A Robust Satellite Telemetry System for IMOS Moorings

D. Hughes, T. P. Lynch, L. Pender, M. Sherlock

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Abstract-**An iridium based telemetry system has been developed and successfully deployed both in the Southern Ocean and for over a year at a coastal station. The major technological development for the system was the encasement of the antennas into a sealed unit with transmission achieved through a thick Delrin® lid. Reliable communications can now be obtained in a system that allows a 250m pull down of the surface canister without leakage, and with file buffering of data until satellite reacquisition. This system has proven to be both low-cost and robust.**

I. INTRODUCTION

An iridium based telemetry system for the Australian Integrated Marine Observing System (IMOS) has been developed and implemented on two test platforms in offshore and coastal waters.

The first test was a satellite modem link, which was successfully deployed on the continental slope on two engineering test moorings for the Pulse project. This system reported engineering data such as position, load cell tension, acceleration information and voltage.

II. PULSE

The goal of the Pulse project is to measure biological and physical parameters at 30m in over 4000m of ocean depth in the Southern Ocean. The challenges of variable currents, and at times extreme sea state, required a novel mooring design utilising a surface buoy coupled to the instrument package via a bungee. In order to optimise the design, two experimental moorings, with differing physical elements were deployed which measured bungee tension, sea-state via a Microstrain motion reference unit (MRU) and GPS position. The load cell and MRU were sampled every 90 minutes, for 5 minutes at 10Hz and the information stored to a datalogger for post-deployment processing. Also, processing of acceleration data from the MRU was carried out and the result stored along with average, maximum and minimum load cell tension and system voltage in a file as part of a first-in, first-out (FIFO) buffer within in the system processor memory. These files were transmitted at 3 hour intervals using Iridium Short Burst Data (SBD) transmission. The GPS position was transmitted every four hours using an autonomous tracker unit.

The constant working of any hardware that is deployed into the Southern Ocean means that there are few examples of surface signature moorings that have survived long (>3 month) deployments. As the Pulse test deployments included a surface signature into the margins of the Southern Ocean (Figure 1), there was a reasonable likelihood that the mooring would fail. Previous tests of similar systems only transmitted position and indeed did fail with total loss of all surface engineering data. Having delayed mode data only, which is lost if the mooring breaks free and can't be recovered, limited our understanding of the failure modes.

The telemetry-fitted test moorings successfully completed a 6 month trial with 100% transmission of engineering data from one mooring and greater than 50% from the other – with the loss being due to a sensor failure crippling the power supply.

III. NRS

The second test deployment was at the coastal Maria Island National Reference Station (NRS) [1]. This deployment expanded the scope of the telemetry system to include reporting of water quality data from two sub-surface Wetlabs

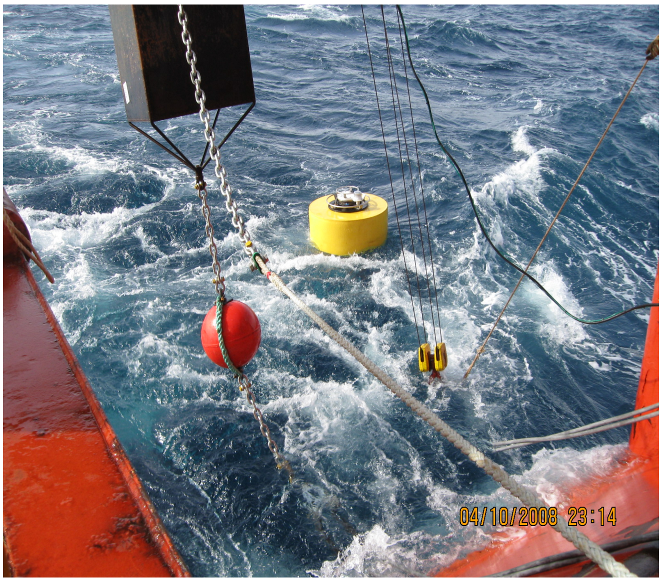

Figure 1. Deployment of the Pulse test mooring.

