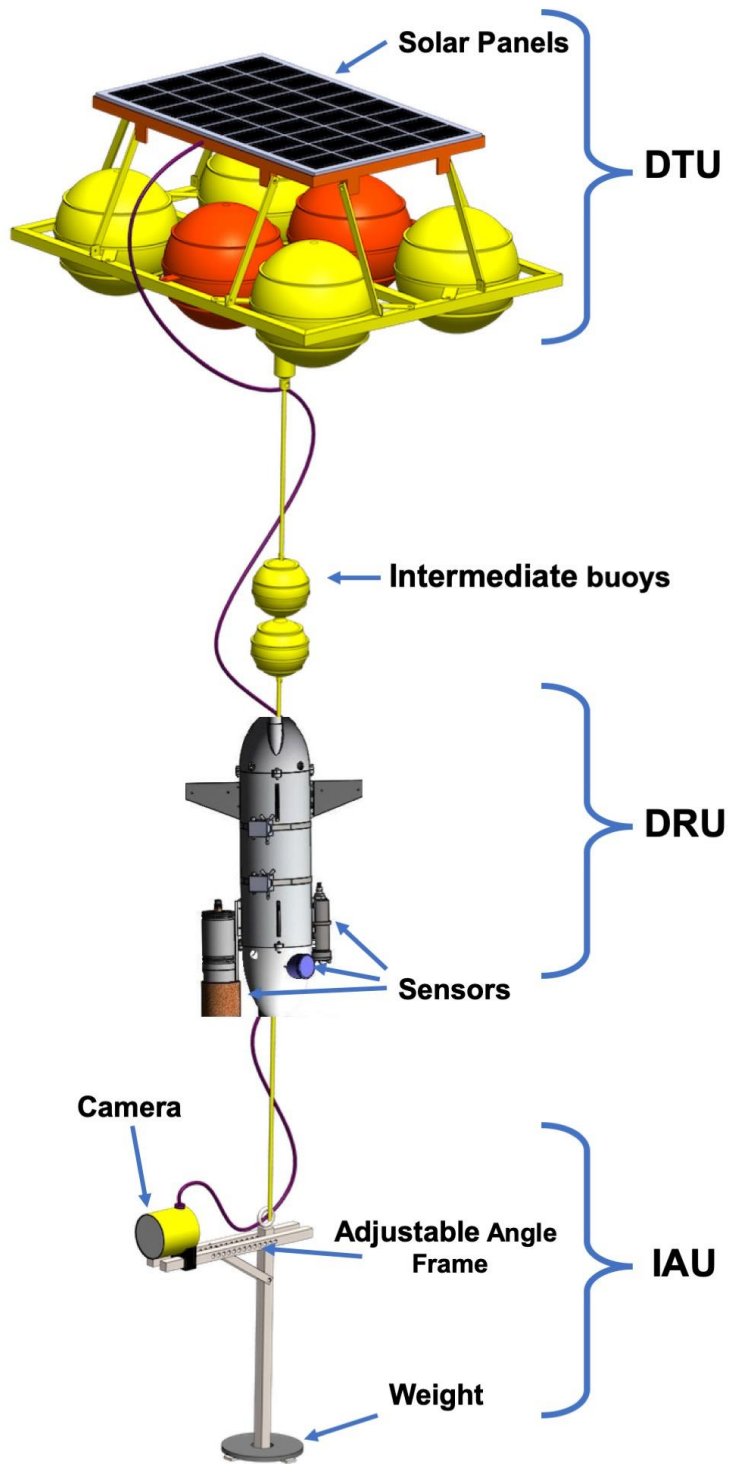
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