

Service-oriented Sensor Data Interoperability for IEEE 1451 Smart Transducers

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Abstract- This paper describes a service-oriented sensor data interoperability architecture for Institute of Electrical and Electronics Engineers (IEEE) 1451 smart transducers. A sensor data interoperability prototype system based on the proposed architecture is presented. A case study of reading sensor data is provided to illustrate sensor data interoperability between the IEEE 1451 smart transducers and Open Geospatial Consortium - Sensor Web Enablement (OGC-SWE) Web services through the Smart Transducer Web Services (STWS).

Keywords: IEEE 1451.0, Interoperability, NCAP, Sensor, Service-oriented Architecture, Smart Transducers, SOA, SOS, STWS, TEDS, TIM, OGC-SWE, Web services.

I. INTRODUCTION

Sensor applications are deployed everywhere, such as industrial automation, process control, aerospace, automotive, manufacturing, health care, smart appliances, intelligent transportation systems, environment monitoring, and homeland security. Sensors and networks are key components in building distributed sensor networks for protecting critical infrastructure, such as airports, bridges, buildings, railways, utility, and water supplies [1]. Fast and easy access to this critical sensor-based data and information enable important and timely decisions to deal with emergency situations. Therefore, sensor data interoperability is very important in facilitating effective exchange and sharing of sensor data among government agencies and relevant organizations.

Service Oriented Architecture (SOA) is an architecture for the development of loosely coupled distributed applications [2]. Using SOA, highly interoperable application services can facilitate platform-, operating-system-, and language-independent interoperability among software applications. Web services are the standard-based way to realize SOA. Web services are software systems designed to support interoperable machine-to-machine interaction over a network [3]. This interoperability of Web services is achieved through a set of Extensible Markup Language (XML)-based open standards, such as Web Services Description Language (WSDL), Simple

Object Access Protocol (SOAP), and Universal Description, Discovery, and Integration (UDDI). The Web Services Interoperability (WS-I) organization is an open industry-based organization committed to promoting interoperability among Web services based on common, industry-accepted definitions and related XML standards support [4]. Therefore, SOA and Web services provide a set of good solutions for sensor data interoperability.

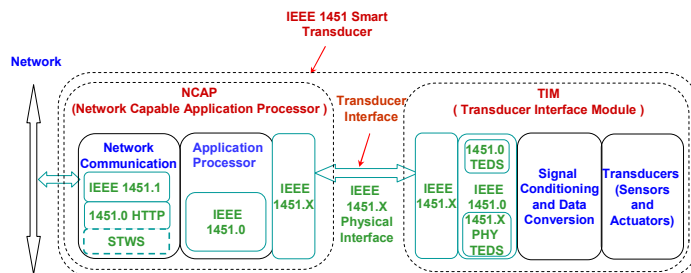


Fig. 1. IEEE 1451 smart transducer.

A smart transducer is the integration of sensor or actuator elements, a processing unit, and a communication interface [5]. An Institute of Electrical and Electronics Engineers (IEEE) 1451 smart transducer provides functions beyond those necessary for generating a correct representation of a sensed or controlled quantity. This functionality typically simplifies the integration of the transducer into applications in a networked environment [6]. In IEEE 1451, a transducer is defined as a sensor or actuator. Figure 1 shows an IEEE 1451 smart transducer, which consists of the Network Capable Application Processor (NCAP), Transducer Interface Module (TIM), and a transducer interface between the NCAP and TIM [7]. The NCAP is the hardware and software that provides the gateway function between the TIMs and the user network or host processor. The NCAP consists of an application processor capable of network communications. The TIM is a module that contains the transducers (sensors and actuators), signal conditioning, analog-to-digital and/or digital-to-analog conversion, transducer interface and a set of Transducer Electronic Data Sheets (TEDS). The IEEE 1451 family of

