A Capable Smart Sensor Interface Module for Interoperable Ocean Observatories

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Abstract. The rapid development of ocean observatories results in a great challenge to integrate so many sensors into one system. Some solutions have been proposed to address this issue, such as MBARI PUCK, IEEE 1451 and OGC SWE. This paper proposes a novel smart sensor interface module solution which is more capable than PUCK. As the interface standardization is achieved at the instrument-side in our solution, the design of ocean observatory systems is simplified. What’s more, the feature of distributed intelligence of the module can benefit many in-situ applications of ocean observatories.

1. Introduction
The rapid development of ocean observatory systems results in dramatic increase in sensor deployments. However, it is a great challenge to integrate so many instruments into one system. The challenge most comes from the fact that there are no widely recognized interface protocols for undersea sensors. The differences of these interface protocols are summarized as below:

- Electrical interface: Undersea sensors adopt various communication interfaces, such as RS232, RS422, RS485 and Ethernet. So multiple interfaces should be designed and reserved in junction box for compatibility. Their pin definitions and input voltages are also different among sensors.
- Communication protocol: The communication protocols of undersea sensors from distinct manufacturers tend to be totally different. It costs a lot of effort to interact with all sensors in a similar manner.
- Data format: The data retrieved from different undersea sensors, even from different versions of the same sensor, are different in formats. They may be delimiter-separated text, XML-based text or binary data, making it more difficult to integrate the increasing number of data streams into a system.
- Intelligence: Sensors have different levels of intelligence. Some may just output an analog signal; some may support scheduled-sampling, PTP protocol, and even a built-in web server.

So a lot of troubles exist in the design, extension, update, and maintenance of ocean observatory systems. In addition, the manual processes[1] to customize and configure hardware and software for each version of sensors introduce large possibility of human-error. In ocean observatories, the cost of an error could be very high due to the high price of undersea sensors themselves, as well as their recovery and maintenance[2].
The standardization benefits the plug-and-play procedures, and promotes observatories a simpler design and higher reliability.

![Interoperable instrument protocol layers](image)

**Figure 1.** Interoperable instrument protocol layers[3].

Current solution to achieve the standardization of instrument interfaces is to add an interoperable protocol layer to the software architecture of an observatory[3], as shown in figure 1. Typically, to standardize the interface protocol, we will need “driver” for each type of instruments. Drivers are responsible for translating between native instrument protocols and standard protocols[4]. Customizing driver for native instrument protocols is a major but inevitable cost of this solution. In addition, we need description files to identify each sensor, so that the upper software knows what kind of parameter it measures, its function, what it is, and how to interact with it.

The individual observatory protocol layer is not mandatory; it’s just a decision of design. Once everything is standardized in one layer, to implement map between two protocols is easy. Since it seems unrealistic to persuade all vendors to implement same interface protocol locally in their instruments, we need an alternate to achieve the standardization, which turns out to be the smart sensor interface module. The smart sensor interface module can be embedded in or attached to the target instruments to allow additional capability.

### 2. Standard Interface Protocols

#### 2.1. MBARI PUCK

MBARI PUCK (programmable underwater connector with knowledge) is considered to be the minimum implementation of a smart sensor interface module; it does not implement standardization itself, but provides the way to achieve it.

The PUCK defines a simple embedded instrument protocol, so that the host can store and retrieve data from a PUCK-enable instrument. The data consist of a predefined minimal metadata and an optional “payload”. The payload can store any data, such as the components of other standards or the executable driver code. So, the description file for implementing interoperable instrument protocol layers is stored in the predefined datasheet and optionally in the payload. The driver code can be stored in the payload or gotten from the database according to the ID of instrument, which is also a solution for description file.
The PUCK can be embedded in an instrument. But for most commercial instruments, it will be a module connecting instruments to a host, as shown in figure 2. It adds additional functions to a traditional instrument. Once a PUCK-enabled instrument is plugged in, the host will detect it by rolling ports, and communicate with it via the PUCK protocol to retrieve data. Once getting all the data needed, the PUCK will be bypassed and the host will communicate with the instrument directly[6].

Figure 2. PUCK connecting the host and the instrument[5].

The PUCK essentially doesn’t implement standardization itself, but provide a way to identify the instruments; the standardization is completed in the host, where the driver runs. So the reliability and the ability lay on the host and the communication link.

