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MALAYSIAN INTEGRATED OCEAN OBSERVATION SYSTEM (MIOOS) BUOY

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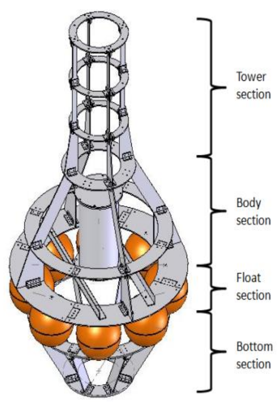
Graphical abstract



Abstract

Marine ecosystem around the world especially in coastal areas are facing threats of extinction from climate change, water pollution, and human activities, and therefore are in an urgent need for a round-the-clock monitoring. A novel Malaysian Integrated Ocean Observation System (MIOOS) buoy has been developed, which integrates an audio and visual surveillance into the traditional ocean data acquisition system (ODAS) buoy with the objective of providing a complete and cost effective coastal monitoring solution for marine parks. The buoy was equipped with sensors to sample oceanographic and meteorological data, and also a hydrophone and two cameras including one omni-directional camera to capture audio and visual data of the surrounding. The buoy embedded system has been designed using a low-power MSP430G2533 from Texas Instrument as the primary microcontroller. The system was powered by an 80Ah Lithium Ion battery, which was rechargeable using two units of 20 Watts solar panels. Data were transmitted to a ground station using XTend 900 MHz wireless module, which were subsequently stored and shared over the internet through a broadband modem. The buoy also has been made configurable using a Short Message Service (SMS) through a GSM modem connected to the ground station. Field testing has been conducted at a coastal area and the oceanographic and meteorological data as well as images have been collected. Data plotted have satisfactorily exposed some trends which are useful in oceanographic and meteorological studies.

Keywords: Intelligent buoy, ODAS Buoy, ocean observation, scientific buoy, coastal monitoring, oceanographic data, marine observation

Abstrak

Ekosistem marin di serata dunia, terutama sekali di kawasan pantai menghadapi ancaman kepupusan hasil daripada perubahan iklim, pencemaran air dan aktiviti manusia dan oleh itu memerlukan pengawasan sepenuh masa. Satu pelampung baru Malaysian Integrated Ocean Observation System (MIOOS) telah dibangunkan, yang menggabungkan pengawasan audio dan visual ke dalam pelampung sistem perolehan data laut tradisional (ODAS) dengan bermatlamat untuk memberikan solusi penuh dan kos efektif untuk pengawasan pantai seperti taman laut. Pelampung ini dibekalkan dengan pengesan untuk mengambil sampel oceanographic dan data meteorology, serta hydrofon dan dua kamera termasuk satu kamera omni-arah untuk merakam audio dan data visual sekelilingnya. Sistem terbenam pelampung ini direka dengan menggunakan pengawal kuasa rendah MSP430G2533 daripada Texas Instrument sebagai pengawal utama. Sistem ini dibekalkan kuasa dengan bateri 80Ah Lithium Ion yang boleh dicas menggunakan dua unit panel solar 20 Watt. Data dihantar ke stesen bumi menggunakan modul tanpa wayar XTend 900 MHz yang berterusan menyimpan dan menghantar data ke internet melalui modem jalur lebar. Pelampung ini juga boleh dikonfigurasi menggunakan Short Message Service (SMS) melalui modem GSM yang disambungkan kepada stesen bumi. Ujian lapangan telah dijalankan di kawasan pantai dan data oceanografik dan meteorology dan juga imej telah dikumpul. Data yang telah diplot telah mendedahkan beberapa trend yang berguna untuk kajian oceanografik dan meteorology.

Kata kunci: Pelampung pintar, pelampung ODAS, pengawasan laut, pelampung saintifik, pengawasan pantai, data oceanografik, pemerhatian laut

1.0 INTRODUCTION

Malaysia is endowed with rich marine ecosystem, which house more than 83 percent of the world's coral species. It has been recognized as one of the 12 nations with megadiversity and is located in the region of the Coral Triangle Initiative (CTI) [1]. Malaysian government has identified several marine and coastal areas to be preserved under the name of a marine park. Up till now, 42 islands in Malaysia have been gazetted by the department of Marine Park, which include Pulau Payar, Pulau Kapas, Pulau Tioman, dan Pulau Perhentian. For many years, these marine parks have been an important element in Malaysian's ecotourism, which helps to generate the local economy [2].