standards defines a set of common communication interfaces for connecting smart transducers to microprocessor-based systems, instruments, and networks in a network-independent environment [8]. As shown in Figure 1, three network communication interfaces can be used to access IEEE 1451 smart transducers: the IEEE 1451.1 communication protocols [9], IEEE 1451.0 Hypertext Transfer Protocol (HTTP), and the proposed Smart Transducer Web Services (STWS) developed at the National Institute of Standards and Technology (NIST) based on the IEEE 1451.0 standard [10, 11]. The IEEE 1451.0 standard defines a common set of commands, TEDS formats, and communication protocols for the IEEE 1451 family of standards [6]. The interface between the NCAP and TIM defines the IEEE 1451.X physical interfaces, where X is 2, 3, 5, or 7. The NCAP controls the TIM by means of the interface which can employ either a wireline or wireless medium.

This paper focuses on service-oriented sensor data interoperability for IEEE 1451 smart transducers using STWS. Section II describes related work. Section III shows a proposed architecture of service-oriented sensor data interoperability. Section IV presents a sensor data interoperability prototype system with a case study of reading sensor data in order to test sensor data interoperability between IEEE 1451 smart transducers and Open Geospatial Consortium - Sensor Web Enablement (OGC-SWE) sensor applications.

II. RELATED WORK

Earlier SOAs include the Distributed Common Object Model, Common Object Requesting Broker Architecture, and Enterprise Java Beans¹. These remote invocation architectures need protocols, such as Remote Procedure Call, Internet Inter-ORB Protocol, and Remote Method Invocation. These protocols typically require a tight-coupling relationship between a client and server. However, Web services require a loose-coupling relationship between the client and service. Web services are a standard-based SOA through the Web. One of the key benefits of Web services is interoperability that allows different distributed Web Services (applications) running on a variety of platforms to communicate with each other and share data through the Internet.

The Sensor Web is a new class of Geographic Information System, developed at the National Aeronautics and Space Administration Jet Propulsion Laboratory, consisting of a sensor network for environmental monitoring and control [12]. Sensors are able to return their location information as well as observations and measurements via the Internet. The missing element for the Sensor Web is a universal framework for describing and tasking sensors in XML [13]. Thus the OGC-

SWE members have developed and tested the following specifications: Observations & Measurements (O&M), Sensor Model Language (SensorML), Transducer Markup Language (TML), Sensor Observation Service (SOS), Sensor Planning Service (SPS), Sensor Alert Service (SAS), and Web Notification Services (WNS) [14]. By combining IEEE 1451, which moves data from transducers to a network, with OGC-SWE, which moves data from network to applications, a bridge between them, such as STWS, is needed to move data from transducers to applications in a seamless manner [1]. The Web services based on the IEEE 1451.1 standard are described in the references [15-16]. The STWS based on the IEEE 1451.0 standard and SOA are unified Web services for IEEE 1451 smart transducers [10, 11]. Therefore, the STWS provide a solution for achieving seamless sensor data interoperability between the IEEE 1451 smart transducers and OGC-SWE.

III. ARCHITECTURE OF SERVICE-ORIENTED SENSOR DATA INTEROPERABILITY FOR IEEE 1451 SMART TRANSDUCERS

A. Architecture of Service-oriented Sensor Data Interoperability for IEEE 1451 Smart Transducers Through STWS

Figure 2 shows the architecture of service-oriented sensor data interoperability for IEEE 1451 smart transducers through the STWS. This architecture consists of three layers: sensor layer, sensor Web service layer, and sensor application layer:

- The sensor layer includes a number of IEEE 1451 TIMs. Each TIM consists of a number of sensors and actuators, and a signal conditioning, data conversion, IEEE 1451.0 TEDS, IEEE 1451.0 transducer service, and IEEE 1451.X communication module.
- The sensor Web service layer consists of a number of IEEE 1451 NCAPs, which are STWS providers. Each NCAP includes a STWS, IEEE 1451.0 transducer service, and IEEE 1451.X communication module.
- The sensor application layer includes different sensor applications, e.g., sensor alert application.

