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A Gateway Middleware for Seafloor Observatory Monitoring upon Junction Box

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Abstract: Recognized as the third observation platform, seafloor observatories enable long term, continuous, real time, all weather and multitask scientific observation and become the most remarkable trend in international marine science and technology. This study is aimed to establish a junction box based gateway middleware prior to the back-end server for diverse seafloor observatory monitoring applications. The design manipulates diverse sensor data with communication and processing balance and also gives reference for representing such kind of middleware in the cyberinfrastructure for seafloor observatories. As considering sensor characteristics of data acquisition and data processing for seafloor observatory monitoring, the proposed junction box based gateway middleware is designed with three bridged function modules including data monitor, transaction executer and network responder, to enable real-time data acquisition, data filtering, data interpretation and visualization, database redundancy and storage and control commands configuration. The cyberinfrastructure representation of the gateway middleware is discussed and designed using service-oriented architectures (SOA) and web services. The middleware is built upon the junction box for two-way communication and interoperation to perform efficient and stable applications. The comprehensive middleware design can be easily utilized for general seafloor observatory sensor network surveillance with expansibility and flexibility.

Key words: Seafloor observatory monitoring, gateway middleware, cyberinfrastructure, junction box

INTRODUCTION

A universally recognized human being's third observation platform, namely seafloor observatories, has become the most remarkable trend in international marine science and technology (Wang, 2007). Projects on seafloor observatories have implemented or are being constructed all around the world, of which NEPTUNE is by far the largest established seafloor observatory network that functions to study various disciplines on plate scale while OOI (Ocean Observatories Initiative) is the most advanced and largest ocean observation program under construction (Favali and Beranzoli, 2006). China is also actively preparing for a seafloor observation system in the East China Sea to study sea-land interactions over this special marginal sea, with the first established Xiaoqushan Seafloor Observatory performing continuous measurements and satisfying operations for more than 900 days (Xu *et al*., 2011).

Seafloor observatories are designed to place all the observation equipments under the sea and provide power and collect information to and from each science node that equipments belong to, enabling long term, continuous, real time and multi-task scientific observations. In terms of supporting this two-way transmission of power and data, junction box technology acts as the crucial intermediate link between the backbone cable and various observation sensors in every science node for centrally processing and managing power and data signals. Introduction of the junction box brings great convenience to the entire work of design, installation, operation and maintenance for seafloor observatories (Chen *et al*., 2006). On the other hand, the concept of gateway middleware has been proved rather beneficial as a centralized network manager for the sensor network environmental monitoring system to bridge the front-end sensors and the back-end server and to support credible two-way communication between sensor networks and operator networks (Hong *et al*., 2011; Hwang *et al*., 2003). The approach is made active on the autoregressive data-driven flow to perform data and commands transmission throughout a heterogeneous sensor network (Hill and Minsker, 2010). Therefore, we combine the concept of junction box with gateway middleware for seafloor observatory monitoring and propose this gateway middleware for the following scopes: (1) Acquire scientific data and infrastructure information in a real-time way (2) Perform dynamic commands control and configuration on various observation equipments (3) Ingest raw data into back-end database server for advanced data applications (4) Represent the junction box with sensors connected as a controllable service in the cyberinfrastructure for seafloor observatories.

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In this study, we firstly identify the design requirements for the junction box based gateway middleware by analyzing the characteristics of data acquisition and related processing in seafloor observatories. Secondly we propose the hardware support and software design for this gateway middleware for seafloor observatory monitoring in accordance with the identified requirements. Thirdly a prototype of this gateway middleware is implemented and some results are given and discussed. Finally we summarize and evaluate the whole research work of this study.

SEAFLOOR OBSERVATORY DATA

At the front-end of seafloor observatory monitoring applications, science nodes for this proposed gateway middleware contain junction boxes with various sensors connected. Junction box is designed and developed as a hub for connecting science nodes with the backbone cable and transmitting the power and data between them. We, therefore first indentify the design requirements of this junction box based gateway middleware by analyzing the characteristic of data acquisition and data processing of various seafloor observation sensors.