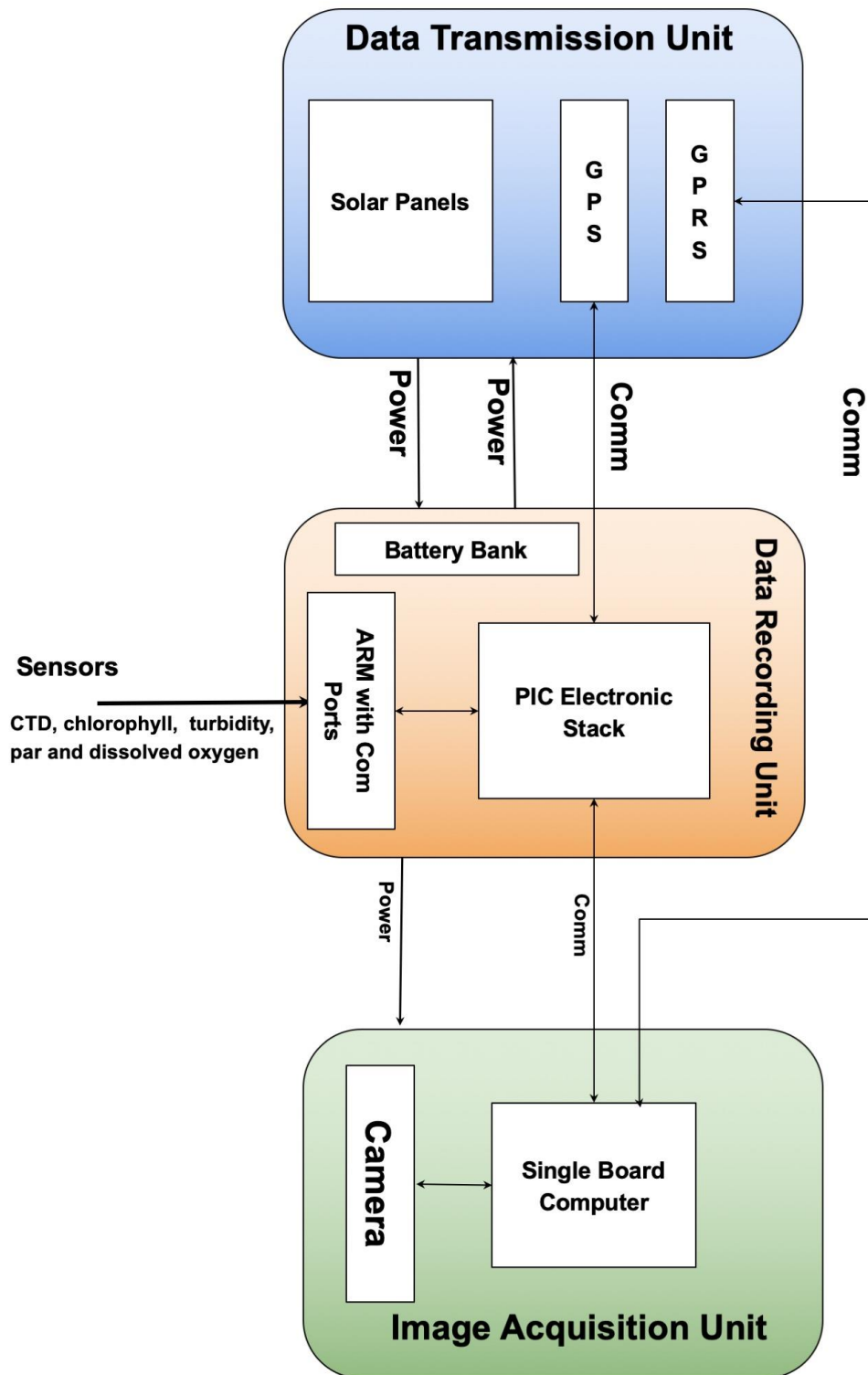
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**Figure Captions**