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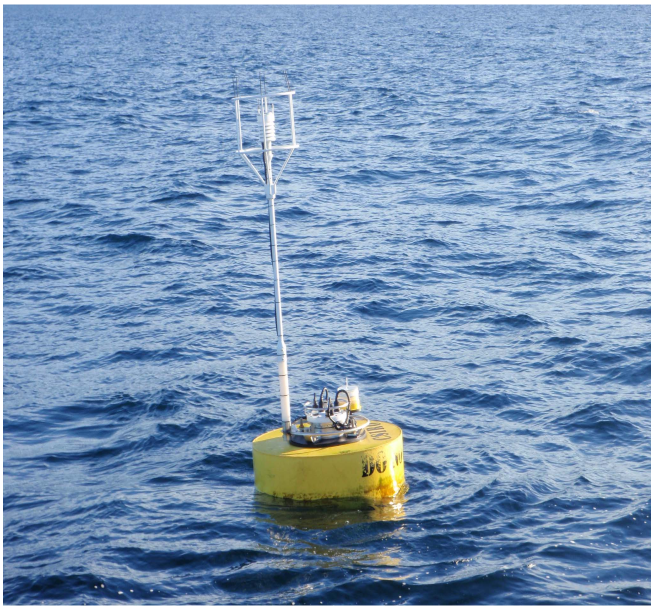

Figure 2. Maria Island NRS surface expression with weather station.

Water Quality Monitors (WQMs) and other sensors such as a Vaisala weather station (Figure 2).

The NRS WQMs are located at 20m and 90m on the mooring line and are programmed to sample conductivity, temperature, pressure, dissolved oxygen, chlorophyll, turbidity and system battery voltage at 1 Hz for 1 minute every 15 minutes. At the end of the sampling period an average is output to Benthos ATM885 acoustic modems configured in datalogger mode. Every hour the surface unit polls the subsurface acoustic modem dataloggers and stores the data retrieved into a file structure along with surface system battery voltages, wave data utilising an MRU, sea surface temperature from a Seabird SBE39 and meteorological data from the weather station . This data is then compressed and transmitted via a number of Iridium SBD transfers. Error checking, file stacking and automatic retry procedures are incorporated in the programming, so that the acoustic link can be broken for up to 48 hours without loss of data and the Iridium link can be broken for up to 1 week without loss of data.

IV. DESIGN CONSIDERATIONS

The design considerations of the telemetry system were driven primarily by the most extreme environment in which the system was to be placed. The Pulse mooring site is deep in the Southern Ocean, an area subject to severe weather conditions, while the NRS moorings are in the more moderate coastal conditions of Australia's continental shelf. As such the telemetry electronics needed to be housed in an enclosure that was sufficiently robust to survive Southern Ocean conditions.

Traditionally, ocean moorings with surface expressions consist of large mooring floats and substantial mounting frames onto which communications antennas are bolted. The anchor and tether structures are then necessarily also large and robust. If the need to mount antennas high enough on a frame to ensure their survivability in large wave conditions could be removed, and there was no requirement to mount external sensors in air, then the float size and corresponding mooring tether equipment could be made smaller. The float size would then be driven more by the requirements of subsurface instrument payload size and mooring physics, rather than by the need to ensure a sufficiently large mechanical structure on which to mount an antenna frame.

Initial experiments using a flat aircraft-type combination GPS and Iridium antenna mounted externally to an electronics canister lid were carried out, however the need to feed antenna cables through the canister lid added a potential failure mode to the system. Further experimentation using Delrin®, an acetal-type thermoplastic, revealed that the material caused very little attenuation to either Iridium or GPS signals [Iridium on 1.6GHz and GPS on 1.2 and 1.6GHz] and as such the aircraft-type antennas could be mounted internally in the canister, rebated into the Delrin® lid, with minimal effect on signal strength or reported GPS position. (see Appendix 1 and 2).

This enabled the construction of a much more robust telemetry system, with both piston and face-type o-rings seals in the lid and all penetrations to the electronics canister made with standard subsurface oceanographic-type connectors. With these improvements the unit could be pulled down to a calculated maximum of 250m depth without leakage into the electronics canister.