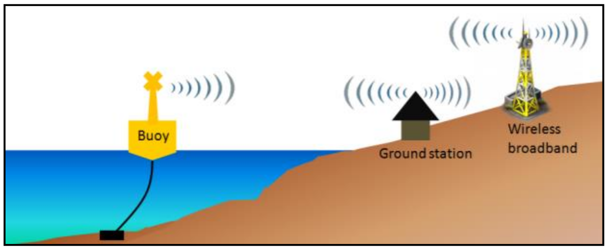
Preserving these marine parks is very challenging in the face of multiple threats from climate change, water pollution, and fishing activities. For example, environmental conditions such as unusually high sea temperatures, low salinity, and exposure to toxic chemicals are known to cause coral bleaching [3]. Several recent events of coral bleaching in Malaysia were recorded in 1998, 2004, and 2010. While not much can be done to prevent coral bleaching, steps can be taken to promote recovery of the coral after the bleaching. To ensure a prompt and appropriate response to help with the coral recovery, a constant monitoring is required on several important cues such as sea water temperature and salinity that will help to predict the bleaching event and trigger an early warning.

In addition to natural forces, human activities also can post serious threats to corals [4]. In some countries, destructive fishing methods such as cyanide fishing, explosive fishing, and bottom trawling are considered to be one of the largest immediate threats to marine ecosystem at the coral reef. This threat can be reduced by having a proper surveillance system around the designated area to be preserved that will guard the area against intrusions by fisherman. Tourist activities such as diving and snorkelling can also have indirect impact on the marine lives [5]. During fish breeding season for example, the presence of tourist in the proximity of breeding fish can affect the breeding pattern. It is therefore important for a monitoring system to be deployed in the affected area that will monitor the breeding pattern of certain species of fish and alert the tourist to stay away from certain areas during the breeding season.

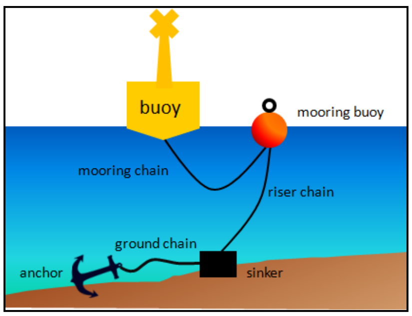
Throughout the world, extensive network of marine buoys has been used to collect and monitor oceanographic and meteorological data in the ocean and coastal area [6-11]. These buoys are generally referred to as the Ocean Data Acquisition System (ODAS) buoy. One example is the data buoy network operated by the National Data Buoy Center (NDBC) [12], which consists of a network of 90 data buoys located in the ocean all over the world. A typical conventional ODAS buoy is equipped with various oceanographic and meteorological sensors such as anemometers, air temperature sensor, water temperature sensor, barometer, salinity sensor, and humidity sensor. However, for the purpose of monitoring a marine park, the function of an ODAS buoy can be extended beyond mere collecting scientific data. Audio and visual surveillance equipments can be added to the buoy to monitor the area for human activities and guard against intrusions. In literature, there were some considerable works done on utilizing buoy-mounted camera for ocean surveillance such as in [13-15]. Furthermore, the audio equipment can also be utilized for acoustic monitoring of marine lives such as in [16]. A well designed buoy can operate for years with minimum maintenance, and thus provide a very cost effective solution to coastal monitoring.

2.0 MIOOS BUOY

Malaysian Integrated Ocean Observation System (MIOOS) is built with the objective of integrating audio and visual surveillance system into a conventional ODAS buoy, making a single integrated ocean observation platform, with the target deployment area around a marine park. Data collected by the MIOOS will be transmitted periodically to a ground station wirelessly, which are then processed and logged by the ground station as shown in Figure 1(a). Data in the ground station are then synchronized with a cloud storage using a wireless internet connection, which can be accessed from anywhere around the world. The ground station is also connected to a GSM network to allow for a remote configuration of the buoy as well as data communication between user and the ground station using a Short Message System (SMS).