Data acquisition: In terms of seafloor observatories, data acquisition is the process of collecting measurements from various physical observation equipments (sensors and related infrastructure) in each science node and preparing them for a cyberinfrastructure understandable format. According to the observation schedule and dynamic monitoring demands, the control center at the back-end coordinates the data acquisition by sending control commands to the gateway middleware that represents the junction boxes with instruments connected in the cyberinfrastructure for seafloor observatories. The gateway middleware is then responsible for interacting with the physical instruments to receive observed data (both scientific data and infrastructure information) and hand them to data processing activities for advanced applications.

Modes of data acquisition from observation instruments generally fall into two categories: Poll mode and push mode (Bello *et al*., 2003). Poll mode (Fig. 1) means that the Gateway Middleware has to dictate when a measurement is made and when the observed data is requested. The physical instrument waits for the control command to execute the measurement and send the sensed data back via the junction box that it connects to.

In contrast, push mode (Fig. 2) applies to instruments that can be scheduled to execute measurements autonomously and the gateway middleware simply receives the observed data in a passive way until new configuration command arrives from the control center at the back-end. In this case, the gateway middleware sends a measurement schedule (e.g., configuring the sampling rate, the acquisition parameters and the output formats) to the physical instrument and then the specified device knows when and how to make measurements and to return the sensed data to the gateway middleware.

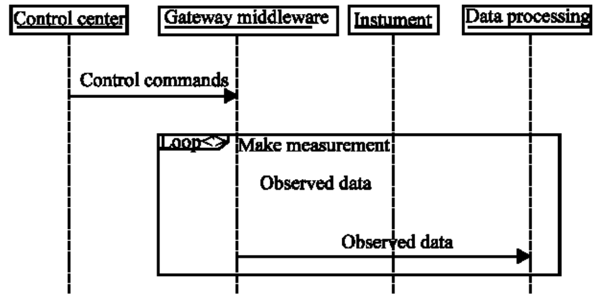

Fig. 1: Data acquisition from polled instrument

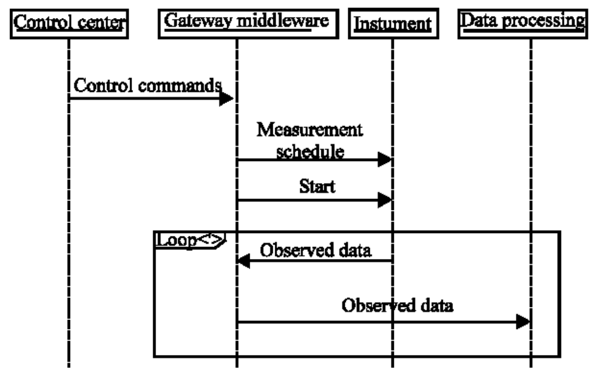

Fig. 2: Data Acquisition from push instrumentc

As seafloor observatories consist of various types of observation instruments, both data acquisition modes must be taken into consideration when designing this junction box based gateway middleware. Only in this way can the scopes of real-time data collection and adaptive commands control in seafloor observatories be fully supported.

Data processing: Seafloor observation sensors fall into different categories considering their data encodings, which are predetermined by the manufacturing process in various instrument companies (Liu, 2009). For instance, the CTD (Conductivity Temperature Depth) sensor collects every observed data frame in the well-known ASCII encoding with a form like 25.3086, -0.00001, 0.025, 0.0060, 0.0000, 0.0000, 1497.525, 26 Sep 2008, 16:43:56. In contrast, the ADCP (Acoustic Doppler Current Profilers)

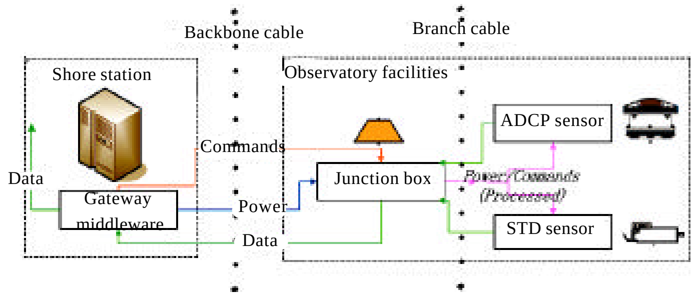

Fig. 3: Hub role of junction box

sensor performs this collection in binary encoding form successively containing Header, Fixed Leader Data, Variable Leader Data, Velocity, Correlation Magnitude, Echo Intensity, Percent Good, Bottom Track Data, Reserved and Checksum. This distinction disables the direct usage of data processing software separately equipped with each sensor type and leads to a customized protocol and supporting application for data transmission, acquisition and interpretation.