Another design consideration was to ensure that the locator system was completely autonomous to the instrument data system. This was implemented by having an Iridium modem handle upload of instrument data, and an Iridium tracker (containing both Iridium modem and GPS) report positional information - the latter being powered from a separate battery system to the main float electronics. This configuration ensured that if there was a catastrophic failure of the main electronics system, which would shut down the Iridium data modem, the tracker would still be capable of providing positional information.

Both these systems required independent antennas, which would be mounted in close proximity to each other. The manufactures' recommendation was that antennas should not be mounted within 75mm from each other. However, in order to make the electronics lid and hence the electronic canister as small as possible, the antennas were mounted within 3mm of each other. There was concern that if both modem and tracker attempted to transmit simultaneously, damage to their receivers might have occurred due to their proximity. However testing, to ensure system stability with the antennas in this configuration, showed no negative effects on the transmission or reception of data by the modem or tracker.

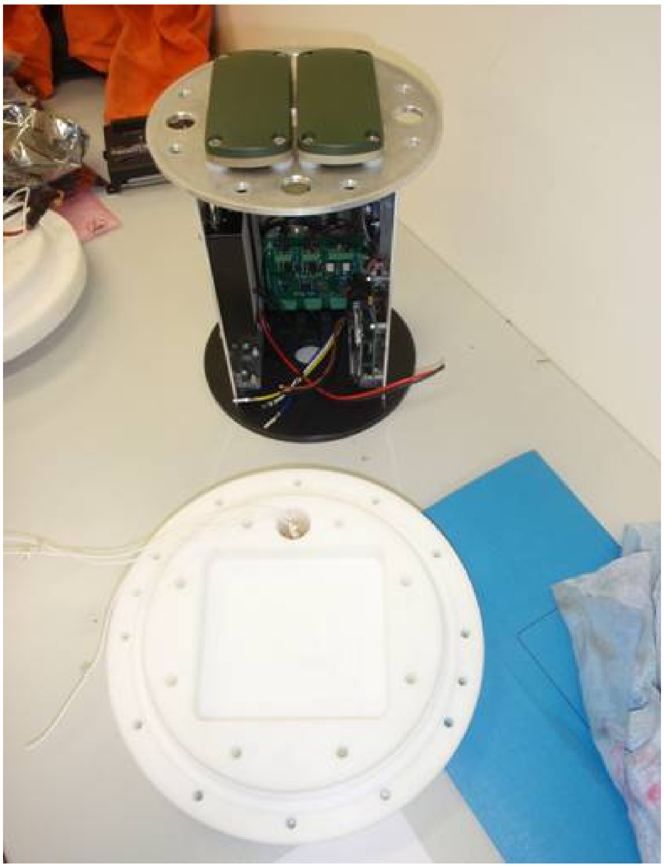

Figure 3. Instrument canister frame- the green devices are the dual GPS/Iridium antennas and the white structure, the Delrin® lid.

This Delrin® encapsulation system has now been successfully deployed and recovered both on dual Pulse test moorings on the continental slope offshore from the southern Tasmanian coastline and subsequently on a fully instrumented Pulse mooring deployed for 6 months into the Southern Ocean (see Pender et al. in this volume). These two examples provide the longest successful telemetry mooring deployments into the Southern Ocean.

V. FURTHER DEVELOPMENT

The development of NRS moorings was an opportunity to expand on the successful satellite telemetry design concepts created during the Pulse mooring builds. Some of the NRS moorings required development of an acoustic link from sub-surface oceanographic sensors to the surface expression, which could then be transmitted via satellite back to base.

Several of these moorings were to be sited in coastal positions which could be exposed to large ocean swell conditions, so there was still a necessity for a robust telemetry platform. The first of these moorings in full operation is off the east coast of Tasmania near Maria Island.

To minimise the effect wave action would have on the suspended sensors, two separate moorings were built. The first was a subsurface mooring, with two instrument frames: One frame near the anchor depth in 90m, and a second at a nominal 20m from the surface [1]. Each frame contains a Wetlabs Water Quality Monitor (WQM) and associated battery pack, and a Benthos ATM885 acoustic modem (Figure 4). The second mooring, sited approximately 300m from the first, uses the same size float as the Pulse mooring. The electronics canister is also very similar which allowed use of the proven Delrin® lid design incorporating the Iridium tracker and modem antennas. Although, the canister length was increased on the NRS mooring in order to incorporate the larger payload and battery requirements.