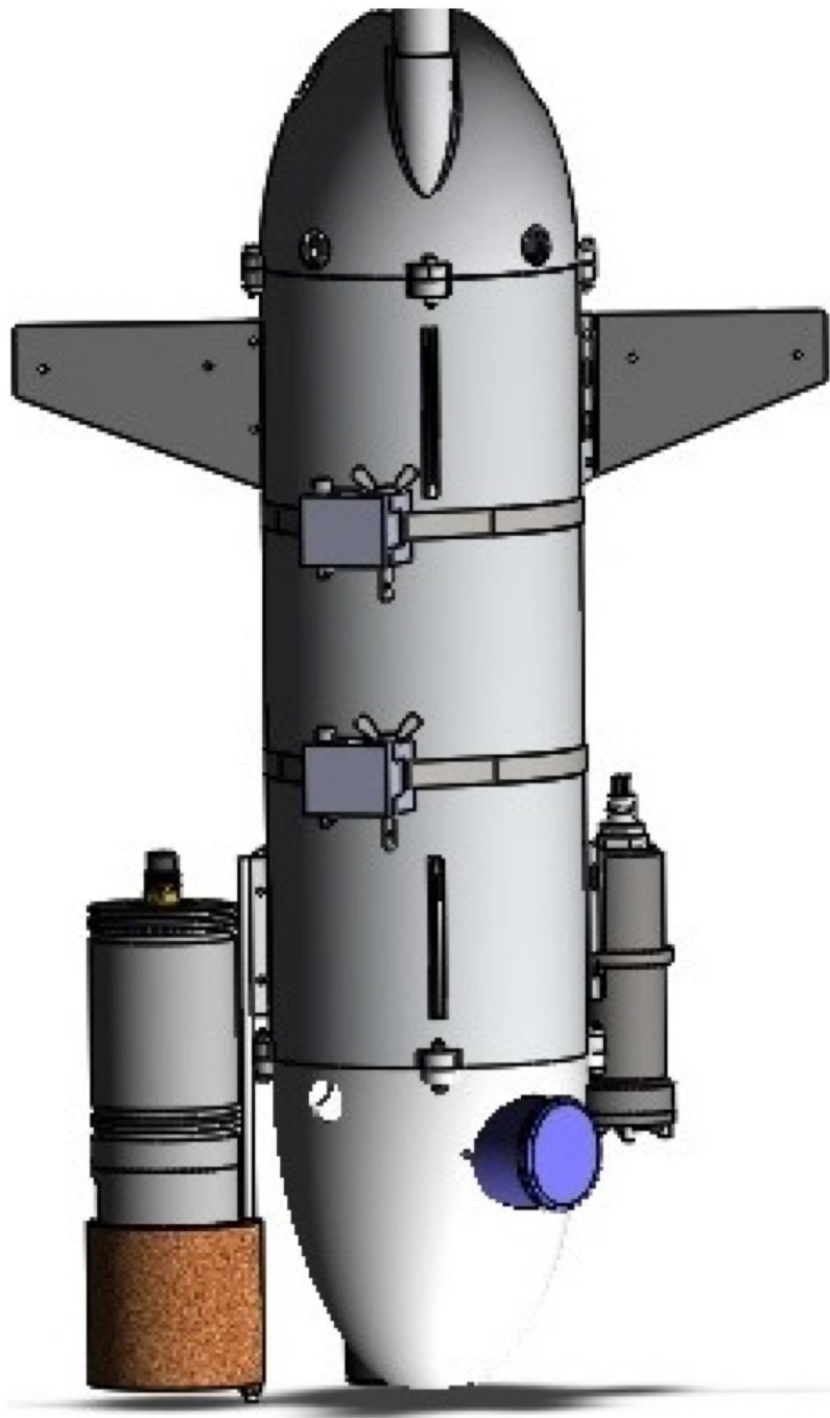
**Figure 1.** A schematic diagram of the whole setup of the Stationary Reef Monitoring System (SRMS)



