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# A Rapid Deployment Integrated Environmental and Oceanographic Assessment System (IEOAS) for Coastal Waters: Design Concepts and Field Implementation

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## ABSTRACT

Emergency response and spill monitoring in coastal and near-shore environments are enhanced with the availability and use of real-time environmental data coupled with numerical simulation in an adaptive sampling framework. Invariably the various modules often exist on different computing platforms, and a common thread is needed to achieve an integrated system suitable for application in spill or emergency response situations. In emergency response operations, information sharing between on-scene command and incident command is often required to facilitate decision-making. Wireless (802.11b) data networks, coupled with use of concepts from distributed computing, can bridge the gap between data acquisition and data availability, thereby reducing the inherent latency within the system. Within the context of environmental monitoring, distributed computing consists of a distributed file system (DFS), remote application services (RAS), network management, and wireless data telemetry for wide-area network services (WAN). This study focuses on the implementation of an integrated rapid response environmental assessment system combining *in situ* monitoring, real-time telemetry, and direct numerical simulation (DNS) with web-based data access and visualization of oceanographic and environmental parameters. The viability of the system was demonstrated in mock-spill response exercises and successful application to scientific dye-tracer studies. Design details are presented.

**Key words:** adaptive sampling; georeferenced mobile platform; real-time data acquisition; data visualization; instrument array; distributed computing; spill monitoring

## INTRODUCTION

Monitoring of water quality parameters and environmental indicators in surface waters poses a challenge due to the spatial extent and dynamics involved. Design of sampling transects for routine monitoring involves a combination of science and experience, but for real-time monitoring of episodic events, *a priori* design of sampling transects is impractical. The ability to observe spatially distributed time series has been made

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possible with the development of sensors deployed on remote platforms such as on satellites and aircrafts, as well as on mobile and fixed sensing platforms. The coverage of these datasets can be extensive, but limited in spatial or temporal resolution. *In situ* sensor deployments from remote platforms (fixed or mobile) are increasingly being used for data acquisition in environmental and oceanographic assessments, data that has to be made available in near real-time to the stakeholder (that is, the public, the scientific community, resource managers and planners).

For instance, in emergency response operations, information sharing between on-scene command and incident command is often required to facilitate decision-making. Wireless (802.11b) data networks coupled with relational database management systems (RDBMS) can bridge the gap between data acquisition and data availability. These real-time measurements can be assimilated into numerical models either to fill in gaps in data or to improve the spatial and temporal resolution of observations from sensing platforms. These data would include instrument measurements (such as surface currents, wind speed and direction, temperature), model predictions (fate and transport), and forensics.

This paper describes a scheme that was developed to guide the monitoring of constituents of interest that couples a real-time data acquisition routine with a numerical model and web-based data visualization. The numerical model is driven by near real-time measurements of spatially distributed coefficients leading to algorithms for estimating the temporal and spatial characteristics of an evolving constituent within the body of water. Model output in terms of trajectory and spatial distribution of the constituents of interest take into account the dynamics involved. A user interface provides real-time correlative visualization between the model output and intensity of the measured variables provided by the deployed instruments mounted on a georeferenced mobile sensing platform to guide the data acquisition and sampling efforts.

## BACKGROUND

The Texas General Land Office (TGLO) has shown interest in a field program to evaluate dispersant use in near-shore waters and has opted to use a "spill of opportunity" for data gathering. Our research group was designated as the boat monitoring team for the Corpus Christi Bay location (Ojo *et al.,* 2003). In addition, we recently deployed real-time *in situ* sensor instruments on fixed platforms in targeted locations in Corpus Christi Bay to monitor important baseline parameters, such as hydrocarbon contaminant concentrations, nutrient levels, and particle size distribution. For spatial characterization, we added sensor arrays to a georeferenced boat to provide valuable information for emergency response planning and activities in surface waters. The georeferenced boat provides valuable real-time data that can be transmitted to a shore-based incident command center to aid the decision-making process during emergency response situations.

## ENVIRONMENTAL MONITORING IN SURFACE WATERS

This discussion provides a synopsis of environmental monitoring to highlight the challenges in this area, especially as they relate to the decision-making process in response to episodic events and emergency response efforts.

### *Sampling*

*Grab sampling.* This method falls within the classification of *ex situ* sampling and is mostly suited to off-line processing. Samples collected are analyzed in a shore-based or onboard laboratory (Volpe and Esser, 2002). Onboard analytical laboratories are expensive and often impractical, especially for small craft. In light of this, collected samples may have to be sent to a land-based laboratory, which somewhat affects the decision-making process. Grab sampling methods are most suited for routine monitoring in which immediate analytical results are not required or the analytical method calls for wet chemistry exclusively. The spatial-temporal resolution with these methods is extremely limited.

*Flow-through sampling.* This method also falls within the category of *ex situ* sampling and is essentially a variant of grab sampling. The water samples are pumped to the surface where they are analyzed by using the same methods applicable to grab sampling. They may also be used in conjunction with some of the sensors used in *in situ* sampling (Hanson, 2000) whenever immediate results are desirable. The drawback with flow-through methods are the effects of the fluid-flow on the sample and the need to allow for fluid flow rates and tubing lengths when determining the exact sample location for georeferencing purposes.

*In situ sampling. In situ* sampling makes use of submersible sensors for real-time or off-line processing of environmental or oceanographic measurements. It eliminates some of the problems inherent in flow-through methods outlined previously. It is especially suited for real-time processing and facilitates the decision-making process by reducing the latency in data availability compared with off-line processing.

A combination of *ex situ* and *in situ* sampling may be necessary whenever data validation is called for. In this case, the results of laboratory analyses are used in validating the data returned by the submersible sensors and for QA/QC.