Once all the observed raw data from various sensors are uniformly converted as data packets in binary encoding under customized protocol, the in situ junction box is ready to transmit these data packets. Thus this gateway middleware shall first be able to receive these data packets in a real-time manner complying with the same communication protocol. In practice, each record of observed data is received by various time intervals and thresholds and a filtering processing is crucial to decrease redundant data transportation and avoid inconsistent data entry before loading into database server for advanced data applications. This means that the junction box based gateway middleware shall also be able to unpack the data packets, check threshold criteria, convert them from A/D volts to physical units and display them in a visualized form against unexpected events in situ. Furthermore, the formatted data records matching the criteria shall be prepared for the database at the back-end server while all observed raw data should be made backup in specified data files in case.

Considering representation in the cyberinfrastructure for seafloor observatories, observation schedule (e.g., sample plan) performed by the junction box with various sensors connected should be accessed and configured by certified authorities across the network (O'Reilly *et al*., 2004).

JUNCTION BOX BASED GATEWAY MIDDLEWARE DESIGN

Hardware support: The junction box based gateway middleware is applied as a pivot of data transmission, acquisition and conversion for remote seafloor observatory monitoring. In terms of hardware support, the in situ junction box is designed in a way that integrates communication control module, photovoltaic signal conversion module, power allocation module, general signal collection and encoding module and so on. Communication control module achieves the transparent conversion among different network transport protocols and enables the two-way transmission of both data and commands between the in situ observatory equipments and the observatory management authorities.

It is just this modular integrated design that fulfills the hub role of the junction box in seafloor observatories as mentioned before and lays a foundation for the remote scheduling and monitoring operations in seafloor observatories and that offers technical ideas for designing this junction box based gateway middleware for seafloor observatory monitoring. In brief, we first need establishing the remote communication between the gateway middleware and the junction box and then interacts with the junction box to play its hub role, namely allocate power as well as process and schedule signal (both raw data and control commands) conversion and transmission in a real time manner.

The hub role of junction box is hinted in the figure below:

As shown in Fig. 3, the power from the shore station is transmitted to the junction box in the form of DC high voltage via the backbone cable (blue stream) and converted in the junction box; and then the converted power is allocated to various observation sensors (magenta stream) to ensure their normal operation in accordance with the power requirements of the corresponding ports they are connected to in the junction box. Control commands relayed by the gateway middleware are first received and processed by the junction box (red stream) and then assigned to the corresponding observation sensors via serial ports (magenta stream) and meanwhile the raw scientific data