The WQMs on each instrument frame are configured to sample temperature, pressure, salinity, dissolved oxygen, chlorophyll and turbidity at 1 Hz for 1 minute every 15 minutes. At the end of the sampling period averages of these parameters, along with sample date and time, is output to its associated Benthos ATM885 acoustic modem, where, configured in datalogger mode, the information is stored for later retrieval.

Mounted on the surface float are an Iridium tracker and modem, weather station, sea surface temperature (SST) sensor, motion reference unit (MRU), acoustic modem, acoustic transducer, datalogger, serial expansion board (SEB), and battery packs.

VI. TELEMETRY FORMAT

In order to allow for future mooring system expansion, a telemetry data format was developed which consisted of an initial 16 byte header followed by a data payload.

The header contains the following: mooring site code, type of data payload, Iridium retries required to send the file, acoustic retry counter, Iridium signal strength measured prior to transmission, date and time of file packaging, number of files left to transmit, number of modems connected to the system, the file number and a flag to indicate if the mooring is active or under test (for pre-deployment testing).

The type of data payload, which is indicated in the header, is predefined in order for the processing facility to correctly handle the data on arrival. The types currently in use are: platform information, mixed records, WQM information, acoustic modem volts and MRU binary file. The single-byte payload type can also be used to define any other type of instrument data that is added to the system. This means the system can be expanded to incorporate extra instruments, with different parsing routines being used depending on the returned data type.

The system uses Iridium SBD transmission to minimise expense. This allows a maximum of 340 bytes in a packet, so

Figure 4. Sensor and acoustics packages mounted in frames for deployment at the NRS. The grey canisters are battery packs, the Teledyne benthos modems are labelled while the WQMs have copper components.

the amount of data to be sent in a single file is limited to 340-16 (header) or a total of 324 bytes per file.

VII. FILE STRUCTURE

A FIFO buffer structure was created within a formatted USR-type drive of the Campbell Scientific CR1000 datalogger. Each grouping of initial header and data payload is saved as a file within this stack during sampling. Two pointers are associated with the stack; one that tracks next available file location, and one which tracks those files that have been successfully transmitted. The depth of the stack is sufficient to allow a week's storage of files if bad weather delays transmission. In practice this depth of storage has not been required as over the last year of operation, the system has seldom missed a transmission even under severe weather conditions.

VIII. SYSTEM CONTROL

The CR1000 datalogger provides control of the float electronics. Running a one-minute scan rate, each hour it powers up the weather station and MRU. The CR1000 samples the MRU at 5Hz for 5 minutes and then processes the data to generate wave spectra and an average of the float heading. The wave spectra is then stored in a file along with a header and added to the file stack. The weather station is interrogated to obtain a five-minute average of wind speed, maximum and minimum wind speeds, air temperature, relative humidity, air pressure and a vector-averaged wind direction. The vector average is incorporated with offsets provided by the MRU's float heading to calculate true wind direction. The MRU and weather station are then powered down. The surface float's SBE39 is then polled to collect "near" SST and the returned temperature, together with samples of platform battery voltages are packaged along with header information into a 'platform information'-type file which is added to the file stack.

The acoustic modem is powered up and each remote acoustic modem in the system is polled sequentially. Error correction routines parse the returned data, with up to three retries allowed to obtain a complete and correct dataset from each modem. Once data is retrieved successfully, the remote modems are commanded to clear their data storage. The data is packaged with header information and added to the file stack, and the acoustic modem is powered down.

The remote acoustic modems have a large storage capacity relative to the size of the data records stored and the float system's parsing routines can handle up to 380 data records per hourly cycle. As such, with two WQMs, acoustic communications can fail for up to 48 hours without risk of loss of data. In practice, monitoring of the Maria Island site acoustic communication over the past year has indicated few failures attributable to poor acoustic path conditions, and these were for a maximum of one reporting period.