### *Data acquisition*

*In situ* instruments can be operated in batch-processing mode in which case onboard or computer-based data loggers are used, as is the case with long-term autonomous deployments. Real-time data acquisition through vendor-supplied software may not be practical, particularly when interfacing more than one instrument to the data acquisition (DAQ) unit. For real-time monitoring, data pre-processing is usually performed with embedded routines in instrument microprocessors or by using external routines on a remote computer. Post-processing may be necessary for the purpose of applying correction factors or some other instrument specific routines to the raw data in order to make the data representative of the parameter being measured (e.g., to go from raw digitized data to engineering units).

### *Real-time visualization*

To take full advantage of real-time data acquisition, real-time data visualization becomes imperative. This could be in the form of time-series or geospatial datasets, vector mapping, contour plots, and animations or a combination of these. Figure 1 presents the data flow structure for implementing the real-time data acquisition and visualization. Within this framework, the data flow is as follows: (1) instrument array, (2) data acquisition, (3) data pre-processing, (4) data transmission, (5) data post-processing, (6) data archiving, and (7) data visualization.

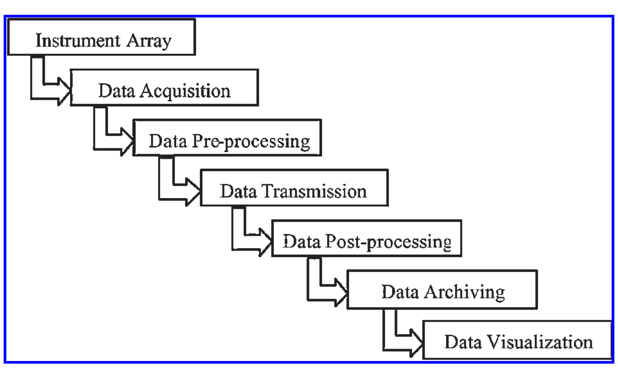


**Figure 1.** Representation of data flow for real-time data acquisition and visualization.

### *Correlative data visualization*

To glean information from environmental measurements that may not be so apparent from single-parameter measurements, correlative data visualization may be used between analogous multi-parameter datasets returned by single or multiple instruments (Treinish and Goettsche, 1991). For example, low-dissolved oxygen levels may be visually correlated with high fluorescence measurements to infer information regarding phytoplankton production.

## NEAR-TERM OBJECTIVES AND PROJECT SCOPE

In building instrument arrays, there are advantages to using commercial, off-the-shelf (COTS) products, but in some cases, the end-user chooses to develop instrument arrays from the ground up. Instrument developers and vendors often provide software to facilitate real-time data acquisition, but the use of instrument specific software interface may become impractical when deploying instrument arrays using instruments from multiple vendors. In such cases, it will be necessary to have a knowledge of low-level commands specific to each instrument in the proposed suite of instruments in order to facilitate the implementation of an integrated interface for real-time applications. In developing such an integrated interface, working with instrument developers is essential for accessing any low-level instrument control routines and other instrument specific data pre-processing schemes.

Developments in sensor technology over the past decade have led to availability of *in situ* instrumentation for oceanographic and environmental measurements. This instrumentation ranges from sensors for basic water quality measurements (such as conductivity, temperature, and depth [CTD] sensors) to more specialized sensors (such as particle size analyzers [Agrawal and Pottsmith, 2000], imaging devices, current profilers [Ocker, 2002], and nutrient analyzers [Hanson, 2000]). These sensors could be deployed by themselves or as part of an instrument array. For geospatial data representation, one vital piece of instrumentation is the global positioning system (GPS), which provides the location and time stamp for each data point returned from the submersible sensors. The *in situ* instrument array as used in this study was built from COTS devices, although the option of building the instruments from the ground up was explored. The instruments used here are highly specialized and have been proven in the field, finding wide acceptance within the user community (particle size analyzers, multi-spectral fluorometers, CTD sensors, and current meters). These were interfaced to a common DAQ system by accessing their low-level operating modes.

The objectives of this study are summarized below:

1. Develop DAQ system, including hardware and software, to guide sampling efforts from mobile and remote sensing platforms in surface waters, particularly when responding to episodic events.
2. Develop algorithms for real-time data acquisition, data analyses, post-processing, and visualization.
3. Deploy DAQ unit with selected instruments including, but not limited to, current meters, particle size analyzers, and fluorometers.
4. Integrate wireless data telemetry for data transmission based on 802.11b protocol.
5. Implement a web server for data synthesis, making data and graphics available on the web in near real-time.

Integrated datasets from sensors and a numerical model operating in near real-time is to be made available for visualization in real-time via the Internet through the implementation of a web server with user-selectable input for sensor selection and determination of coefficients needed to drive a numerical model. High-level data synthesis is facilitated through conformity to a widely accepted format, the network common data form (NetCDF) (Rew and Davis, 1990).

## DESIGN CONCEPT

For environmental sampling, increasing use is being made of *in situ* sensors mounted either on fixed or mobile sensing platforms (Wiebe *et al.,* 2002; Volpe and Esser, 2002; Schofield *et al.,* 2002; Austin *et al.,* 2002), interfaced with DAQ units using the RS232 data transmission protocol. For our purpose, an array of sensors mounted on a tow-body capable of performing undulating profiles through the water column was used within the context of response to episodic events and mapping of surface waters for environmental spatial characterization. The multiple subsurface instruments were interfaced with the shipboard DAQ unit using a multi-port RS232 device server with transmission control protocol/internet protocol (TCP/IP), thereby overcoming the limitations inherent in RS232 communications with respect to distance while at the same time multiplexing the data into a single stream. High data throughput, reliable connectivity, and seamless integration into existing data networks were some of the conceptual design considerations.