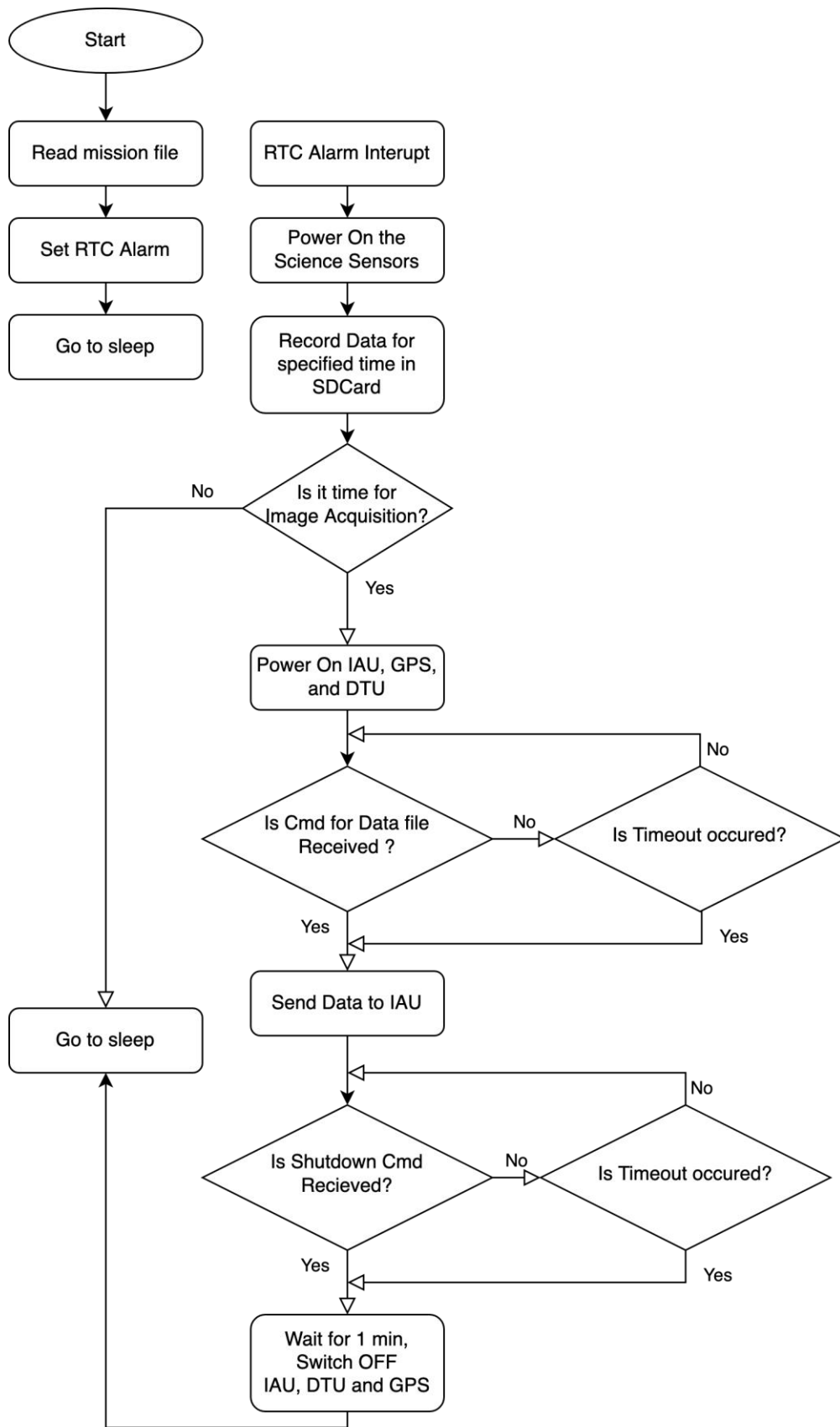
**Figure 2:** Electronic block diagram showing the connections between the Data recording, Image Acquisition, and Data transfer units.







