SENSOR STANDARDS HARMONIZATION – PATH TO ACHIEVING SENSOR INTEROPERABILITY

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Abstract – Distributed sensor networks are emerging technology for building applications in control and condition monitoring of equipment and machinery in government and industry. Open sensor interfaces, standard sensor data formats, and messaging standards are needed to enable the integration, access, fusion, use, and delivery of sensor-derived data for these applications. The Sensor Standards Harmonization Working Group was formed at NIST to address these types of issues. This paper examines some relevant open standards that can help to achieve seamless sensor connections, integration, discovery, access, and usage within and across systems, networks, and enterprises through the Web.

Keywords: CBM, condition-based maintenance, interoperability, open standards, sensor interface, sensor network, sensor standards, sensor standards harmonization, wireless sensor.

INTRODUCTION

Sensors are ubiquitous. They are used in a variety of applications that touch people's lives everyday, ranging from industrial automation to machinery condition monitoring to intelligent transportation systems to homeland defense. These and many other sensor applications are fast moving toward using standardized digital, networked, and wireless communications technologies for distributed measurement and control purposes [1]. Examples are plentiful, such as the US Navy exploring thousands of networked and wireless sensors in naval vessels to reduce manning, enhance automation, and achieve effective condition-based maintenance (CBM) [2]; airplane manufacturers using networked and wireless sensors systems to lower operational and lifecycle costs; and homeland security organizations applying networked and wireless sensors for remote monitoring and situation awareness. All these and other examples are seeking open standards solutions. An open standard is a standard that is developed based on consensus and public availability, and has various rights to use associated with it.

Because of the diversity of sensor system and network requirements and the need to accommodate unknown future systems, information networks for these and other sensor applications must be able to support heterogeneous, multi-vendor networks. Thus, a framework for interoperability is needed to accommodate these systems and networks. Without open, standardized interfaces and data formats to guide developers in building systems and networks that can effectively and rapidly discover, access, integrate, fuse, and use sensor-derived data, it will be impossible to connect such a wide variety of sensors and networks and communicate the sensor information in an effective and timely manner. Hence, a coherent framework of open, consensus-based standards is needed to connect many sensor networks into a large network.

OPEN SENSOR STANDARDS

The open sensor interface standards developed by the Institute of Electrical and Electronics Engineers (IEEE), such as the IEEE 1451 suite of standards [3], provide ways to interface transducers (sensors or actuators) to networks, systems, and instruments. The goal of the standards is to achieve sensor-to-network plug-

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and-play and interoperability. Meanwhile, the Sensor Web Enablement (SWE)** specifications [4,5] developed by the Open Geospatial Consortium (OGC) provide methods for sensor discovery and control based on the OGC's framework for geo-processing. Simply speaking, the IEEE 1451 standards deal with sensor information from the physical sensors to the network, while, SWE takes the sensor information from the Web and brings them into geospatial-type applications [6].

IEEE 1451

The trends toward digital, network, and wireless communications have enabled engineers to simplify sensor system design by eliminating high-maintenance, analog wiring for sensor connections. The use of low-cost microprocessors for sensor applications has opened the opportunity for adding intelligence to sensors. However, without standardized interfaces, sensor-network interoperability is not possible. In addition, sensor integration becomes an exercise of custom interface design for each application. It is a time-consuming effort and is not the optimal approach for sensor users and manufacturers to utilize resources. Hence, the IEEE 1451 smart transducer interface standards were established for sensor and actuator connectivity.

The IEEE 1451 is a set of open communication interfaces that accommodates transducer connectivity to networks with support for multiple sensor connection configurations including wired and wireless means. The conceptual diagram of IEEE 1451 is shown in Figure 1. IEEE 1451.0 [7,8] provides a common set of commands for sensor module discovery and access. The sensor module, defined as Transducer Interface Module (TIM), is based on the concept of "plug-and-play" smart transducers. A smart transducer is defined as a transducer that has enough descriptive information associated with it that the information can be used by a processor through a standard interface to automatically determine the transducer's characteristics and operating parameters. The descriptive information is called "Transducer Electronic Data Sheets" or TEDS, which is equivalent to the paper data sheet that contains sensor type, measurement range, and calibration data and user information. However, in this case, the data sheet is in an electronic format stored in an Electrically Erasable Programmable Read-Only Memory (EEPROM). Upon power up, the TEDS is first sent to the network for self-identification. The TEDS enables the TIM to plug-and-play with the Network Capable Application Processor (NCAP). As a node on a network, the NCAP can perform TIM discovery and access sensor and actuator data and sensor characteristic information, process them, and pass them onto the network for client consumption. The IEEE 1451 suite of standards define a common TEDS and a set of commands for transducer access via various IEEE 1451.x physical interfaces: wireless, serial, and multi-drop.

