Multi-parameter Instrument Array and Control System (MPIACS): A Software Interface Implementation of Real-time Data Acquisition and Visualization for Environmental Monitoring

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***Abstract* - Recent developments in sensor technology over the past decade have shifted the paradigm in environmental as well as oceanographic sampling and monitoring. The environmental and oceanography scientific communities continue to deploy more and more *in-situ* sensors either as single-unit deployments for generation of time-series and vertical profiles or as a towed-array for mapping environmental variables in surface waters in multi-dimensional space. Emergency response activities also are enhanced by way of real-time geo-referenced data acquisition using mobile *in-situ* sensor arrays. Against this backdrop, we developed a software interface for real-time data acquisition, analysis and visualization from a towed-array of sensors. This is the Multi-parameter Instrument Array and Control System (MPIACS) described in this paper and was used in the fall of 2002 during a mock oil-spill exercise in Corpus Christi Bay, TX under the auspices of the Texas General Land Office (TGLO). The interface is designed for correlative visualization along the transect between as many as six state variables or environmental indicators allowing for the implementation of adaptive sampling schemes. The software can also be used for scheduled sampling of water quality parameters in surface waters.** †

I. INTRODUCTION

Environmental and oceanographic monitoring in surface waters can be enhanced with the use of *in-situ* instrumentation. Given the spatial extent of the domain of interest, the mode of instrument deployment determines the temporal and spatial resolution that can be achieved during such assessments. Fixed platforms with single or multi-instrument deployments while providing high temporal resolution, only provide limited spatial resolution. Mobile platforms on the other hand provide high temporal resolution and medium to high spatial resolution, the highest resolution being achieved by using a fleet of mobile platforms.

While mobile platforms can be used with grab sampling and flow-through (*ex-situ*) instrument deployments, in situations where real-time data are required such as in response to episodic events, *in-situ* instrument deployments are highly favored. Given the state-of-the-art in submersible sensor development, the environmental and oceanographic communities as well as emergency responders have a new set of tools for real-time monitoring in surface waters. Particular applications may demand the use of instrument arrays with the application of correlative data visualization between multiple environmental and oceanographic parameters returned by the suite of instruments. Correlative data visualization is a semi-analytic data post-processing tool, which helps to reduce the uncertainties in data returned from a single instrument by correlating with data from other instruments or sources [1]. It essentially throws more light on state variables returned from oceanographic surveys and environmental monitoring by way of visual indicators.

For example, concentration measurements from a fluorometer tuned to measure the concentration of biogenic particles can be visually correlated with the particle size distributions from a particle size analyzer. In another example, a salinity/temperature profile from a CTD sensor can be visually correlated with depth and concentration of biogenic particles. This paper describes the implementation of a software interface, the Multi-parameter Instrument Array and Control System (MPIACS) for real-time environmental monitoring. MPIACS employs correlative data visualization and can accommodate an array of up to six instruments with simultaneous display of up to six parameters from either a single instrument or instrument array.

II. ENVIRONMENTAL MONITORING IN SURFACE WATERS

This section provides a synopsis of environmental monitoring for the purpose of highlighting the challenges especially as it relates to the decision-making process in response to episodic events and emergency response efforts.

A. Sampling

1) Grab Sampling

This method falls within the category of *ex-situ* sampling and is commonly applied for off-line processing. Samples collected are analyzed in a laboratory (land-based or onboard). Onboard analytical laboratories are expensive and especially for smaller craft, they are impractical. In light of these, collected samples have to be sent to a land based lab which somewhat affects the decision making process. Grab sampling methods are most suited for routine monitoring where immediate lab results are not required.

2) 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

† The authors thank the Texas General Land Office for supporting this project.

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 (described in the following section) whenever immediate results are required. 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 geo-referencing purposes.

3) *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 as outlined in the previous sub-section. It is especially suited for real-time processing and facilitates the decision-making process by reducing the latency in data availability when 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 also for quality control purposes.

B. 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 instrument software interface may not be necessary unless the user needs to use any instrument specific routines.

For real-time monitoring, data pre-processing are 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.

When building instrument arrays, there are advantages to be derived from using commercial-off-the-shelf (COTS) products. However in some cases, the end-user may choose to develop instrument arrays from the ground up. Instrument developers 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 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 may be essential for accessing any low-level instrument control routines and other instrument specific data pre-processing schemes.