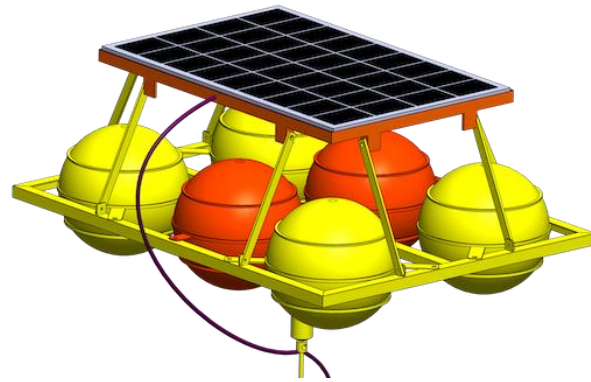
**Figure 3:** The Data Recording Unit (DRU) comprising a point moored AVP with sensors. (3a) DRU underwater; (3b) A 3D model diagram of the DRU.



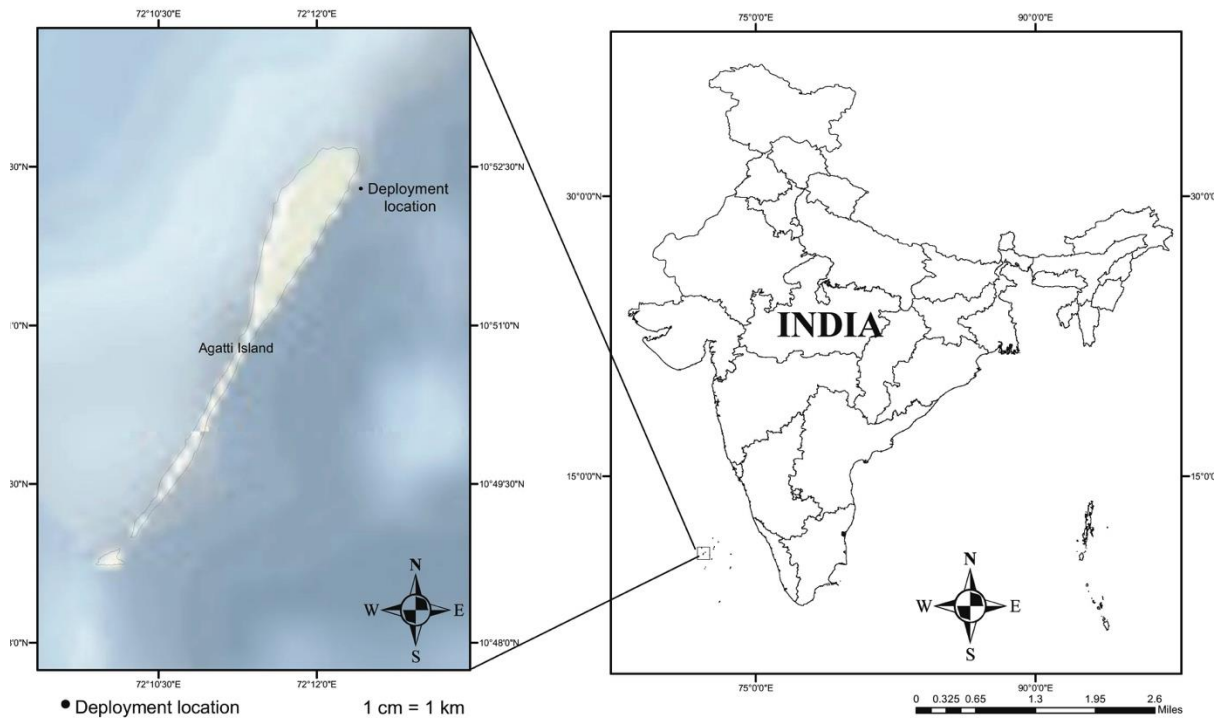
**Figure 4:** Flow chart of the micro-controller program for controlling the IAU and DTU.



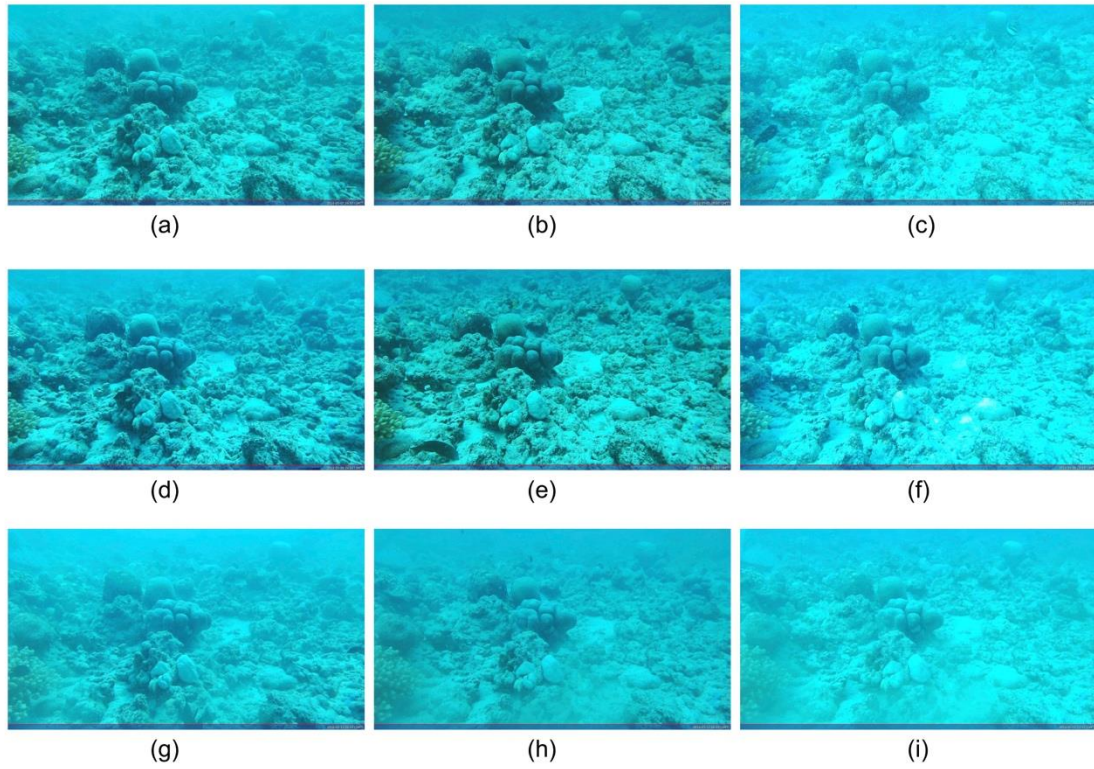
**Figure 5:** The Image Acquisition Unit (IAU) deployed at the seabed in the vicinity of a coral cluster.