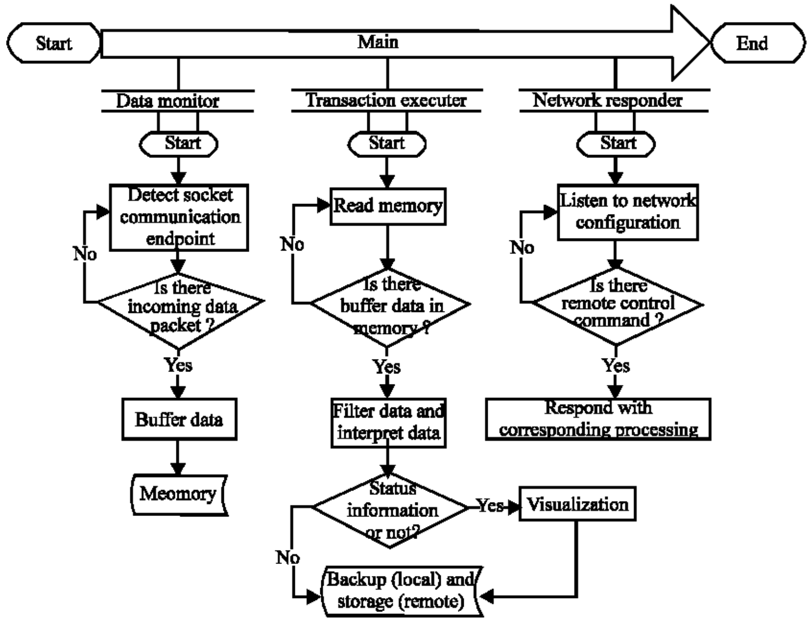

Fig. 4: Flowchart of Data Processing in the Gateway

and infrastructure information gathered from undersea observatory facilities (green stream) are transmitted and acquired by the gateway middleware at the shore station via both the communication control module and the general signal collection and encoding module of their connected junction box. In this way the junction box fulfills the hub role and gives out an initial concept for designing and developing the junction box based gateway middleware for seafloor observatory monitoring. Furthermore, the gateway middleware will filter the acquired raw data and ingest the formatted ones into the back-end database server at the control center.

Bridged function modules: A bridged gateway that relays data flow between the sensor nodes and the back-end server is often employed in most sensor network applications for environment monitoring. Its common functions can be summarized as listening to the serial port, transacting on the data log and forwarding to the Internet protocol.

In terms of the junction box based gateway middleware for seafloor observatory monitoring, we propose function modules including data monitor, transaction executer and network responder to together drive the auto-process of data acquisition, data filtering, data interpretation and storage and commands control. We design the data monitor to listen and acquire the real-time incoming sensor data packets from the in situ junction box with sensors connected. The transaction executer is responsible for filtering the received data packets, interpreting the status information, backing up the validated data and writing them into the remote database at the back-end server and meanwhile recording all the system transactions. Furthermore, we consider the network responder to receive the control commands from the seafloor observatory management center and process those queries to the communication control module of the junction box for configuring the corresponding seafloor observatory sensors. In summary, the data monitor detects and obtains the incoming sensor data and then buffers the received data in memory. The transaction executer reads and filters these data packets with criteria, interprets and visualizes the status information, backs up the validated data and meanwhile writes them into the remote database. The network responder accepts the commands from the remote control center server and forwards those to the in situ junction box and various observation sensors connected. The functions are programmed with three threads in the flowchart illustrated in Fig. 4 and the components are detailed below.

Data monitor: Upon detecting any signals from the in situ science nodes, the data monitor retrieves the incoming sensor data packets encapsulated in customized message format and buffers those data in memory. Otherwise, the data monitor keeps detecting. The received data packets from the front-end science nodes comply with TCP/IP protocol, as the communication control module of the junction box in each science node is integrated with serial connectors for gathering observed data from various sensors and socket program for sending and receiving message under TCP/IP protocol. As the data packets sent by the front-end science nodes are socket enabled, every packet contains the header and footer data automatically added to the segmented raw observed data by TCP/IP protocol and this addition can be correspondingly parsed once the packet is received by the same communication endpoint namely socket. Noting that every observation sensor collects the observed data on its own time intervals according to the periodic or dynamic schedule, the data monitor is designed with Socket Class of .NET Framework to establish a complete association in internetwork communication and to monitor any incoming signals at any time in a separate thread.

Transaction executer: Once there are incoming sensor data packets from the front-end science nodes, the data monitor receives and buffers them in memory to further hand the data processing rights to the transaction executer. The transaction executer filters the received data in memory by invoking the interpreters and related functional Classes (e.g., InterpretData Class) and buffers the filtered data in the form of DataTable Instance in memory. Based on this, the transaction executer could back up all the filtered data into the predefined data log files and write the validated physical data into the remote database at the back-end server. What's more, the transaction executer could simultaneously visualize status information of the observatory infrastructure in the form of both data tables and data graphics in the graphic user interface.

Network responder: The major task of the network responder is receiving the incoming commands from the back-end server and processing those queries to configure the corresponding seafloor observatory sensors via the in situ junction box that they connect to. Once new observatory plan are required to update because the analysis results or new thresholds are fed back from the back-end, the responder supports the control center server to remotely drive the control commands under Internet protocol. Once a command is accepted, the network responder will evoke the corresponding thread for desired processing. The proposed commands can control the necessary data management such as sensor data acquisition, log file retrieve, junction box reset, instruments configuration, battery capacity reading and so on. Besides, the network responder involves in the cyberinfrastructure representation of the junction box based gateway middleware for seafloor observatory monitoring, which is further discussed in the text below.