The TCP/IP also serves as a common thread to weave different platforms and modules into an integrated computing system. A ship-based local area network (LAN) was established through the submersible device server that links the various *in situ* sensors to the onboard computer. The onboard computer performs the role of a data post-processor and communications server, linking the field sampling station with the onshore modules and transferring data to stakeholders, such as an incident com-

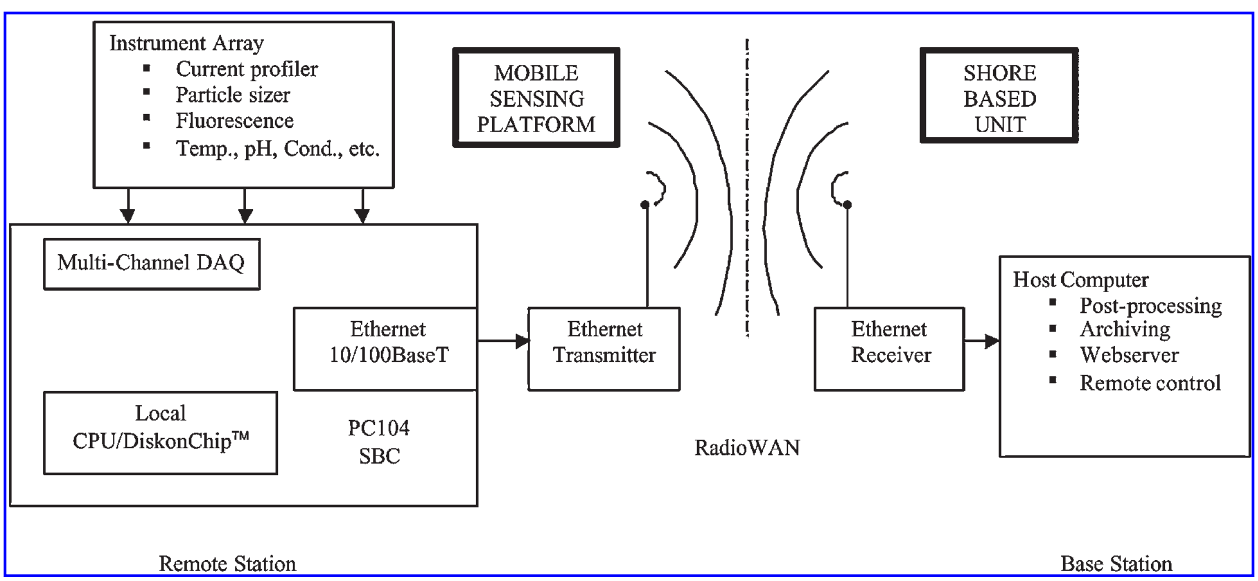


**Figure 2.** System block diagram for IEOAS.

mand center. A wide area network (WAN) connectivity, based on wireless broadband communications, facilitates the ship-to-shore link.

## SYSTEM DESCRIPTION

### *Integrated data acquisition communications and control unit*

A block diagram of the IEOAS design discussed above is presented in Figure 2. For the shipboard data acquisition unit, an integrated data acquisition communications and control (IDACC) unit was developed, as well as a submersible multi-port instrument interface. A schematic of the IDACC and submersible instrument interface is provided in Figure 3.

As the main hardware component for data acquisition, IDACC comprises a single board computer with a 15" touch-screen display mounted in a NEMA 4X sealed moisture-proof vented enclosure. The unit was built as a portable self-contained unit for easy transportation and fast onsite hookup and runs on regular AC power with optional 12 VDC capabilities. Incorporating an AC/DC power converter, it provides a data acquisition interface to the subsurface instruments and acts as a communications server for ship-to-shore data telemetry through a software application that was developed in house. The IDACC includes a differential global positioning system (DGPS) for georeferencing and connects with multiple RS232 submersible instruments through the subsurface multi-port instrument interface using TCP/IP. A five-port Ethernet switch facilitates communication between the IDACC and the multi-port instrument interface.

Power supply to the instruments and other devices comes from a 375 W AC/DC power converter mounted in the IDACC enclosure running through a power distribution box providing 5, 10, 12, and 24 VDC supply. The 24 VDC output is sent through a winch/slip-ring assembly, down the sea cable to the undulating tow body and the submersible instrument interface. The voltage drop at full load between the deck and subsurface units was measured at ~2 V. The balance of the 24 V supply is then converted to 15 VDC and distributed to the individual subsurface sensors.

The sea cable is made of stranded and twisted pair wire, providing both data communications as well as power supply. Data telemetry is facilitated by the five-port network interface, connecting the IDACC to the subsurface device for data acquisition and sending command signals via TC/IP to the sensors mounted on the tow vehicle. The network interface also provides WAN connectivity by wireless telemetry through a radio link to a shore-based network, thereby ensuring real-time data accessibility for decision makers and stakeholders. In addition, IDACC allows for local data archiving on the hard drive through the software module, the multi-parameter instrument array and control system (MPIACS). Built for rapid deployment, IDACC is portable, completely sealed, and moisture proof. It can be deployed on the open deck of a boat, if cabin space is at a premium, and requires just three quick connections: AC main power supply, DC power and data link to the subsurface device server, and antenna connection for the GPS unit. A single power switch activates the entire system, booting up the main computer and the subsurface unit and powering the instruments.