The PUCK has been implemented on RS-232 and Ethernet[7], and is being used on MBARI moored and cable-to-shore observatories[8].

2.2. IEEE 1451 and OGC-SWE

The IEEE (Institute of Electrical and Electronics Engineers) 1451 smart transducer interface standards defines a set of open, network-independent communication interfaces for connecting transducers[9]. So the control software can automatically detect a transducer and also issue commands to interact with the transducer. An IEEE 1451 smart transducer has two parts: A Smart Transducer Interface Module (STIM) and a Network Capable Application Processor (NCAP). The predefined description file in STIM, i.e. Transducer Electronic Data Sheet (TEDS), provides the information needed to identify and connect the device.

The OGC-SWE (Open Geospatial Consortium - Sensor Web Enablement) defines an open standard framework to exploit sensors via the Web. Several specifications have adopted in the SWE framework[10], including some XML-based specifications for description, such as SensorML, and some for the standard web service. What’s more, the PUCK has been adopted as part of the SWE, and the SWE offers “Hooks” for IEEE 1451 and other standards.

The IEEE 1451 and OGC-SWE are not customized for ocean observatories; they are quite comprehensive but also very complex. Though some work has been done[11], people tend to combine them with the PUCK solution to achieve interoperability[3, 4, 12], rather than locally implement these complex standards completely in the firmware of traditional ocean instruments.

3. Capable smart sensor interface module

Refer to the PUCK protocol, we have designed that a more capable smart sensor interface module, named smart instrument adapter (SIA), which may be more suitable for the complex marine environment.

Suppose the connection to the host is lost or blocked on an ocean observatory, the data retrieved may be lost, but a smart instrument is capable to detect this event and take actions, such as buffering the data or reducing the sampling frequency and waiting for communication restored, and then retransmit the data.

3.1. The Concept of SIA
The SIA aims to achieve standardization at the instrument-side, rather than at the host-side as in the PUCK solution, leading to a more capable interface module as shown in figure 3. Like the PUCK, the SIA can be embedded in instruments or be an external double-end firmware. One end is connected permanently to the corresponding instrument(s) and the other end is used to communicate with the external objects. The SIA will not be passed by as the PUCK do, but be the middleware between the traditional instruments and the observatory network. To the observatory network, instruments with an SIA are treated as a standard SIA-enabled instrument. The process of adaptation is transparent to the network. So the driver is running on the SIA, the upper software on the host can interact with the SIA-enabled instrument in a standard way, e.g. getting the formatted data. It simplifies the design of the software architecture and enables the “plug-and-play” function.

The SIA is featured by distributed intelligence. The relation between a host and a SIA-enabled instrument is not “master-to-slave” as the PUCK protocol, but “peer-to-peer”. From the view of the SIA, there is no difference among the host and other SIAs. So these networked SIAs can interact with each other and that’s the reason why SIA-enabled instruments don’t connect directly to the host in figure 3.

3.2. The “plug-and-play” process
The “plug-and-play” process of a SIA can be summarized as follow:

1. A SIA-enabled instrument is plugged in and powered.
2. The SIA configures itself and establishes a connection with the host.
3. The host reads the description file from the SIA and knows the capability of the SIA-enabled instrument.
4. The host requests services from the SIA-enabled instrument.
5. The SIA-enabled instrument receives and responses to these requests.

The establishment of connection can be passive by rolling, or be active by connecting to certain IP address or broadcasting.

3.3. Considerations

3.3.1. Connectivity. The “interface” in the figure 3 refers not only to the software protocol, but also the electrical interface. In order to accommodate various electrical interfaces, many interfaces will be reserved and there will be a power adapter module in the firmware of a SIA; but the electrical interface of the other end can be uniform, e.g. 48V and Ethernet ports, leading to the simplified design of the science instrument interface module (SIIM)[13]. The SIIM is only needed to provide standard interfaces to connect SIAs.
The traditional instruments are hard wired to the SIAs, while the connection between the SIAs and the network can be either wired or wireless, e.g. acoustic or optic links.