C. Real-time Visualization

To take full advantage of real-time data acquisition, real-time data visualization becomes imperative. This could be in form of a time-series or geo-spatial datasets, vector mapping,

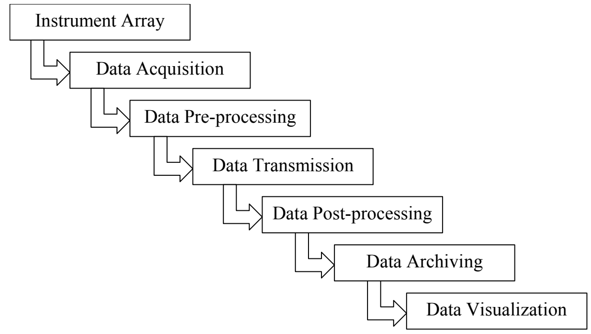

Fig. 1. Representation of integrated data network for real-time data acquisition and visualization.

contour plots, and animations. These visualization methods could also be used in combination.

D. Correlative Data Visualization

Correlative data visualization may be used between analogous multi-parameter datasets returned by single or multiple instruments. This helps in gleaning additional information from environmental measurements that may not be so apparent from single parameter measurements. For example, low dissolved oxygen levels may be visually correlated with high fluorescence measurements resulting from high phytoplankton counts.

E. Sensors

Developments in sensor technology over the past decade have led to availability of *in-situ* instrumentation for oceanographic and environmental measurements. These range from sensors for basic water quality measurements e.g. Conductivity, Temperature, Depth, (CTD) sensors to more specialized sensors such as particle size analyzers [2], imaging devices, current profilers, nutrient analyzers [3] etc. These could be deployed by themselves or as part of an instrument array. For geo-spatial data representation, one vital piece of instrumentation is the Global Positioning System (GPS) that provides the location and time stamp for each data point returned from the submersible sensors.

III. MPIACS

"The Multi-Parameter Instrument Array and Control System", MPIACS (Fig. 2) is a software interface that provides real-time data visualization of up to 6 different parameters measured by single or multiple instruments simultaneously. These parameters could be concentration measurements from fluorometers, particle size analyzers, salinity and temperature to name a few. For each parameter, the percentage of the parameter (measured value relative to a pre-set peak value) generates a color trace corresponding to the horizontal 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. This visual reference will aid or guide data acquisition efforts and may be implemented in an Adaptive Sampling scheme [4]. Each color-coded trace is displayed against a map outline of the study area by geo-referencing the

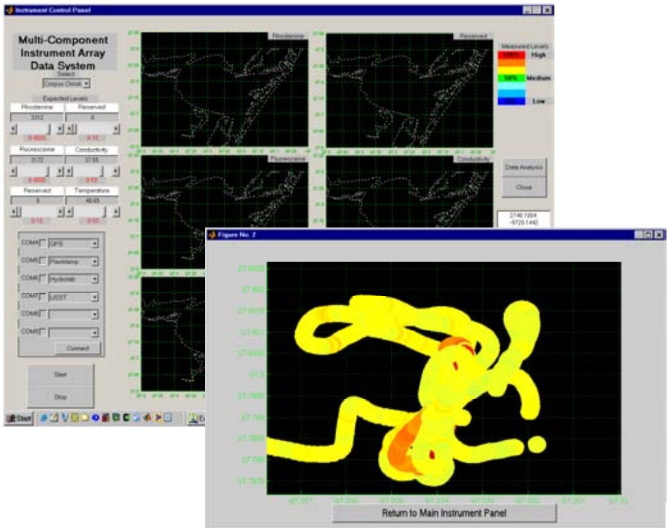

Fig. 2. The MPIACS software interface. Lower right panel is a zoomed in portion of one of the 6 data visualization panes from the main instrument panel.

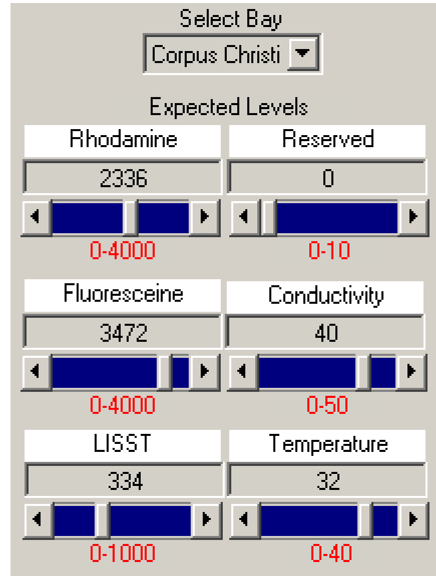

Fig. 3. Data Acquisition module with slider controls for setting instrument levels and drop down menu for selecting study area.

instrument raw data through the data acquisition GPS unit. The spatial resolution achievable depends on the data rate of the GPS employed (typically 1 Hz) and the travel speed of the vessel on which the instrument array is deployed.