For portability and transportability, the entire assembly comprising the IDACC and its ancillary modules (keyboard, GPS, power distribution) are mounted in a custom molded plastic grab-and-roll (wheeled) ATA shipping case with pressure equalizing valve. The IDACC main module is a hinged assembly supported by gas-springs, allowing the unit to be folded down and packed up for transportation. For on-site deployment, the top of the shipping case is simply removed, the IDACC main unit swings up into the open position, and the connections are made to the respective ports. When the unit

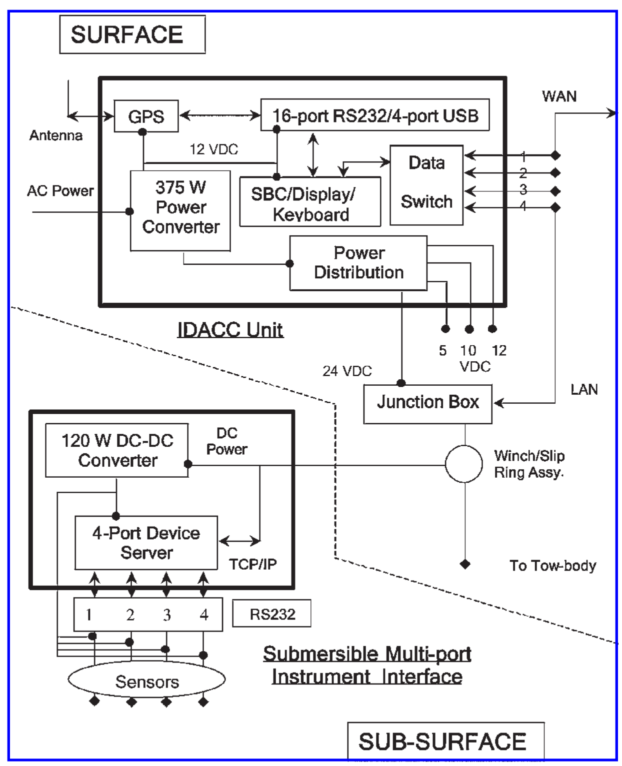


**Figure 3.** Schematic of IDACC and submersible multi-port instrument interface.

is powered up, it is ready for data acquisition. In mounting the IDACC inside the shipping case, a set of rubber mounts was used to protect the sensitive electronics from exposure to excessive vibration. Figures 4 and 5 show the IDACC interfaced to the tow body through the submersible multi-port instrument interface.

### *Submersible multi-port instrument interface*

The subsurface electronics are mounted on the end cap of a sealed housing made from PVC; they include power and data interface, comprising five sealed underwater connectors for power and data connection to the IDACC, and up to four instruments mounted on the tow body. This four-port subsurface unit acts as a power distribution and data communications unit. It comprises a multiport RS232 serial device server and a DC/DC power converter, which acts as a power conditioner, receiving DC supply in the range of 15–36 VDC from the IDACC and distributing 15 $\pm$ 0.07 VDC to as many as four different sensors simultaneously.

Providing the data link between multiple *in situ* sensors and the shipboard IDACC unit, the device server is essentially a multiplexed RS232 serial instrument interface. It uses the TCP/IP protocol and addressing to implement virtual COM ports between the sensors mounted on the tow body and the IDACC, the data being sent over twisted pair wire through the sea cable. Maintenance access to the electronics is easy as the end cap screws onto the main housing and the entire electronics and wiring are mounted on the end cap. Driver files are required on the host computer to access the virtual COM ports on the device server, which includes a web interface for diagnostics, configuration, and monitoring.

**Figure 4.** Submersible multi-port device server (top). IDACC comprising GPS unit, industrial computer in NEMA 4x enclosure, NEMA keyboard, power distribution, and four-port network interface. The main unit, which houses the electronics, tilts up into operating position, supported by gas springs.

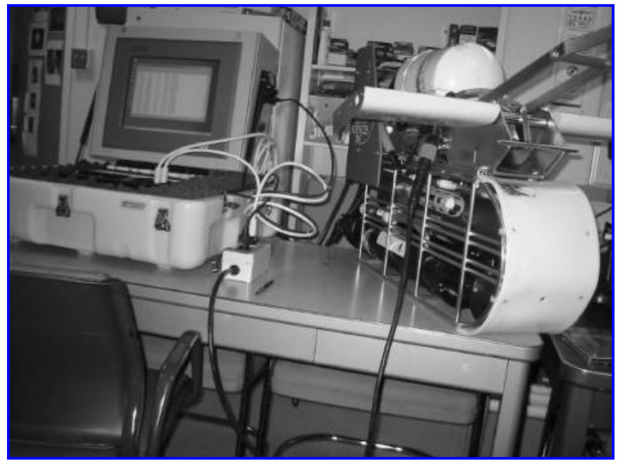

**Figure 5.** IDACC and tow body with instrumentation and submersible multi-port device server undergoing bench tests.

### *Multi-parameter instrument array and control system*

The multi-parameter instrument array and control system (MPIACS) (Fig. 6) is a software interface that provides real-time data visualization of up to six different parameters measured by single or multiple instruments simultaneously. These parameters could be concentration measurements from, for example, fluorometers or particle size analyzers. For each parameter, the percentage of the parameter (measured value relative to a preset peak value) generates a color trace corresponding to the travel of the instrument array through the water. This gives a visual indication of the spatial distribution of intensity of the constituent of interest or sampled parameter. Since not all constituents of interest in environmental sampling lend themselves to visual contact, MPIACS was developed as a tool that provides instantaneous visual feedback to operators during environmental monitoring in surface waters. The interface is user-friendly, allowing for quick configuration and minimal intervention from the operator.