Finally, the CR1000 powers up the Iridium modem and the system attempts to acquire a satellite connection for 2 minutes. If this is unsuccessful, the system will enter sleep mode until the next hourly cycle. If acquisition occurs, the system will poll the modem for up to 2 minutes until it reports a received signal strength of greater than 2 out of 5 to ensure the best chance of achieving a successful upload. It will then attempt to sequentially upload all un-transmitted files in the stack, checking signal strength between each transmission. The CR1000 will power down the Iridium modem and terminate the active cycle once all files are transmitted or the signal strength test fails.

Every 24 hourly cycles, the CR1000 also polls the remote acoustic modems on each instrument frame to obtain their onboard voltage levels, and adds this information together with an appropriate header to the file stack. The addition of this data along with other file information ensures all battery voltages in the system can be monitored remotely to help plan mooring rotation requirements.

This system is now reliable technology that has been successfully reporting from Maria Island NRS since April 2009 and can be accessed via the IMOS data portal (http://imos.aodn.org.au).

IX. TECHNICAL SIGNIFICANCE

The technical significance of the telemetry system is manifold. With the use of ordinary aircraft antenna sealed inside canisters and small buoys, the costs of the system are greatly reduced relative to larger buoys that are designed to never be submerged. This small system has also proved to be extremely robust, surviving several southern ocean deployments without loss. These technological advances open the way for our system to fulfil the many roles proposed for telemetry. First, worldwide principles for Marine Observing Systems have a tendency for data to be open access, provided in real time and continuous [2]. With real time access the Pulse mooring and Maria Island NRS are providing open access data that is being used both by researchers and the public. The transmitted data is also not reliant on information being manually retrieved from instruments post-deployment and is thus timely and a continuous stream, rather than staggered discrete downloads.

Second, a long-term aim of oceanographic research is to incorporate forcing into predictive models. The transmitted data avoids a four to twelve month lag between sampling and the data becoming available. Also, with the multiple data streams being developed, numerous models, including those run by meteorologists and biologists, can use the data. The next step in development of the telemetry system will provide two-way communications, allowing for changes in sampling rates.

Third, transmitted data is collected data. It is not at risk from weather, delays in boat charters to recover instruments, or mooring failure. Telemetry thus reduces the projects exposure to risk while also providing constant system monitoring enabling early fault identification. Batteries, sensors or electronics can all fail and without telemetry these failures may not be detected for months, resulting in large gaps in what should be continuous datasets. Telemetry data can also speed up the design process. For example the data supplied from the Pulse engineering test moorings allowed the design process to be commenced for the science mooring while the test moorings were still *in situ*.

Fourth, telemetry assists in quality control. It allows for rapid identification of sensor drift and a prompt response to fix the problem. This not only maximises data returns but encourages quality control. With no redundancies in the deployed sensors, telemetry is also important to maintain the integration of the observing systems. Many sensors are reliant on data from others and a failed sensor can put at risk the quality, analysis and calibration of this and other data streams.

Fifth, telemetry can assist operationally in timing the co-location of assets such as sea-gliders. Windows of opportunity can be chosen based on knowing local conditions, which are being monitored in real time. An understanding of actual conditions enables changes to mission timings and routes to best target emerging events. Independent real time data will also allow for the sensors of co-located assets to be calibrated both for errors and to focus onto a more precise range of measures for the known conditions.

Finally, the current telemetry system provides ease of access to the data for a wide cross section of the community. In particular water temperatures, weather conditions and wave height are data streams with broad community applications. In other, international examples of oceanographic moorings the building of a wide stakeholder community on the back of telemetry has been cited as the reason for the programs' success and longevity.

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X. APPENDIX 1 -Testing of Iridium Satellite Transmission and Reception Through Increasing Thicknesses of Delrin® Material

A. Purpose of Test

To assess the possibility of mounting an Iridium satellite antenna within a pressure housing which would minimise risk of damage to the antenna and the risk of the pressure housing leaking due to extra penetrations. The proposed material to form the top seal of the housing was Delrin®.

B. Hardware

A NAL Research 9601-DN modem coupled to a NAL Research SAF 4070-IG antenna. The 9601-DN modem communicating via an RS232 to USB adapter connected to a Dell Laptop.

C. Testing

The modem can be interrogated to report received signal strength on a scale of 0-5 via an AT+CSQ command.