(a)



(b)

Figure 1 (a) MIOOS System (b) Buoy mooring

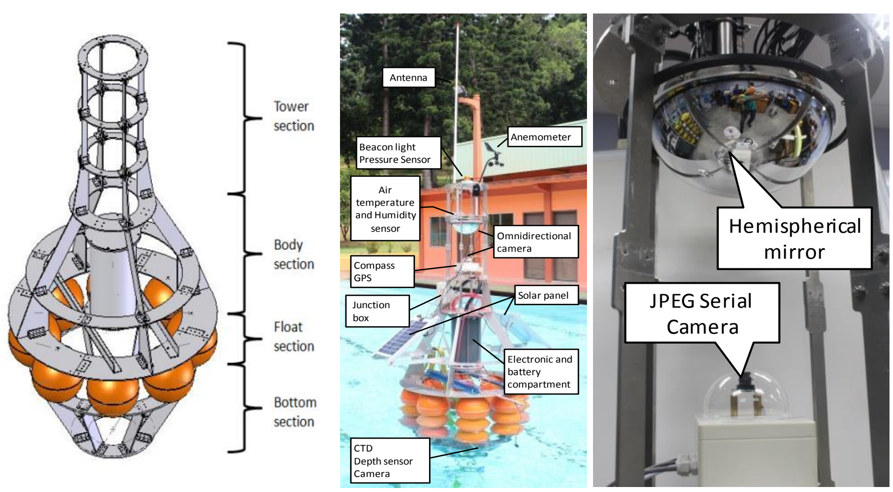
2.1 Buoy Mooring

One of the essential parts of a buoy deployment is the mooring structure, which ties the buoy to the sea floor. The mooring system for the MIOOS buoy consists of an anchor, a sinker, chains, swivels, and shackles. As shown in Figure 1(b), a single point mooring (SPM) system is used for the deployment of the MIOOS buoy where the buoy is tied to a single mooring buoy by a mooring chain. The mooring buoy, in turn, is tied to a 180 kg steel block sinker by a riser chain. To prevent the sinker from being moved around on the sea floor, it is secured to an anchor by another chain. The use of the mooring buoy allows for easy retrieval and redeployment of the MIOOS buoy in case it requires servicing.

2.2 Structure Design

The structure of the MIOOS buoy is made up almost entirely of marine grade aluminum and is divided into four sections, namely the tower section, the body section, the float section, and the bottom section as shown in Figure 2(a).

The tower section provides elevated platforms where the antenna, several sensors, and beacon light are mounted. Directly below the tower section is the large body section which houses the electronic and battery compartment and also provides the mounting for the solar panels. The whole tower and body sections assembly sits on top of a float section which provides buoyancy to the buoy. The float section is constructed from an array of center hole trawl floats. The bottom section of the buoy is where the underwater sensors are mounted. Here is also where additional weights assembly (keel) is attached to, which functions to shift the center of gravity of the buoy below the center of buoyancy. Figure 2(b) shows the placement of all the sensors, antenna, and cameras on the MIOOS buoy, whereas the Figure 2(c) shows the structure of the omni-directional camera.

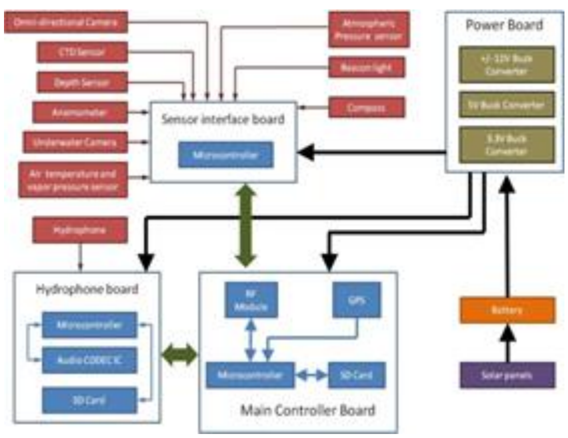


(a) (b) (c)

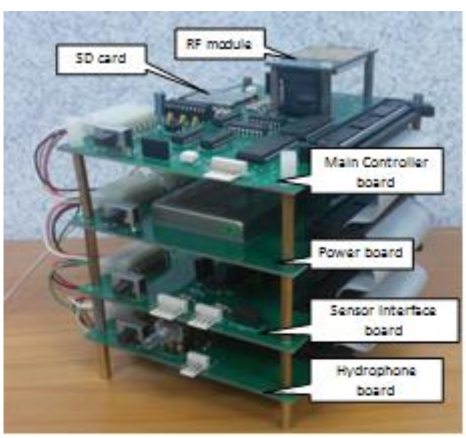
Figure 2 (a) MIOOS buoy structure (b) Sensor placements (c) Omni-directional camera