As a real-time environmental monitoring tool, the visual feedback aids the data acquisition process by providing immediate identification of "hot" and "cold" spots within the water body for the constituents of interest through measurements from submersible sensors. Each data point is location and time stamped through the IDACC's integrated GPS unit. The data stream is archived on the local hard drive in plain ASCII text, tab-delimited file format for off-line processing where re-

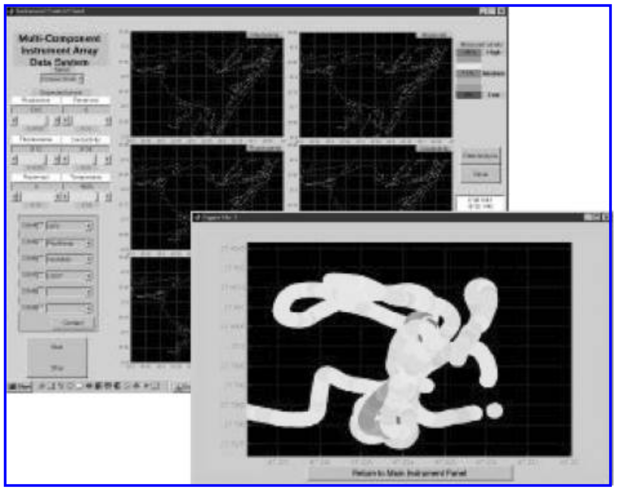

**Figure 6.** The MPIACS software interface. Lower, right panel is a zoomed-in portion of one of the six data visualization panes from the main instrument panel.

quired. By allowing for correlative data visualization, MPIACS aids the data acquisition effort in an adaptive sampling framework (Stein and Ettema, 2003) by removing the guesswork inherent in environmental monitoring, especially relating to constituents of interest that do not provide visual identification or if sampling was being performed during periods of low-visibility conditions. Each color-coded trace is georeferenced and displayed against a map outline of the study area by combining the instrument data stream with the GPS unit time and location information.

MPIACS was implemented in a modular form to facilitate expandability as well as flexibility to accommodate a wide variety of instruments. The software modules comprise data acquisition, instrument control, data post-processing, data visualization, and data archiving. Unlike other data visualization programs that are written for off-line data visualization (He and Hamblin, 2000), the MPIACS prototype was developed with the objective of providing real-time data visualization while the data acquisition vessel is underway. A version of MPIACS was also developed, that operates in playback mode, suitable for off-line data visualization.

The GPS unit operates in three modes and can be set to autoselect between GPS, DGPS (differential GPS), or WAAS (wide area augmentation system) modes, depending on service availability. The accuracy of the GPS varies with the mode: DGPS mode is accurate within 1 m or 3 ft; WAAS mode, 5 m or 15 ft; and GPS mode, 10 m or 30 ft. Sampling rate of the instrument array will be governed primarily by the acquisition rate from the GPS unit (fixed at 1 Hz) since all data points are georeferenced. Travel speed of the sensing platform is governed by the tow body and would typically average 5 knots; given this set of conditions, a spatial sampling resolution of ~3 m (9 ft) would be expected. Actual spatial resolution would vary, depending on the operational mode of the GPS unit.

### *Ship-to-shore wireless telemetry*

For the ship-to-shore data telemetry, various options were explored, including cellular, satellite, leased line links, and, the most cost-effective option, unlicensed radio links in the 2.4 GHz frequency range, which we chose to use. This link provides broadband 10BaseT wireless Ethernet transmission up to a theoretical throughput limit of 11 Mbps and a distance limit of 24 km. In selecting the antenna type and height, a link budget analysis was performed. The design considerations are presented below, specifically addressing issues of frequency, throughput, antenna type, and mounting (with or without directional tracking).

For the shore end of the point-to-point link, a 2.4 GHz, 14 dBi sectoral antenna with variable horizontal beam width between 60° and 160° and vertical beam width of ±10° was used. The ship-based radio was configured as the base station for the network and for this purpose a 15 dBi omnidirectional antenna with a vertical beam width of ±27°, providing 360° horizontal beam width was used. The omnidirectional antenna was selected for the mobile platform in order to ensure a constant link, regardless of the ship's heading. Other options considered for the base station were: (1) collocation radios using multiple sectoral antennas to increase horizontal coverage and (2) directional antenna with a tracking device to re-orientate the antenna and compensate for movement of the platform. The omnidirectional antenna provided the best option for our present purposes, being easier to implement and more cost effective.

In designing the radio link, a number of factors have to be considered, such as coverage, throughput, terrain, Fresnel zone, antenna characteristics (vertical/horizontal beam width, radiative power, polarization, propagation pattern), and frequency. The link budget analysis is necessary to determine the available transmitted power, which must be greater than the receive threshold for the receiver plus some margin. If the link is determined to be feasible, a reliability check is then performed to determine the uptime of the link, which is affected by environmental factors, such as curvature of the earth, obstructions between the sites, and Fresnel zone clearance.

Generally, a line of sight (LOS) is required between the sites; the earth's curvature is not usually taken into account for link lengths shorter than 10 km. The general formula for performing link budget analysis is provided below. For this project, it was determined that a link length of 16 km (10 miles) was sufficient to provide coverage. Figure 7 shows a profile of Corpus Christi Bay and the expected coverage, which is directly related to the horizontal beam width of the antenna and, in turn, is derived from the antenna radiation pattern.

$$A_{free} = 32.45 + 20\log_{10}(d) + 20\log_{10}(f) \quad (1)$$

$$RSL_{free} = (\mathrm{P_{TX}} + \mathrm{G_{ANT}}) - \mathrm{L_{loss}} - A_{free} \quad (2)$$

$$\text{Thermal fade margin (dB)} = RSL_{free} - RTL \quad (3)$$

where $d$ (km) is the distance between the stations (link length), $f$ (MHz) is the frequency, $A_{free}$ is free space attenuation (dB), $RSL_{free}$ is free space receive signal level, $\mathrm{P_{TX}}$ is transmitter power (dBm), $\mathrm{G_{ANT}}$ is the sum of antenna gain for both transmit/receive, $\mathrm{L_{loss}}$ is the sum of all transmission losses (lines, connectors etc.), $RTL$ is receiver threshold level based on a minimum bit error rate (BER). Thermal fade margin must be a positive value and a value of ~10 dB is considered good for a feasible link.