Cyberinfrastructure representation: Cyberinfrastructure integrates hardware for computing, data and networks, digitally-enabled sensors, observatories and experimental facilities and an interoperable suite of software and middleware services and tools. Cyberinfrastructure constitutes the integrating element that links and binds types of seafloor observatories and associated sensors into a coherent system-of-systems and provides domains of authority with ubiquitous access to a system that enables simple and direct use of various seafloor observatory resources to accomplish their scientific or educational objectives and tasks. Considering representing this junction box based gateway middleware in the cyberinfrastructure for seafloor observatories, Service-Oriented Architectures (SOA) and web services could be introduced to facilitate this vision (Uslander *et al*., 2010). A service is a software component that can perform a set of well-defined functions and can be accessed by clients anywhere in the cyberinfrastructure through the service interface. A service interface defines the operations or methods that the service can perform on behalf of clients, including the input and output data types. As designed and developed in a modular integrated way, this gateway middleware represent itself as a service to the seafloor observatory network and parts of its functional domains can be designed as service interfaces with precisely defined service access protocols based on message exchange. For example, a certified user could subscribe the service and call the interface IMonitor to view the real-time in situ infrastructure status in visual form with no need for knowing the implementation details by the transaction executer.

RESULTS AND DISCUSSIONS

The junction box based gateway middleware designed in this study emphasizes the threads of data monitor and transaction executer for acquiring and processing diverse data packets from the front-end sensors, while the network responder may enable communication with the back-end database server. In this practice, the prototype of gateway middleware was first implemented with a variety of sensors for seafloor observatory monitoring test in the seafloor observatory laboratory of the State Key Laboratory of Marine Geology at Tongji University and this tank test proved that the prototype meet all the design requirement. Besides, this prototype has been tested in China's first Seafloor Observatory (Xiaoqushan Seafloor Observatory) and has been proved to function well during the entire testing