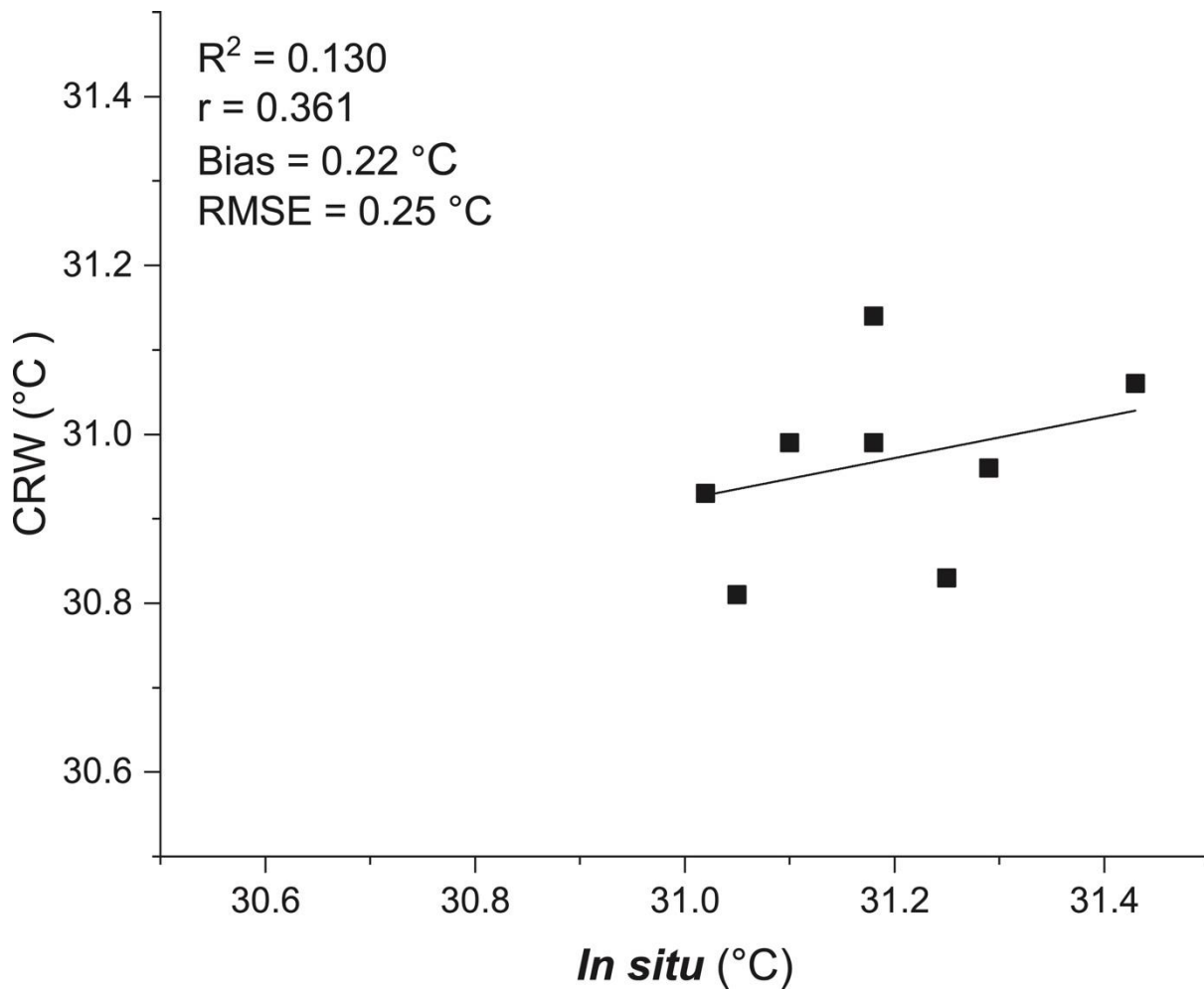
**Figure 6:** (6a) A 3D model diagram of the Data Transfer Unit (DTU); (6b) DTU as seen on the surface of the sea after deployment of the whole system.