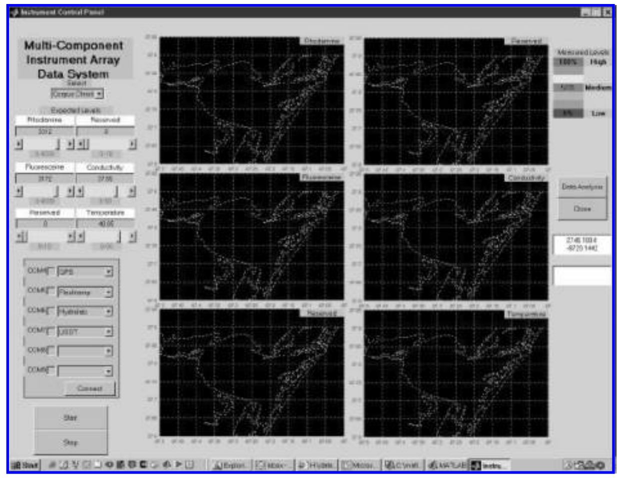


**Figure 8.** Data acquisition module with slider controls for setting instrument levels and drop-down menu for selecting study area.

## IMPLEMENTATION

The novel scheme in this implementation is the ability of a shore-based incident command center or stakeholder to observe, in near real-time, data stream from a mobile sensing platform. In addition to data streaming, post-processed data available for display in near real-time through a web server was also investigated. The web server allows the user to run remote applications, which accepts the data stream as input. In this implementation, we were looking at DNS of constituents in surface waters, driven by data from surface current measurements, which was coupled with output from the mobile platform in an adaptive sampling framework (Thompson and Seber, 1996). Central to this is the MPIACS, as described below.

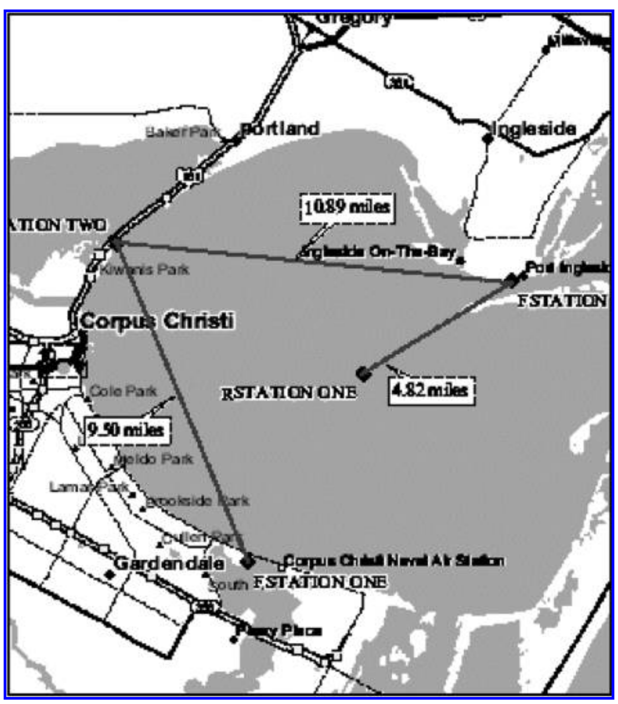


**Figure 7.** Map of coverage area.

### *Data acquisition module*

The data acquisition module consists of a drop-down selector menu and 6 slider controls. The user selects the study area from the drop-down menu and a georeferenced map outline of the study area is displayed in all six panels. The expected maximum levels for each parameter to be measured are set using the six-slider controls. Based on these maximum values and a minimum value of zero, a simple algorithm is then used to scale the color-coded trace that is displayed on screen in the corresponding panel for each parameter.

### *Instrument control module*

The instrument control module (Fig. 8) provides data communications with the instruments and consists of a set of six selections in a drop-down menu. As many as six instruments can be interfaced through this module and, depending on the instruments selected, a communications (COM) port is opened for data acquisition. Instrument-specific settings are hard-coded in this implementation, but future enhancements will include a dialog box, which will allow the user to set or change instrument communication parameters, such as baud rate and flow control. Once the individual instruments have been associated with a COM port, the "connect" button at the bottom of the main panel is used to initiate communications and control with the instruments.

The two buttons labeled "start" and "stop" are then used to begin the data acquisition after all the required settings have been selected. Instrument data are parsed into variables corresponding to the parameter of interest. Each line of data from each instrument is location and time stamped through the GPS data stream, representing a sample point within the study area. This process is continuous, terminating only when the operator hits the stop button.

### *Data post-processing module*

Some instruments return raw data that need to be post-processed in order to obtain the actual measurements for a particular parameter. Instrument-specific algorithms are used to convert the raw data, for example, from calibration curves or other mathematical routines. Correction factors that may be needed are also included in these instrument modules. Following post-processing, the final instrument data are archived in plain ASCII tab-delimited format. The instrument-specific algorithms are individual modules that are called up depending on whether the instrument is included in the instrument array and connected using the instrument control module discussed above. In future enhancements, it may be necessary to come up with a database of such instruments or allow users to write their own routines to accommodate sensors applicable to their deployment.