MPIACS is implemented in a modular form to facilitate expandability and flexibility to accommodate a wide variety of instruments. The modules comprise: Data Acquisition, Instrument Control, Data Post-processing, Data Visualization and Data Archiving. These modules are discussed in the following subsections. Unlike other data visualization programs that are written for off-line data visualization [5], 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 implemented that operates in "playback" mode and can be used for off-line data visualization.

A. Data Acquisition Module

The Data Acquisition module (Fig. 3) consists of a drop down selector menu and 6 slider controls. The user selects the study area from the drop-down menu and a geo-referenced map outline of the study area is displayed in all the six panels. The expected maximum levels for each parameter to be measured are set using the 6 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. A typical pane is shown in Fig. 4 with a map outline of the study area, in this case, Corpus Christi bay, TX.

B. Instrument Control Module

The Instrument Control module (Fig. 5) provides data communications with the instruments and consists of a set of 6 drop down selector menu. As many as 6 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, flow control etc. 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 2 buttons labeled "Start" and "Stop" are then used to begin the data acquisition after all the required settings have been made. With the "Start" button, 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, representing a sample point within the study area. This process is continuous and only terminates when the operator presses on the "Stop" button.

C. 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,

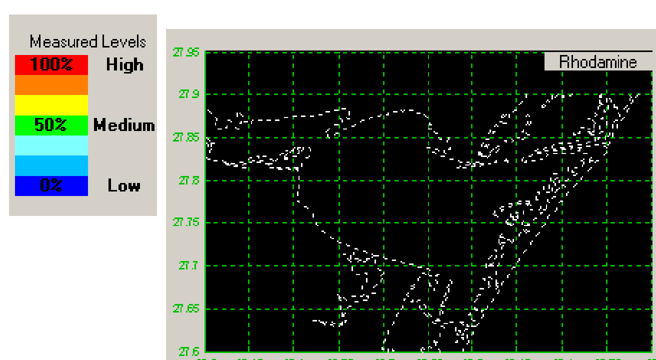

Fig. 4. Visualization pane. One of the six panes available for geo-referenced color-coded trace output. Top left is color-coding for the measured parameters.

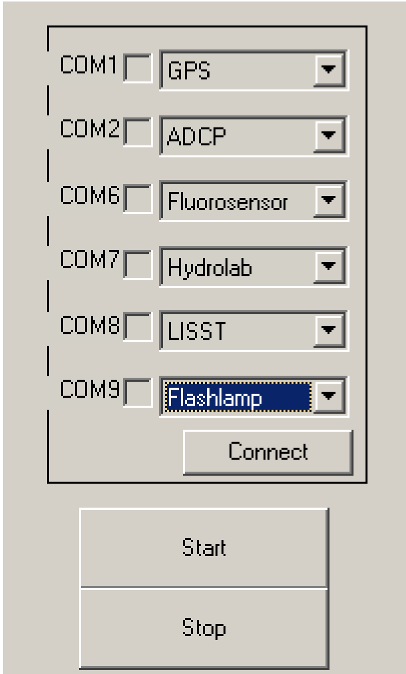

Fig. 5. Instrument Control module. Comprises drop down selector menu for initiating data communications with instruments and buttons for starting and terminating instrument data stream.

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. It may be necessary in future enhancements, to come up with a database of such instruments or users would have to write their own routines to accommodate sensors applicable to their deployment.

D. Data Visualization Module

For each parameter, a percentage number variable (measured value against a pre-set 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 6 respective panels as shown in Fig. 2 with the panels being expandable by a mouse click (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.

E. Data Archiving Module

This implementation of MPIACS includes a data archiving routine which allows for 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.

IV. DEPLOYMENT

The Texas General Land Office (TGLO) is interested in a field program to evaluate dispersant use in nearshore waters, and has opted to use a “spill of opportunity” for data gathering. Based on a review of historical spill data, Galveston Bay and Corpus Christi Bay have been targeted as the most likely locations for such a spill to occur. So TGLO has provided study teams to be based in both locations, where each team will be equipped with aircraft for dispersant application and a boat crew for monitoring of the dispersed-oil plume.