2.3 Buoy System Design

Figure 3 (a) shows the system block diagram of the MIOOS buoy. There are four electronics boards stacked on top of each other namely the main controller board, power board, sensor interface board, and hydrophone board as shown in Figure 3(b). The MSP430G2533 from Texas Instrument has been chosen as the primary microcontroller, whereas the Xtend 900 MHz wireless module was chosen for the communication. The MSP430 microcontroller family is known for their low power consumption and is suitable for remote sensor node applications as demonstrated in [17-18]. A Radio Frequency (RF) communication is preferred over satellite telemetry for this application because of the short distance between the buoy and the ground station, and also due to the lower cost of operation despite a higher data rate capability [19]. The whole system is powered by an 80 Ah Lithium Ion battery, which is recharged by two sets of 20 watts solar panels.



(a)



(b)

Figure 3 (a) Buoy system block diagram (b) Electronics board

The main controller board controls the overall functioning of the buoy. The board consists of the main microcontroller, RF module, SD card, and a GPS module. The board's primary function is to sample sensor data according to the sampling rate set for each sensor and transmit the data to the ground station through RF module. The primary element of the main controller board is the 16-bit ultra-low power MSP430G2533 microcontroller from Texas Instrument. Summarized below are some of the key features of this microcontroller:

- Low Supply-Voltage Range: 1.8 V to 3.6 V
- Ultra-Low Power Consumption
    - Active Mode: 230 µA at 1 MHz, 2.2 V
    - Standby Mode: 0.5 µA
    - Off Mode (RAM Retention): 0.1 µA
- 16-Bit RISC Architecture, 62.5-ns Cycle Time
- 512 Byte RAM
- 16 KB of flash memory
- 1 UART port
- 1 I2C/SPI port

The UART port is expended by using 74HC4067 16-channel analog multiplexer/demultiplexer to allow for up to 16 serial devices to be connected to the microcontroller. The number of digital output pin is also expended using three 74HC595 8-bit serial in parallel out shift registers, which provide additional 24 digital output pins. The microcontroller is configured to use 32 kHz external crystal, which serves as the basis for the real-time clock. The timing of the sampling is managed by the real-time clock, which is synchronized with the satellite clock in timely manner using a UP501 Fastrax GPS module. This ensures that the clock remains accurate down to one second at all time. The GPS module also serves to provide location data of the buoy. The sampled data are temporarily stored inside a 4 Gigabyte SDHC card before they are formatted and transmitted to the ground station. The communication between the buoy and the ground station is achieved using XTend 900 MHz RF module from Digi, whose key features are summarized below:

- 1 Watt Power Output (variable 1 mW – 1 W)
- Range (@115,200 bps throughput data rate):
    - Indoor/Urban: up to 1500' (450 m)
    - Outdoor RF line-of-sight: up to 7 miles (11 km) w/dipole antenna
    - Outdoor RF line-of-sight: up to 20 miles (32 km) w/high-gain antenna
- Continuous RF data stream up to 115,200 bps
- Receiver Sensitivity:–100 dBm (@ 115200 baud)
- Network Topologies Supported: Mesh, True Peer-to-Peer (no Master device required),Point-to-Point, Point-to-Multipoint & Multidrop
- 2.8 – 5.5 V Supply Voltage

The main reasons for choosing this module are the communication range of up to 32 km with RF line-of-sight and the Mesh networking topology, which allows a decentralized communication between modules with same network ID. In this topology also, a message from one module can hop from module to module until it reaches the destination module, therefore extending the communication range further in a multi-buoy environment. On this buoy, the RF module is hooked to a marine-grade CXL 900-6LW collinear high gain antenna with a gain of 8 dBi to ensure a maximum communication range.

The second board is the sensor interface board where the sensors are connected to. The function of this board is to standardize the output of the sensors into serial output before there are channelled to the main controller board. The same type of microcontroller, the MSP430G2533 is used for this board. Outputs from analog sensors are level-shifted and fed into the analog-to-digital converter channels of the microcontroller. The digital values are then computed and sent to the main controller board through serial port. Outputs from digital sensors with RS232 voltage level on the other hand are input to MAX3232 ICs where the voltage levels are shifted to CMOS level before there are sent to the main controller board. Powers to all the sensors are switchable through solid state relays. Most of the sensors are switched on only just prior to taking the reading and switched back off right after the reading to save power. In addition to reading the sensors, the sensor interface board is also responsible for controlling the flashing characteristic of the beacon light of the buoy.