### *Data visualization module*

For each parameter, a percentage number variable (measured value against a preset peak value) generates a color trace corresponding with the horizontal travel of the instrument array through the water, giving a visual indication of the spatial distribution of relative intensity for the constituent of interest or sampled parameter. Each parameter's colored trace can be displayed in one of the six respective panels, with the panels being expandable by a mouse click (or, for touch screens, by touching) on any one of the six available panes. The expanded screen has infinite zoom levels and the operator can zoom in to any level of detail. The user returns to the main screen through the click of a button on the bottom of the expanded screen.

### *Data archiving module*

This implementation of MPIACS includes a data archiving routine, which allows off-line analyses of the acquired data. The data files are time and location stamped and one data file is generated for each sensor in plain ASCII text, tab-delimited format. This data format can be read into most spreadsheet or word-processing applications. Each data file contains a metadata in the header describing the data format and other sensor specific information.

## DISCUSSION

The advantages of the IEOAS within the framework of environmental monitoring are summarized in this section.

- IEOAS is cost-effective, built entirely using COTS devices, and lends itself to rapid deployment in emergency response mode.
- Existing infrastructure can be interfaced directly with very little modification, while new services can continue to run in their native format.
- Upgrades or changes can be made to one part of the system without reconfiguring the whole system.
- The system can be expanded without regard to memory or data storage capacity. Each service being independently optimized contributes resources into the pool, including memory, storage, and CPU and data processing.
- Broadband connectivity facilitates the transmission of large sets of data with information exchange taking place over the network using TCP/IP (such as live video feeds or large image files) to shore-based units, making information available to stakeholders in near real-time.

The system comprising both hardware and software modules was first deployed in Corpus Christi Bay and Galveston Bay, Texas, during a series of mock oil-spill response exercises. The system was used for dye-tracer experiments during the summer and fall of 2003 and continues to find application in conducting studies related to hypoxia in Corpus Christi Bay. The entire system, including the undulating tow-body, can be readily deployed by a three-man crew within a half-hour timeframe and it lends itself to transportability. The prototype unit, particularly the IDACC, is somewhat bulky and can be reduced in size and weight by specifying custom-built enclosures. Future enhancements would include an NMEA 2.0 interface to an autopilot unit, which accepts input from a waypoints module in the software interface for a full implementation of the adaptive sampling scheme.

Prior to field deployment, two series of operational tests were performed for the IEOAS (namely, bench and field tests; Table 1), which were designed to test the individual modules, as well as the entire system, to identify parts requiring refinement or fine tuning. For instance, the field tests allowed independent assessment of the radio link for availability, bandwidth, throughput, reliability, and range. The IEOAS could be implemented in two or three operational modes; in the final analysis, the choice would be dictated by such factors as reliability, interoperability, ease of use, and rapid deployment. Most, if not all, background processes should be trans-