The antenna was initially mounted in the centre of a 450mm diameter piece of 10mm stainless steel plate. In this configuration the modem reported a signal strength of 5.

A 13mm- thick sheet of Delrin® was placed over the antenna and the signal level was again found to be 5.

A second sheet was added for a total thickness of 26mm with a signal level again reported as 5.

A third sheet was added for a total thickness of 39mm and the signal level again checked at 5.

The antenna was then demounted from the metal plate and placed on a wooden surface with no Delrin® cover and the signal level checked at 4.

Surprisingly as the first 13mm sheet was added the signal strength returned to 5 and stayed there whilst another two sheets were added to bring the thickness to 39mm.

This stage was repeated several times over an hour to ensure the effect was not due to incidental satellite positioning, and produced the same results. To truth the signal level output the 13mm stainless steel mounting plate was placed over the antenna to obscure its view of the sky and the signal level dropped to 0 as expected.

The experiment was repeated with and without the steel mounting plate forming a ground plane and with a total covering of 39mm of Delrin®. Several test messages were then sent in each of these configurations to confirm transmission capability. The antenna was then covered with the steel plate and a message connection attempted – the communication failed as expected.

Further testing was carried out with the antenna on various angles to the horizontal to simulate angular transmission due to wave action, with the results suggesting little attenuation through the 39mm of Delrin®.

D. Conclusion

The test suggested that little attenuation appears to occur through the maximum tested thickness of Delrin®. On this basis a lid constructed of 50mm thick Delrin® will be machined to form a 25mm-deep rebate into which antennas can be mounted.

E. Limitations of Test, and Further Testing Required

It was not able to be established how accurate the signal level test values were – i.e. a value of 5 may not be the upper limit of signal strength – there may be a level of dynamic overhead related to the signal. As such the signal may be attenuated by the Delrin®, but not at a level sufficient to register on the signal level indicator. This would then become an issue if the unit was deployed in an area where the nominal signal strength was marginal. Further testing may be required using a screen material that will partially attenuate the signal down to (say) 4, and then re-test with the Delrin® sheets to observe the effect on the received signal level.

Further testing also needs be carried out to assess the effect of installation in a stainless steel canister, and the effect a 12mm stainless steel guard ring above the Delrin® lid will have (*see Appendix 2*).

Testing is also required regarding the attenuation of GPS signals through the Delrin® although the two systems operate in a similar area of the frequency spectrum so it is thought the differences will be minimal. The effect of accuracy on position fixes however will need to be established (*see Appendix 2*).

XI. APPENDIX 2 - Testing of Accuracy of GPS Fix with Iridium/GPS Antennas in Delrin® Canister Lid

A. Purpose of Test

To ensure the accuracy of the GPS fix is not adversely affected by mounting the Iridium/GPS antenna under a Delrin® lid.

B. Hardware

2 x NAL Research 9601-DGS-LP Trackers
2 x NAL Research SAF 4070-IG antennas
Pulse canister with rebated Delrin® lid
4 x RG174 interconnect leads
2 x SMA to TNC connector adapter
Antenna support pole

C. Testing

A test was carried out to see what effect the Delrin® lid had on GPS position reporting. One tracker was set up inside a canister with its antenna mounted in the Delrin® lid. Another was mounted approximately a metre away, with its antenna mounted in free air, to a short pole. Both units were set to report every half hour for six hours, and the results of their Iridium and GPS unit reports tabulated.

From the collected data, it was found that the maximum variations between the antennas in clear air and in the canister was 0.010 minutes of latitude and 0.008 minutes of longitude for the same [or similar] fix time. Based on the following, that at latitude 40 Degrees south, 1 minute of latitude =1.85km and 1 minute of longitude = 1.42km, this gives a positional variation of 18.5m latitude and 11.4m longitude which is well within an acceptable fix radius.

D. Conclusion

GPS fix performance was not adversely affected by having the antennas mounted in the Delrin® lid. During subsequent testing with the fully assembled canister incorporating a stainless steel guard ring around the top of the canister, and a navigation light mounted to the side of it, GPS fix capability did not appear to be adversely affected.