This architecture also consists of two interfaces among the three layers: the STWS interface and IEEE 1451.X physical interface.

The STWS consumers, or sensor applications, can find the STWS deployed and invoke the STWS through SOAP/XML messages. The STWS consumer sends a sensor data request to the STWS provider. The STWS provider receives the request, invokes the IEEE 1451.0 transducer service, and communicates with a TIM for sensor data via the IEEE 1451.X communication module. When the TIM gets the request, the sensor data from the specified transducer channel is read, and is sent to the STWS provider (NCAP). Finally, the STWS provider sends the sensor information back to the STWS

¹ Commercial equipment and software, many of which are either registered or trademarked, are identified in order to adequately specify certain procedures. In no case does such identification imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

consumer using SOAP/XML messages.

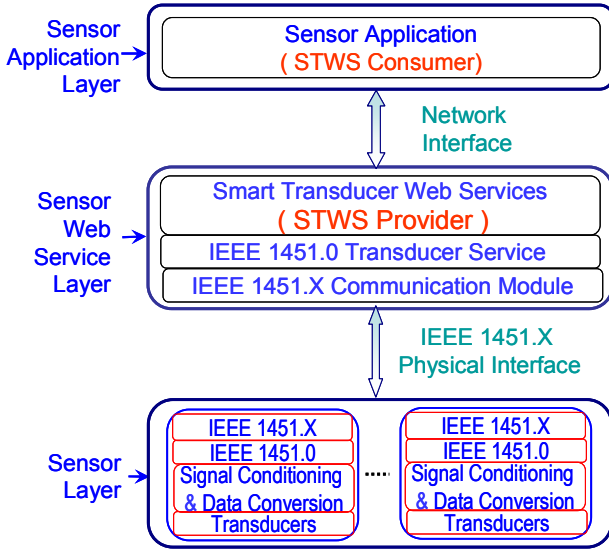


Fig.2. Architecture of service-oriented sensor data interoperability for IEEE 1451 smart transducers.

B. STWS - A Unified Web Service for IEEE 1451 Smart Transducers

Figure 3 shows that the STWS work as a unified Web service for IEEE 1451 smart transducers in three different manners as follows:

- The STWS works as a separate Web service module, which is a bridge between IEEE 1451 smart transducers and sensor applications.
- The STWS is integrated into a NCAP. It serves as a Web service interface for a sensor network based on IEEE 1451 standards.
- The STWS is integrated into an IEEE 1451 smart transducer, which has a Web service interface.

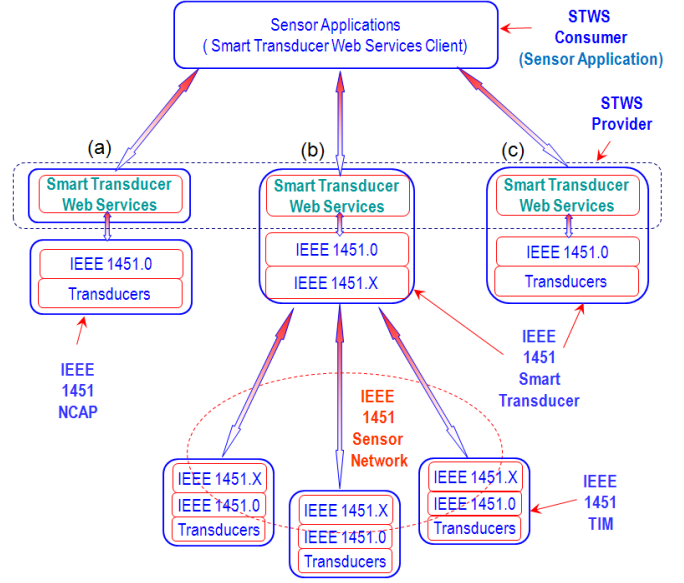


Fig.3. STWS- A unified Web service for IEEE 1451 smart transducers.