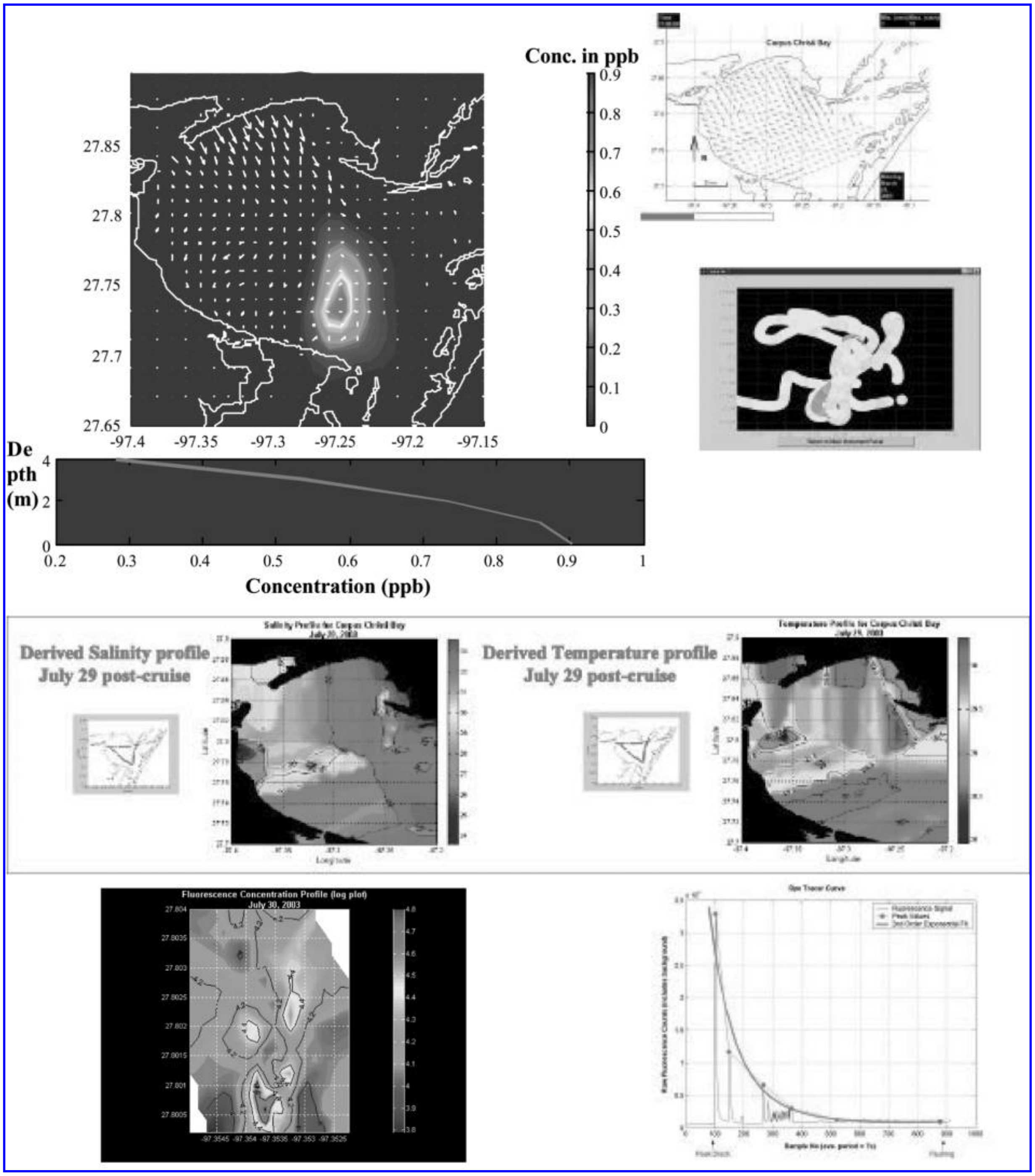


**Figure 9.** Typical output from IEOAS unit: current vectors, contaminant plume, trajectory simulation, concentration profile. The study area for the temperature-salinity profiling covers the entire bay, whereas the study area for the dispersion experiments covers a grid cell area ranging from 1 to 10 sq km.

parent to the user, requiring little user intervention and allowing the operator to focus attention on the main tasks.

One particularly interesting mode of operation allows direct streaming of data from the sensor array to the shore-based computer over a WAN, with the instruments appearing to be directly connected to the shore-based computer through virtual COM ports provided by the device server to which the sensors are connected. This was made possible by TCP/IP addressing. The ship-based computer is then freed from the task of data post-processing and visualization and can be dedicated to other services, such as navigation, communications, and data archiving.

### *Field deployment*

To date, three scheduled drills have been conducted: Galveston Bay, July 2002; Corpus Christi Bay, September 2002; and Galveston Bay, May 2003. MPIACS allowed for real-time visualization of five parameters measured by three instruments. These include rhodamine and fluorescein concentrations from a multispectral fluorescence sensor (SAFire by WETLabs, Philomath, OR), salinity and temperature from a CTD sensor (FastCAT by Sea-Bird Electronics), and total particle volume concentration from a particle size analyzer (LISST100 by Sequoia, Redmond, WA).

Raw data was locally archived on the main computer by generating an ASCII text file for each sensor as well as the GPS unit. The dataset was sent at predetermined intervals by telemetry through a ship-to-shore WAN. A shore-based computer at the incident command center ran a version of the MPIACS and retraced the instrument color-coded track lines in near real-time. With a zero data dropout from the instrument array, the incident command computer was able to regenerate the track lines without user intervention. A series of dye-tracer experiments were also conducted between summer and fall of 2003, including a profile of Corpus Christi Bay in July 2003. Typical output and visualization screens from parts of the system are shown in Figure 9.

Generally, dye-tracer experiments rely on visual contact with a diffusing dye patch, but under certain conditions, this type of "tracking" becomes unreliable and is at best subjective. The MPIACS visualization interface implemented on the IDACC relies on data from *in situ* instruments for on-screen display of the extent of the dye patch based on concentration, limited only by the detection limits of the fluorometric instrument, which is well below the concentration level required for visual contact. During the 2003 diffusion experiments, this translated to significant improvements in tracking the extent of the dye patch compared to methods relying on visual contact. Long after visual contact with the dye patch had been lost, the instrument continued to detect the concentration down to $\sim$1 ppb levels. It would also be possible to use tracers that do not lend themselves very well to direct visual contact. The spatial and time stamping from the GPS readout in real-time was also very important for analyzing the temporal variations of the diffusing dye patch data necessary for the evaluation of diffusion parameters that govern constituent fate and transport.

The shore-based host computer running trajectory tracking models or interfaced to surface current mapping (Fig. 9) would be valuable in guiding the transects run by the vessel, which are sometimes arbitrary. This takes the guesswork out of transect design and provides for adaptive sampling schemes whereby the transects are designed on-the-fly, based on the combined output from sensors on the moving platform, model trajectory predictions, and surface current mapping in near real-time.

**Table 1.** Services implemented for IEOAS bench test.

| *Service* | *Description* | *Purpose* |
|---|---|---|
| Hydrodynamics | Surface current measurements from radar | Near real-time data driven constituent transport model |
| Transport Model | Prediction of concentration profile of constituent, driven by real-time data | Provide visual indication of trajectory and extent of plume |
| Meteorological | Weather and other environmental variables (air/weather temperature, tide etc.) | Provide information to vessel during sampling exercises |
| Data Acquisition | Environmental and oceanographic data from sensors | Provide actual measurements of constituent concentration and other environmental and oceanographic variables |

## CONCLUSION

We successfully designed and built a multi-sensor, multi-parameter, rapid deployment instrument array for environmental and oceanographic assessments in surface waters using COTS devices. Central to the IEOAS is the IDACC, which provides the link between subsurface instruments and onshore post-processing and archival services. The wireless telemetry link as tested provided a cost-effective implementation of Ethernet connectivity in a mobile marine environment. Although designed for land-based connections, the routers were adapted and used in developing a portable, easily deployable network for environmental monitoring. The results from field trials, combined with the results from the bench tests, show that the technology holds promise for environmental monitoring and emergency response in the marine environment. This tool has been used successfully in several deployments in simulated emergency spill response and routine water quality monitoring, as well as in dye-tracer experiments.

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