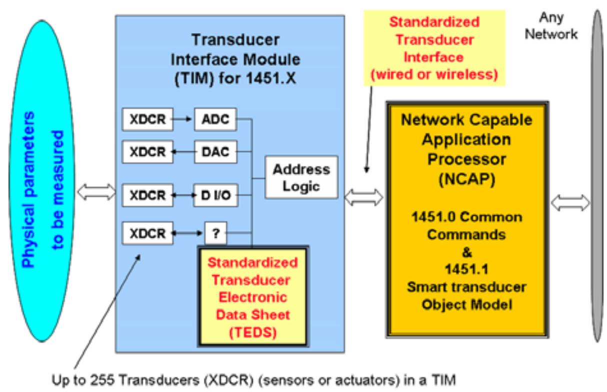

Figure 1. Conceptual Diagram of IEEE 1451

Sensor Web Enablement (SWE)

There are some sensor networks in the market that take advantage of the Web, a widely used open standards infrastructure. However, the lack of standards at this level for sensor description, data messaging, and sensor location has resulted in non-interoperable Web-based sensor networks. The OGC has established an open platform for exploiting Web-connected sensors and devices such as environment monitors, flood gauges, Webcams, and satellite-borne earth imaging devices. The SWE concept is shown in Figure 2.

As shown in Figure 3, OGC has adopted IEEE 1451 as its sensor infrastructure for retrieving sensor information from the network and providing this information to applications using the Web. Essentially, the OGC Sensor Web Enablement makes sensors accessible to clients over a network through the IEEE 1451 Network Capable Application Processor.

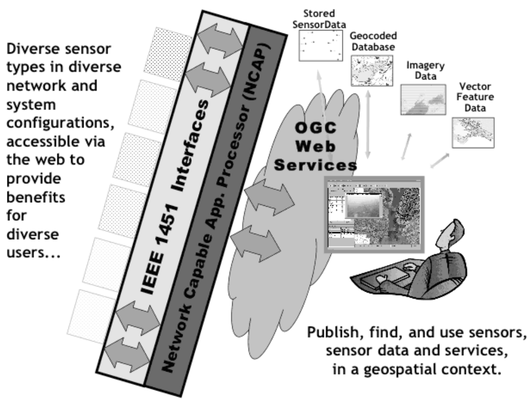

Figure 2. Concept of Sensor Web Enablement

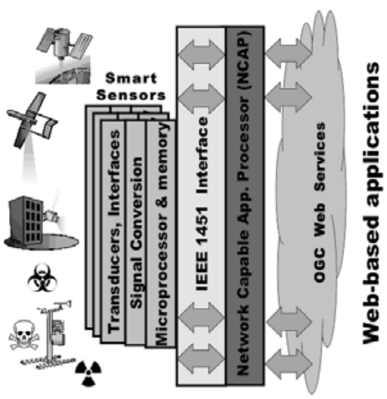

Figure 3. OGC Sensor Web Services Interface with IEEE 1451

The Web provides a wide range of capabilities such as publishing and discovery, vendor neutrality, an environment for distributed computing and service-oriented architectures. SWE is built on sensor Web services. It is based on the concept that sensors are Web accessible, sensors and sensor data are discoverable, sensors can self-describe to humans and software, and sensor observations can be easily accessible in a timely manner over the Web. The SWE framework involves several OGC encoding and service specifications designed for general geospatial uses with the following specifications specifically related to sensors:

- Two schema specifications: OpenGIS® SensorML (models and schema for describing sensor characteristics) and OpenGIS Observations & Measurements (O&M) (models and schema for encoding sensor observations)
- Two service specifications: Sensor Observation Service (access sensor information encoded in SensorML and sensor observations encoded in O&M) and Sensor Planning Service (task sensors or sensor systems).

Sensor Markup Language (SensorML)

SensorML provides standard models and an eXtensible Markup Language (XML) encoding for describing any process, including the process of measurement by sensors and instructions for deriving higher-level information from observations. The processes described in SensorML are discoverable and executable. All processes define their inputs, outputs, parameters, and methods, and they provide relevant metadata. In a nutshell, SensorML models detectors and sensors as processes that convert real phenomena to data.