**Figure 7:** Map showing the deployment location of SRMS at Agatti Island, UT of Lakshadweep.



**Figure 8:** Representative images taken by SRMS during the deployment period on 7<sup>th</sup>, 10<sup>th</sup>, and 12<sup>th</sup> May 2016. Figures 8 (a), (d), and (g) are taken at GMT 0400 h; 8 (b), (e), and (h) at GMT 0800 h and, 8 (c), (f), and (i) are taken at GMT 1200 h.



**Figure 9:** Scatter plots between the in situ and NOAA CRW temperature dataset recorded during nighttime at the SRMS deployment site at Agatti Island.



**Table 1:** List of commands used by Mission Software

Sl	Command	Description
1	<b>\$Profile:04:08:12\r\n</b>	<b>\$Profile:time1:time2:time3\r\n</b> time is image acquisition time in GMT. If only 2 images are needed per day then 2 fields can be used eg: <b>\$Profile:04:12\r\n</b>
2	<b>StartLog\r\n</b>	Used to initiate Image capture manually.
3	<b>12VON\r\n</b>	Turns on GPS and GPRS by turning on 12V line.
4	<b>12VOFF\r\n.</b>	Turns off GPS and GPRS by turning off 12V line.
5	<b>GPSData\r\n</b>	Used to request for GPS fix data. To test if GPS is working perfectly. Need to turn ON 12V line first and wait for 30 Secs for a fix then request GPS data.
6	<b>InitTime\r\n</b>	Used to initialize the RTC to GPS time. Turn off 12V line first and wait for 40 secs before issuing this command.
7	<b>OneHourInt\r\n</b>	Used to initialize the RTC to interrupt the PIC microcontroller every hour. This command is executed on every boot of the PIC Controller.
8	<b>Voltage\r\n</b>	Command used to get the Battery voltage of the System.
9	<b>\$Debug\r\n</b>	Command used to inform the Beagle bone black not to shut down after taking an image. This is used when an SSH into the beagle bone black is needed. Only used when the Beagle bone black has an USB cable connected to the computer and is ready for SSH. After issuing this command issue a capture image command.



**Table 2:** Daily average values of the environmental parameters measured by SRMS at the deployment site in Agatti Island, Lakshadweep.

<b>Date</b>	<b>Temp (°C)</b>	<b>PAR (<math>\mu\text{mol m}^{-2}\text{s}^{-1}</math>)</b>	<b>Chlorophyll (mg/l)</b>	<b>Turbidity (NTU)</b>	<b>Salinity (PSU)</b>	<b>DO (mg/l)</b>
05-05-16	31.4	491.11	0.11	0.39	35.24	6.84
06-05-16	31.3	505.68	0.13	0.31	35.31	6.70
07-05-16	31.3	591.93	0.12	0.13	35.3	6.85
08-05-16	31.0	563.65	0.10	0.12	35.5	6.90
09-05-16	31.1	478.12	0.16	0.13	35.4	6.80
10-05-16	31.2	564.23	0.08	0.15	35.4	6.87
11-05-16	31.2	488.92	0.12	0.30	35.4	6.85
12-05-16	31.1	427.93	0.18	0.33	35.5	6.98