C. WSDL-based STWS Interoperability

Figure 4 shows an example of WSDL-based STWS interoperability. The STWS have been defined using WSDL based on the IEEE 1451.0 standard. The STWS provider can be generated from the WSDL file using Web service development tools, such as NetBeans. After that, the STWS Web service can be implemented and deployed. Meanwhile, STWS consumers can be generated from the STWS Web reference using different programming languages, such as Java, C#, or C++. The STWS consumers can be bound to the STWS provider with SOAP and then invoke the Web services of the STWS through SOAP/XML messages. Consequently the STWS consumer can interoperate with the STWS provider. The STWS consumer could be any sensor application, such as Open System Architecture - Condition-Based Maintenance/ Machinery Information Management Open Systems Alliance [19], OGC-SWE sensor applications [20], and other sensor applications. Therefore, these sensor applications can interoperate with the IEEE 1451 smart transducers through the STWS based on the WSDL of the STWS.

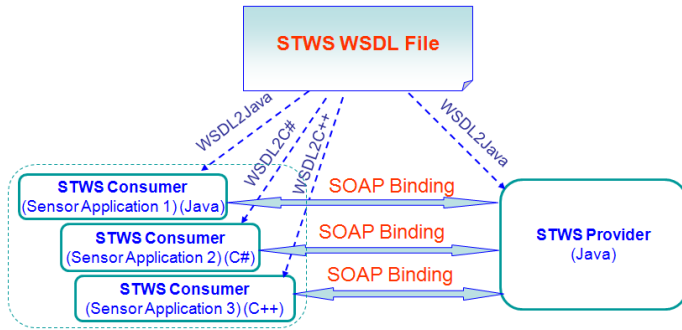


Fig.4. WSDL-based STWS interoperability.

IV. A PROTOTYPE SYSTEM OF SERVICE-ORIENTED SENSOR DATA INTEROPERABILITY

A. Prototype Service-oriented Sensor Data Interoperability System

The OGC-SWE framework provides interoperability among disparate sensors and sensor applications. The OGC Web Services, Phase 5 (OWS-5) Testbed was an initiative of OGC's Interoperability Program to collaboratively extend and demonstrate OGC's baseline for geospatial interoperability [21]. The SWE thread of the OWS-5 initiative shown in Figure 5 mainly focused on the integration of IEEE-1451 smart transducers and the OGC-SWE SOS. The STWS works as a bridge between IEEE 1451 smart transducers and the OGC-SWE SOS.

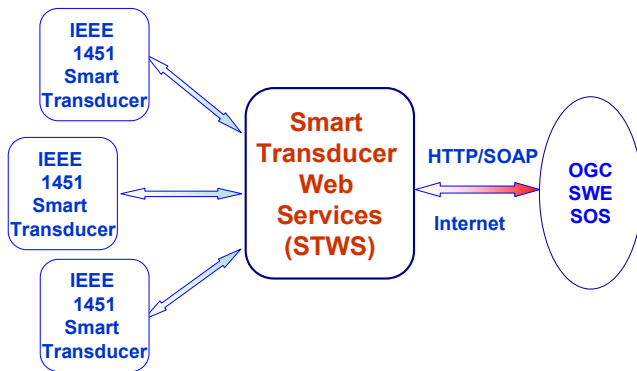


Fig. 5. Integration of IEEE-1451 smart transducers and OGC-SWE SOS through STWS.