The Conrad Blucher Institute for Surveying and Science (CBI), located at Texas A&M University-Corpus Christi, has been designated as the boat monitoring team for the Corpus Christi Bay location. Recently, CBI has focused on deploying real-time *in-situ* sensor instruments for improved oil spill detection and response. These sensors can be deployed on fixed platforms in targeted areas such as Galveston and Corpus Christi bays, and monitor important baseline parameters, such as hydrocarbon contaminant concentrations, nutrient levels, particle size distribution and characterization, etc. CBI has added sensor arrays to a geo-referenced boat that can provide valuable information for oil spill response planning/activities. The information gained from the platform sensors can provide background (baseline) data and after an oil spill has occurred, the monitoring strategy can be mobilized using the sensor-arrayed geo-referenced boat. Valuable real-time data can be transmitted to the Incident Command Center to aid in oil spill response decisions.

In preparation for an actual spill of opportunity, a series of exercise drills are being conducted by TGLO. To date, two scheduled drills have been executed, including the Corpus Christi Bay drill in September of 2002. MPIACS allowed for real-time visualization of five parameters measured by three instruments. These include rhodamine and fluorescein concentrations from a multi-spectral fluorescence sensor (SAFire by WETLabs, Inc.), 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). The data was geo-referenced through a marine GPS unit (Furuno model GP-37).

The GPS unit was run in the auto-selection mode during this exercise, allowing the unit to operate in GPS, DGPS (dynamic GPS) or WAAS (wide area augmentation system) mode, depending on service availability. The accuracy of the GPS varies with the mode: DGPS mode (accuracy is within 1 m or 3 ft), WAAS mode (5 m or 15 ft), or GPS mode (10 m or 30 ft).

Sampling rate of the instrument array was governed primarily by the acquisition rate from the GPS unit (fixed at 1 Hz) since all data points require geo-referencing for visualization. Travel speed of the tow-body was governed by the speed of the deployment vessel, which averaged 5 knots.

Under this set of conditions, a spatial sampling resolution of ~3 m (9 ft) was expected. Actual spatial resolution during the exercise was between 3-10 m (9-30 ft) depending on the operational mode of the GPS unit.

V. FUTURE ENHANCEMENT

The current implementation of the MPIACS allows for display in the horizontal plane (2-D space). Future enhancement to the software will allow for visualization in 3-D space as well as the inclusion of statistical tools for data analyses. Another enhancement in future versions of the software will allow for near real-time generation of contour plots and time series from the data sets.

Instrument configuration files and/or dialog boxes will be created to enable the user load or create instrument specific configuration and data post-processing modules. At the moment only three study areas are included in this implementation of MPIACS. Expansion of the dataset of study areas or the capability to load and store digitized map outline of study areas will be considered in future developments.

It will also be possible in future developments of the interface to increase the number of panes available for display from the current six. COM ports availability will not be hard-coded but will be determined through the operating system.

VI. CONCLUSION

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. This tool has been used successfully in two deployments in a simulated emergency spill response. MPIACS can also be used during routine monitoring of environmental and water quality parameters.

As a real-time environmental monitoring tool, the visual feedback aids data acquisition by providing immediate identification of "hot" and "cold" spots for the constituents of interest through sensor measurements, with location and time stamps provided by a GPS unit. The collected data are also archived in plain ASCII text, tab delimited file format for off-line processing. The multi-parameter instrument array implementation allows for correlative data visualization, which further aids the data acquisition effort by removing the "guess-work" inherent in environmental monitoring especially relating to constituents of interest that do not provide visual identification or during periods of low-visibility.

REFERENCES

[1] L. A. Treinish and C. Goettsche, "Correlative visualization techniques for multidimensional data," *IBM J. Res. Dev.*, vol. 35, pp. 184-204, Jan-Mar 1991.

[2] Y. C. Agrawal and H. C. Pottsmith, "Instruments for particle size and settling velocity observations in sediment transport," *Mar. Geol.*, vol. 168, pp. 89-114, August 2000.

[3] K. H. Hanson, "A new in situ chemical analyzer for mapping coastal nutrient distributions in real time," *Oceans 2000 MTS/IEEE Conference Providence, Rhode Island*, p.1975-1982, 2000.

[4] A. Stein and C. Ettema, "An overview of spatial sampling procedures and experimental design of spatial studies for ecosystem comparisons," *Agric. Ecosyst. Environ.*, vol. 94, pp. 31-47, January 2003.

[5] C. He and P. F. Hamblin, "Visualization of model results and field observations in irregular coastal regions," *Estuar. Coast. Shelf Sci.*, vol. 50, pp. 73-80, January 2000.