The third board is the hydrophone board that processes input from a hydrophone and records the sound into an SD card. The primary components of the hydrophone board are the dsPIC30F4013 16-bit Digital Signal Controller and the VS1063a audio CODEC IC. Listed below are the key features of both ICs:

a) dsPIC30F4013
   - 16-bit modified Harvard architecture
   - 48 KB program memory
   - 2 KB RAM
   - 7.37 MHz, 512 kHz internal oscillator
   - 2 UART, 1 SPI, 1 I2C digital communication interface
   - 1-A/D 13x12-bit @ 200(ksps) analog peripherals
     1.

b) VS1063a
   - MP3, Ogg Vorbis, PCM, IMA ADPCM, G.711 (u-law, A-law), G.722 ADPCM encoders
   - MP3 (MPEG 1 & 2 audio layer III (CBR+VBR +ABR)), MP2 (layer II) (optional), MPEG4/ 2 AAC-LC(+PNS), HE-AAC v2 (Level 3) (SBR + PS), Ogg Vorbis, FLAC; WMA 4.0/4.1/7/8/9 all profiles (5-384 kbps), WAV (PCM, IMA ADPCM, G.711 u-law/Alaw, G.722 ADPCM)
   - Up to 96 KB RAM for user code and data
   - Bass & treble controls
   - Alternatively a 5-channel equalizer

The dsPIC30F4013 serves as the main controller on the board that analyse the sound signal from the hydrophone using the Fast Fourier Transform (FFT) and trigger the VS1063a CODEC IC to start and stop sound encoding process. The dsPIC30F4013 will also read the encoded sound file from the encoder IC and store the file inside the SD card through SPI interface. Some information from the sound is sent to the main controller board using serial communication, which is then transmitted to ground station. The hydrophone board will also alert the main controller board when sound level exceeds certain predefined threshold. In addition to the main and the CODEC IC, the hydrophone board also contains level shifter, analog filter, and audio amplifier circuit to condition the signal before it is fed to the dsPIC and the CODEC IC.

The last board is the power board, which serves to distribute power to all the boards. The power board receives 12V from 80 Ah lithium ion battery and convert it to +/-12 V, 5 V, and 3.3 V using three high efficiency buck converters. The lithium ion battery is connected to two 20 Watt solar panels to recharge the battery during the day.

2.4 Sensors

Malaysian integrated ocean observation system buoy is equipped with sensors to collect some oceanographic and meteorological data, together with relevant system data. In addition to that, the buoy can provide audio and visual data both from the sea surface and underwater to aid with the visual surveillance of the area being monitored. Table 1 below lists all the sensors installed on the buoy.

Table 1 Buoy Sensors

Sensor	Data collected	Range	Accuracy
Air temperature	Sea surface air temperature	-40 °C to 80 °C	0.1 °C
Air pressure	Sea surface air pressure	15 to 115 kPa	± 1.5%
vapor pressure	Vapor pressure	0 to 47 kPa	0.01 kPa
Anemometer	Wind speed	2 to 129 mph	± 5%
	Wind direction	0° to 360°	± 7°
CTD	Conductivity	0 to 120 dS/m	± 10%
	Water temperature	-40°C to +50°C	± 1°C
Depth transducer	Depth	300 M	-
Hydrophone	Underwater sound	10Hz to 100kHz	-

In addition to the above mentioned sensors, the buoy is also equipped with an omni-directional sea surface camera as shown in Figure 2(c), an underwater camera, and a compass. Also, For the purpose of monitoring the inner condition of the electronic compartment inside the buoy, a temperature sensor built-in inside the microcontroller MSP430G2533 is used to measure temperature inside the compartment.

3.0 GROUND STATION

All the data from the buoy is sent to ground station through RF communication. As shown in Figure 4, the ground station consists of an Xtend 900 MHz RF module, a computer, and a Huawei Hilink E3131 GSM/broadband modem. The RF modem is connected to a CXL 900-6LW collinear high gain antenna to receive data from the buoy and output the data to the computer through USB port. Inside the computer, the data is logged in files inside a Dropbox folder. The Dropbox is basically a popular file sharing application that allows files and folders to be synchronized with cloud storage. This allows the files to be viewed on any computer with Dropbox installed and logged in using the same account with that of the ground station. The Dropbox files and folders are synchronized with the cloud storage using an internet connection through the GSM/broadband modem. The GSM/broadband modem also allows user to communicate with the ground station, and subsequently with the buoy, using a Short Message Service (SMS).