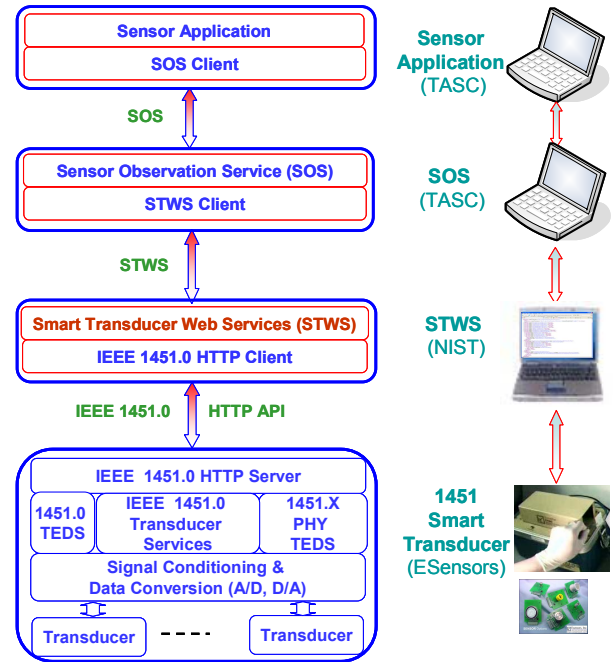


Fig. 6. Prototype service-oriented sensor data interoperability system

Figure 6 shows a prototype service-oriented sensor data interoperability system. The system consists of a sensor application (SOS client) and a SOS module at The Analytical Science Corporation (TASC) of Northrop Grumman, a STWS at NIST, and an IEEE 1451 smart transducer at Esensors. In this case, the STWS works as an independent module, which is separated from the IEEE 1451 smart transducer. The sensor application and SOS module in a TASC computer located in Virginia communicate with the STWS computer located in Maryland via the Internet. Similarly, the STWS accesses the IEEE 1451 smart transducer located in Buffalo, New York via the Internet using the IEEE 1451.0 HTTP protocol. This configuration is chosen to demonstrate remote distributed measurements.

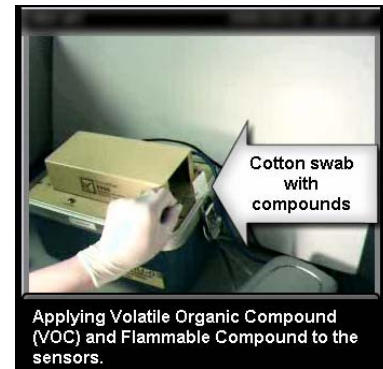


Fig. 7. An IEEE 1451 smart transducer was tested with a volatile organic compound.

B. IEEE 1451 Smart Transducer

Figure 7 shows an IEEE 1451 smart transducer - Environmental Monitoring Unit (EMU), which is used as an early-warning system to detect hostile or hazardous gas levels [23]. The EMU consists of up to six sensors, such as volatile organic compound (VOC) sensor and flammable compound sensor (FLM). The EMU, which combines the function of an IEEE 1451 NCAP and TIM, is a Web-enabled, IEEE 1451.0-based smart transducer.

C. STWS

The STWS described in WSDL consists of a set of Web services such as TimDiscovery, TransducerDiscovery, ReadTransducerData, ReadGeolocationTEDS, and ReadTimMetaIDTeds services [10-11]. The STWS communicates with IEEE 1451 smart transducers through the IEEE 1451.0 HTTP protocol.

D. OGC-SWE SOS

The OGC-SWE SOS Interface Standard provides an application programming interface (API) for managing deployed sensors and retrieving sensor data, specifically observation data [24]. The SOS has three mandatory operations: GetObservation, DescribeSensor, and GetCapabilities. The GetObservation operation provides access to sensor observations and measurement data via a spatio-temporal query that can be filtered by phenomena. The DescribeSensor operation retrieves detailed information about the sensors that make those measurements and the platforms that carry the sensors. The GetCapabilities operation provides the approaches to access SOS service metadata. The OGC-SWE SOS including a STWS client communicates with the STWS through a STWS client. The OGC-SWE SOS is implemented in Microsoft .Net at TASC.