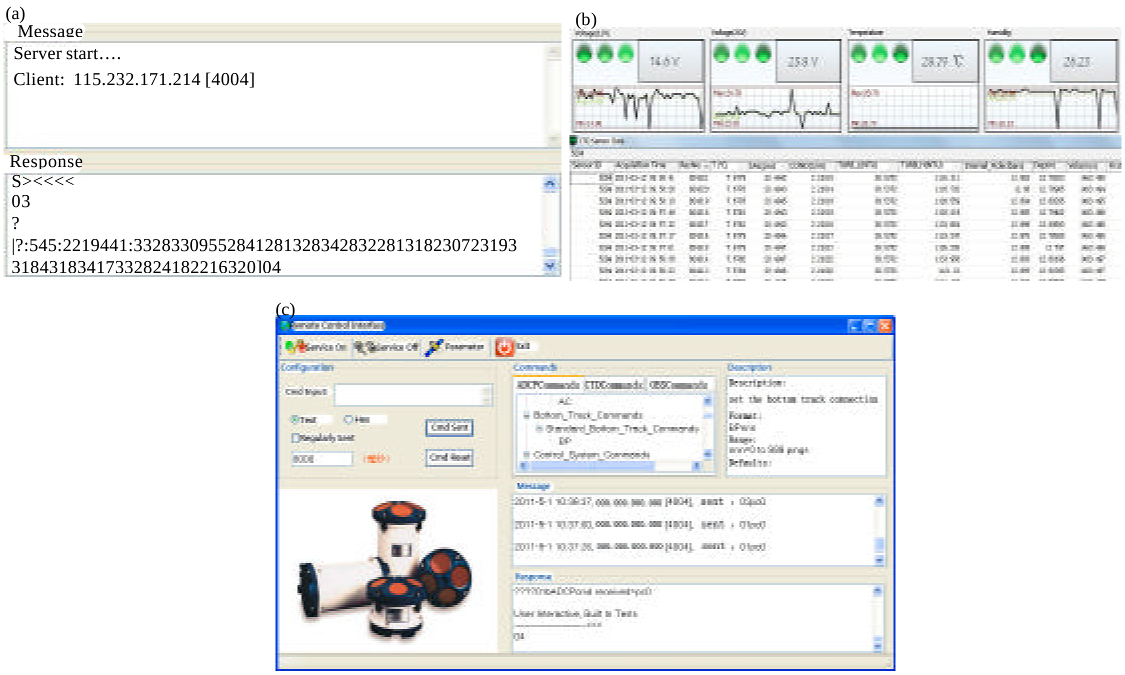

Fig. 5(a-c): Simulation of data packet processing in the junction box based gateway middleware: (a) Acquire data packets within the data monitor, (b) Filter and interpret data within the transaction executer and (c) Remote control interface

process. Some data flow of simulation results was given by screen-shot figures for discussion while running the developed gateway middleware.

Data acquisition: Figure 5a presents the data acquisition process when the data monitor was detecting whether any sensed datum arrived or not. The arrival data packet was parsed by the receiver function of Socket Instance and was buffered in memory. Meanwhile, the transaction executer created a thread to cyclically read the data in memory and filter the sensed data.

Filtering and interpretation: Figure 5b shows the filtering and interpretation process on parsed data flow within the transaction executer by calling the interpreter and related functional Classes (e.g., InterpretData Class). Consecutively, the thread filtered the packets by the specific criteria for storing those qualified data or dropping the incomplete data and interpreted and visualized them in user graphic interface.

Remote control interface: In terms of cyberinfrastructure support and representation, Fig. 5c presents the interface for remotely controlling the in situ junction box and observation sensors connected by means of calling the service interface Icontrol that this gateway middleware

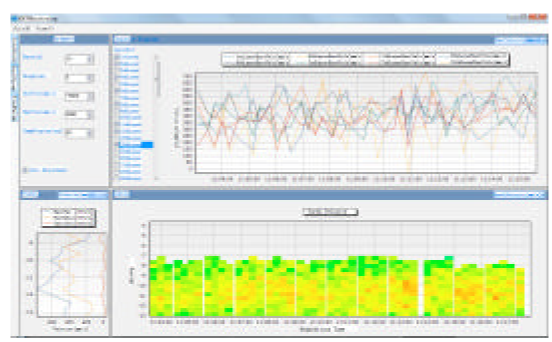

Fig. 6: Real-time Presentation of ADCP sensor data

has published in the seafloor observatory network. Here you can perform the configuration of observatory plan on various science nodes by forwarding control commands to the junction box on the established socket complete association. Furthermore, the data stored in the database server at the back-end were prepared for advanced analysis.

D. Real-time data presentation: In this practice, the ADCP sensor was discussed for the seafloor observatory monitoring tests. The data packets were filtered and processed with the junction box based gateway middleware that was adaptive to the back-end server. And the figure below was illustrated by the real-time online chart plotter function of the monitoring system at the back-end server using the validated data in the database. In Fig.6, the chart illustrates statistical data of current velocity returned from the ADCP sensor and displays them in both curve and profile.

CONCLUSION

This approach catalogued typical sensors in seafloor observatory monitoring and developed an innovative junction box based gateway middleware prior to the back-end server. This middleware not only manipulates diverse sensor data with transmission and processing balance but also gives reference to the cyberinfrastructure representation for seafloor observatories. According to the seafloor observatory monitoring test in this study, the junction box based gateway was designed with threads of data monitor, transaction executer and network responder to implement real-time data acquisition and necessary data processing such as filtering sensor data, interpreting and visualizing the filtered data, remaining data log redundancy and writing the validated data into remote database and configuring control commands on the in situ science nodes with various observation sensors. The hardware support adopted the junction box integrated with various modules such as communication control module to cooperate with this gateway middleware for seafloor observatory monitoring in an efficient and stable manner. The development of the junction box based gateway middleware can be easily expanded to other seafloor observatory sensor network surveillance.

In the current study, the developed junction box based gateway middleware essentially completes the design and practice on acquiring and processing sensed data and configuring control commands; thus, the prototype model is feasible to expand for a variety of sensor specifications in the future. In further studies, the issues regarding fully representing the gateway middleware for seafloor observatory monitoring in the cyberinfrastructure will become the next challenge.

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