Figure 4 Ground station block diagram

4.0 RESULTS AND DISCUSSION

4.1 RF Communication Range Test

Central to the operation of the MIOOS is the RF communication between the buoy and the ground station. RF module is connected to a marine-grade CXL 900-6LW collinear high gain antenna with a gain of 8 dBi to ensure a maximum communication range. To measure the communication range of the Xtend 900 MHz RF module, a loop-back test has been performed in Pulau Bidong, Terengganu.

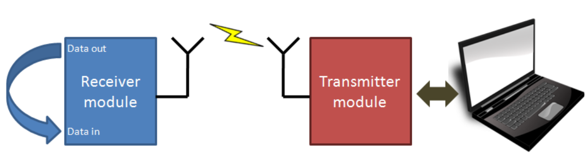


Figure 5 RF communication range test

A loop-back test is basically a test where one RF module (transmitter) sends a string to another RF module (receiver) and the receiver echoes back the received string to the transmitter. This is achieved by tying together the data input pin and the data output pin on the receiver module as shown in Figure 5. The transmitter module is connected to a computer running a program called X-CTU, which will compare the transmitted string against the received string. If the two strings match, then the communication is marked as good, or else, the communication is marked as bad as shown in Figure 6. The receiver module has been placed on a buoy anchored to the sea floor while the transmitter module, together with the computer, has been placed on a boat. The power output of both modules was set to 1 Watt and the antennas for both modules were placed about 1.7 meter above the water surface. The boat was then moved away from buoy while the loop-back test was running. The boat continued to move away until a bad communication was detected. The point-to-point distance between the boat and the buoy as then calculated to be around 3.3 kilometres. Figure 7 shows the mooring structure of the buoy.

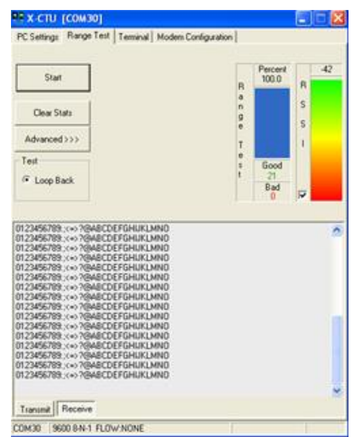


Figure 6 X-CTU Loop-back test

(a)

(b)

(c)

Figure 7 Buoy mooring structure (a) Sinker (b) Riser chain (c) Anchor

(a) (b)

(c) (d)

Figure 8 (a) Map of the buoy on Penang Island (b)CEMACS beach (c) Deployed MIOOS buoy (d) Ground Station

4.2 Final Buoy Deployment

The complete prototype of the MIOOS has been deployed on 25 June 2014 at 05°28.10900'N, 100°11.97560'E at the depth of 3 meters while the ground station has been placed at the seashore about 138 meters from the location of the buoy as shown in Figure 8. The buoy was left for about 2 weeks at the location to collect the oceanographic and meteorological data as well as surface and underwater images. Figure 9 show the ground station setup placed on the land.

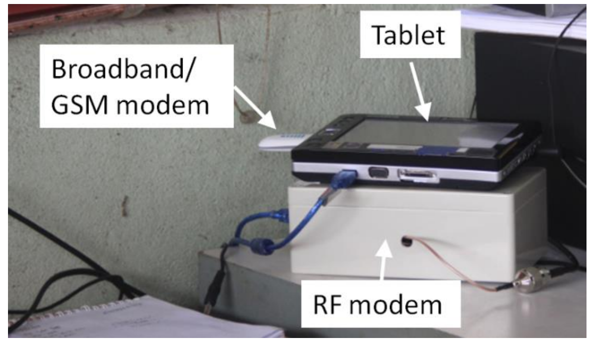
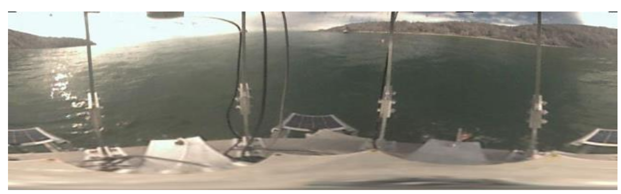


Figure 9 Ground station

Figure 10(a) and (b) show the surface and underwater images captured during the testing while the charts in Figure 11 show the data collected within a specific time frame during the testing. The surface image shows a 360 degree view of the surrounding, which has been stretched into a panoramic view. Despite the low quality of the image, boats and large objects will still be visible in the image. The underwater image however appeared to be murky, which indicates the high quantity of suspended algae or phytoplankton in the water. The plots of the collected oceanographic and meteorological data on the other hand show that certain parameters vary according to certain trends. The plot of the atmospheric pressure in Figure 11 (e) for example, exhibits the typical semi-diurnal cycle pattern, which is more pronounced in tropical regions like in Malaysia due to the influence of the atmospheric tide.