D. Sensor Application

The sensor application could be any application, such as environmental monitoring and sensor alert application. In this case, the sensor application is an OGC-SWE SOS client. The sensor application communicates with the OGC-SWE SOS through the SOS client.

E. Case Study of Reading Sensor Data

The functionalities of the prototype system include TIM discovery, transducer discovery, reading of the TIM Meta ID TEDS, reading of the Geolocation TEDS, and the reading of

transducer data [22]. In this paper, a case study of reading transducer data is discussed in detail to validate one of the functionalities. The OGC-SWE SOS client can invoke the GetObservation service of the SOS, which can discover sensors using the TimDiscovery and TransducerDiscovery services and locate sensor position using the GeolocationTEDS service. It also can remotely read sensor data using the ReadTransducerData service. The STWS receives the sensor reading request from the SOS through the STWS client, and sends a sensor reading request to IEEE 1451 smart transducer using IEEE 1451.0 HTTP protocol. The IEEE 1451 smart transducer receives the sensor reading request, reads the sensor data from the specified transducer channel, and then sends the sensor data back to the STWS, which in turn sends the sensor data back to the SOS. Ultimately the SOS client receives the sensor data from the SOS.

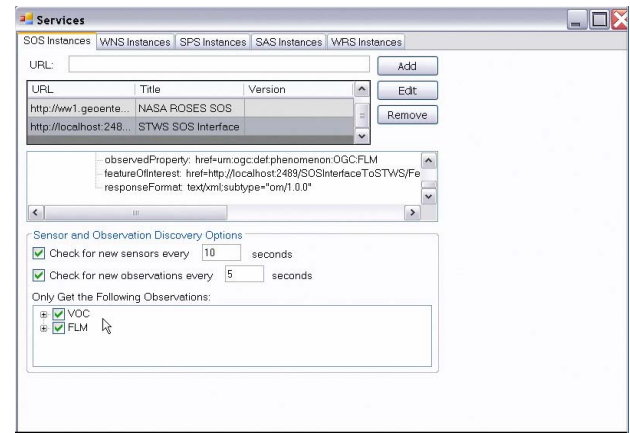


Fig. 8. Screenshot of a request for reading sensor data.

Figure 8 shows a screen shot of a request to the SOS client for reading sensor data, which includes the VOC and FLM sensors. Figure 9 shows a screen shot of the SOS client with a VOC sensor reading of 735.692.

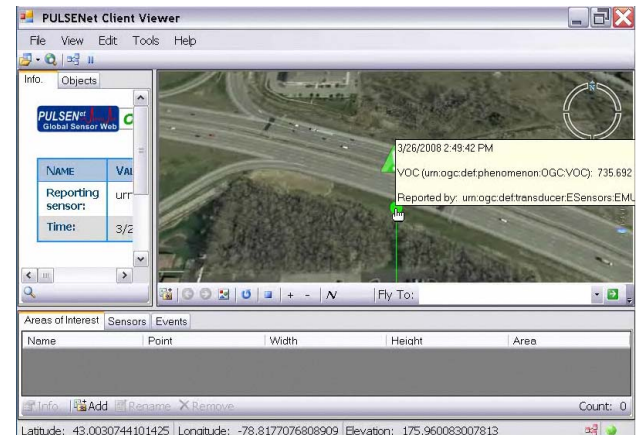


Fig. 9. Screenshot of a response of reading sensor data.

V. CONCLUSION

An service-oriented sensor data interoperability architecture for IEEE 1451 smart transducers was introduced. A prototype system and a case study were presented to show sensor data interoperability of the IEEE 1451 smart transducers with OGC-SWE SOS sensor applications through the STWS. The STWS provides a unique solution to help achieve service-oriented sensor data interoperability of IEEE 1451 smart transducers with any sensor application because it is based on the IEEE 1451.0 and service-oriented architecture. In the future, we plan to apply the STWS to more sensor applications and further explore sensor data interoperability.

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