3.3.2. Standard communication. We have designed a novel observatory protocol for the SIA, and the possibility of implementing part of the IEEE 1451 standard is under evaluation. Considering the variety of instruments in the ocean observatories, we need a flexible method to describe the interfaces of the SIA-enabled instruments. So in the current, the description file is based on XML, and the XML-based SensorML is also being considered. The data is formatted to XML and attached with useful meta-data, so that it enable upper software to process the data by a uniform tool set.

3.3.3. Functionality. Benefit from the capable design, the SIA can not only encapsulate the existing functions of instruments, but also add valuable functions. By this way, various instruments can have similar function packages, including but not limited to:

- Positioning and timing: The positioning and timing are the foundation of many important scientific tasks in an ocean observatory system, but so few instruments support these two functions. The SIA provides a platform to enable precise positioning and timing for each SIA-enabled instrument.
- Reliable transmission: The SIA can ensure a reliable data transmission by buffering data and also the retransmission mechanism.
- Warning mechanism: The SIA can detect the working status of the connected instruments, benefiting the fault detection of the system.
- Hybrid communication: The SIA can use a mixture of communication interfaces, such as Ethernet and acoustic, so that the communication can be more reliable.

3.3.4. Reliability. Thanks to the distributed nature of SIAs, the reliability of the whole system is relative high. One component failure will not crash the whole system; while the failure of the host controller will disable all PUCK-enabled instruments on the platform. To improve the reliability, the function of remote upgrade is implemented in the software of the SIA. When bugs are discovered, we can fix it remotely.

3.3.5. Power consumption. As the SIA circuit will not be passed by, there will be extra power consumption while operation. But, the SIA can also power down the connected instruments and get into sleep mode to save energy. It is not an issue in a cabled seafloor observatory which has abundant power. But in a moored observatory or in wireless sensor networks, where power is limited, we need to do a trade-off design.

3.4. Compare with PUCK
A comparison between SIA and PUCK is given in table 1.

Table 1. Comparison between SIA and PUCK.

| Item                     | SIA                | PUCK                                           |
|--------------------------|--------------------|------------------------------------------------|
| Where to achieve         | Instrument-side   | Host-side                                      |
| standardization          |                    |                                                |
| Numbers of connected     | One or more        | One                                            |
| instruments              |                    |                                                |
| plug-and-play            | Support, passive or active | Support, passive through rolling by host |
| Active time              | The whole work time | First time be plugged in, and then be passed by. |
| Electrical interface     | Mixed              | RS232 or Ethernet                              |
4. Other applications
Many applications of ocean observation can benefit from SIA.

4.1. Underwater Wireless Sensor Network

Wireless sensor networks have encountered great difficulties when implemented underwater[14]. The SIA meets the need of underwater wireless sensor networks and its capability can be expanded to implement the latest acoustic technology of networking, positioning and timing[15]. It can be used as an access point in the underwater wireless sensor network, enabling the traditional instruments to access the wireless network. And, the SIA connected to the seafloor observatory can act as a gateway to provide communications to the nearby access points.

4.2. Cooperative sensing

Because of the communication delay, it is difficult to achieve real-time manipulation of the instruments on the underwater wireless sensor network. If the host loses connection with the underwater instruments, the important data may be lost.

These SIA-enabled instruments can interact with each other, so that they can cooperate to achieve one goal. Based on the concept of swarm intelligence[16], many individuals with small intelligence can interact to find the best answer[17].

In the case of the ocean observatory system, a SIA-enabled AUV can require relevant observation from nearby SIA-enabled instruments. These instruments can response the needed parameters along with their locations, and then the AUV can adjust the moving direction and finally locate the special event, such as algal blooms to be detected.

Another example comes that when an earthquake is detected by a SIA-enabled instrument, it can notify other relative instruments to speed up the sampling, so that scientists can get more valuable data about this event.

5. Conclusion

The paper has proposed a capable smart sensor interface module for ocean observatory system to address the challenge of integration of various traditional ocean instruments. Comparing to the PUCK solution, the capability of the SIA is considered to provide more possibilities for ocean observation. Many applications can benefit from the feature of distributed intelligence, and the SIA promises ocean observatory a simpler and more robust design.

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Acknowledgments
This work was supported by Shanghai science and technology innovation action plan fund through project 16DZ1205000 “Research on the power system of large-scale scientific cabled seafloor observatory networks”.