(a)

(b)

Figure 10 (a) Surface image from omni-directional camera (b) underwater image

The whole system is setup by connecting the PI camera module to the CSI port on the Raspberry PI board via ribbon cable while the LCD screen is connected to the board via HDMI cable. The wireless keyboard and mouse is connected to the board using wireless USB adapter. This is only needed when manipulation of code is required. The power is supplied to the board by connecting a micro USB to

USB cable to a wall socket USB adapter or power bank.

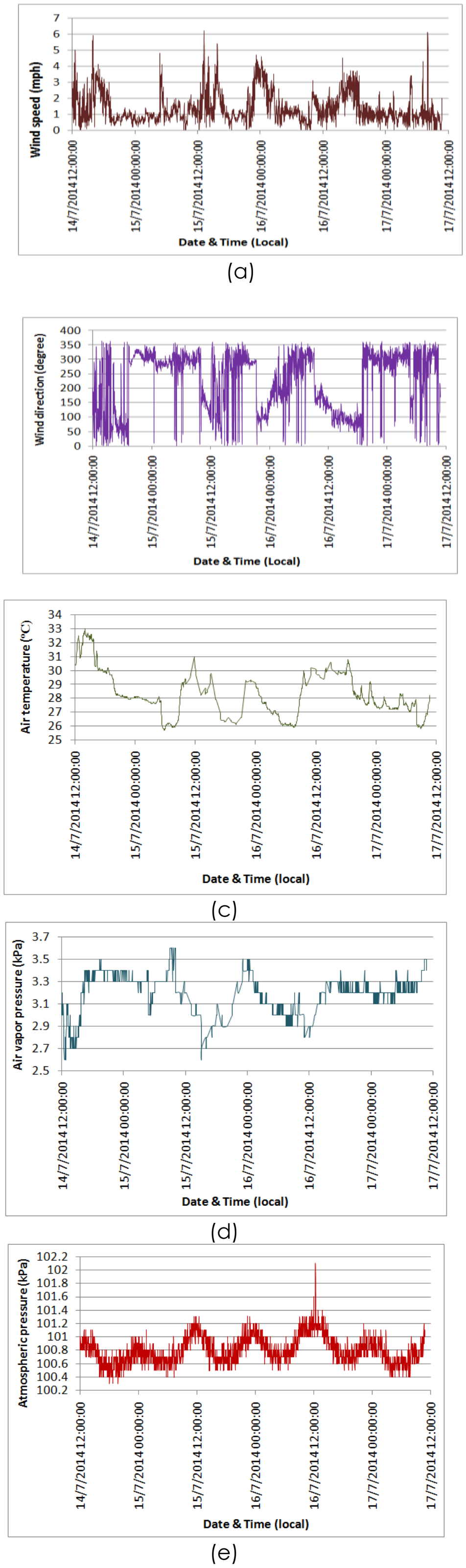


Figure 11 (a) wind speed (b) wind direction (c) air temperature (d) air vapour pressure (e) atmospheric pressure

5.0 CONCLUSION

The final MIOOS system testing was in fact the first and the only full prototype testing managed to be done on the real environment, given the time constrain. As expected, the test has exposed lots of problems and bugs related to the hardware, software, and mechanical design. By and large, the concept of the buoy as an integrated ocean observation system has been successfully proven during the testing. Data were successfully transferred to the ground station and synchronized with the cloud storage over the internet, making them accessible from anywhere around the globe. The MIOOS buoy has also been successfully configured remotely using SMS over the GSM network. In addition to that, latest data from buoy also has been successfully requested by users and updated to the users via the GSM network using SMS. In the future design and deployment of this type of buoy, all the problems encountered during this prototype testing will be properly addressed. A more effective deployment method will also be devised and routine maintenance will be planed to ensure a longer service life of the buoy.

Acknowledgement

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