Transducer Markup Language (TML)

TransducerML, or TML, is a digital data structure that permits streaming of sensor data. It is used to exchange data between a sensor and a processor. TML is an XML-based specification that describes how to capture and time tag sensor data. It also includes a complete description of the data. Since TML is self-contained, a TML-enabled processor is able to process data from any sensor without any additional information. Since no single data format exists to handle all sensors, TML thus provides a standard data format for sensors so that data exchange between different types of sensors is possible.

Common Alerting Protocol (CAP)

The Common Alerting Protocol (CAP) was developed by the *Organization for the Advancement of Structured Information Standards (*OASIS). The purpose of CAP is to develop a simple and standardized format for exchanging alerts and warnings over various types of networks. It is compatible with legacy and emerging "transport" methods such as Web Services.

Emergency Data Exchange Language (EDXL)

The goal of Emergency Data Exchange Language (EDXL) is to facilitate emergency information sharing and data exchange across the local, state, tribal, national and non-governmental organizations of different professions that provide emergency response and management services. These emergency messages will utilize standardized data content. The EDXL Distribution Element (DE) is the metadata for distributing the XML content. The message content could be that generated by CAP and sensors.

Sensor Data Model

Due to the diversity of sensor system and network requirements for existing sensors and detectors, and future sensors and systems, information networks must be able to support heterogeneous, multi-vendor networks. Thus, a framework for interoperability is necessary to accommodate these systems and networks. Furthermore, a framework of open, consensus-based standards is needed to connect many sensor networks into one large network. Work is being conducted to develop a common sensor data model that is based on a common configuration of sensors and common sensor data specification. The data can be accessed via the Web based on a sensor XML schema. The CBRN sensor data model leverages existing standards such as SensorML, IEEE 1451, CAP, and EDXL discussed above for reuse and mapping, and it supports Web Service Interoperability (WS-I) [9]. All sensor data that can be transmitted, received, and stored must use the sensor data model as the basis for data representation.

IEEE 1451 Web Service Interface

The IEEE 1451.0 standard provides three possible ways to access IEEE 1451 sensors via a network: IEEE 1451.1, IEEE 1451.0 HTTP (Hypertext Transfer Protocol) protocol, and a proposed Smart Transducer Web Services (STWS) [10]. Figure 4 shows the IEEE 1451 interfaces to the network and Figure 5 shows an implementation of IEEE 1451.0 and IEEE 1451.5 wireless sensors applying the IEEE 802.11 protocol [11]. The main goal of the proposed STWS is to help achieve seamless standard-based transducer applications interoperability. IEEE 1451 takes the Web services approach of WS-I, which provides standard-based interoperability solutions for Web services. Web services client access to IEEE 1451 transducers is shown in Figure 6. For IEEE 1451.0, interoperability is provided via the definition of STWS in the Web Service Definition Language (WSDL). The STWS based on the IEEE 1451.0 standard have been defined using WSDL. A Web service provider can be generated from the WSDL file using service development tools in Java or other programming languages. On the other hand, a Web service consumer also can be generated from the developed WSDL file in different programming languages, such as Java, C#, or C++. Web service consumers, such as sensor alert systems, OGC-SWE, or sensor applications, implemented in Java, C#, or C++, can interact with the Web service providers using STWS based on WSDL through Service-Oriented Architecture Protocol (SOAP) /XML messages.

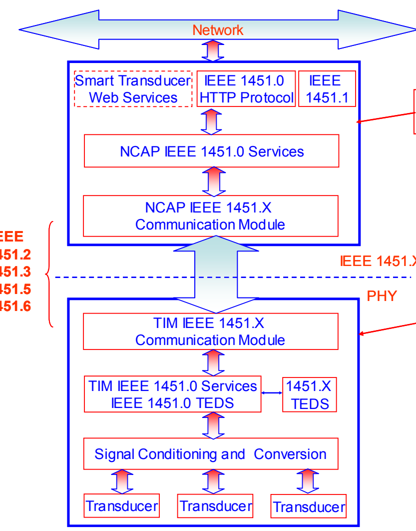

Figure 4. IEEE 1451 Interfaces to the Network.

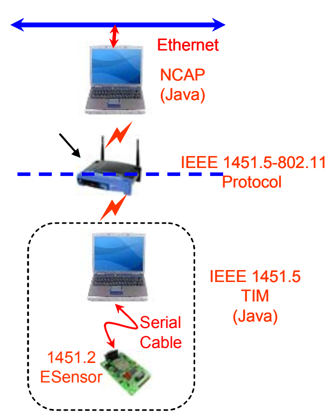

Figure 5. Implementation of Wireless Sensors.

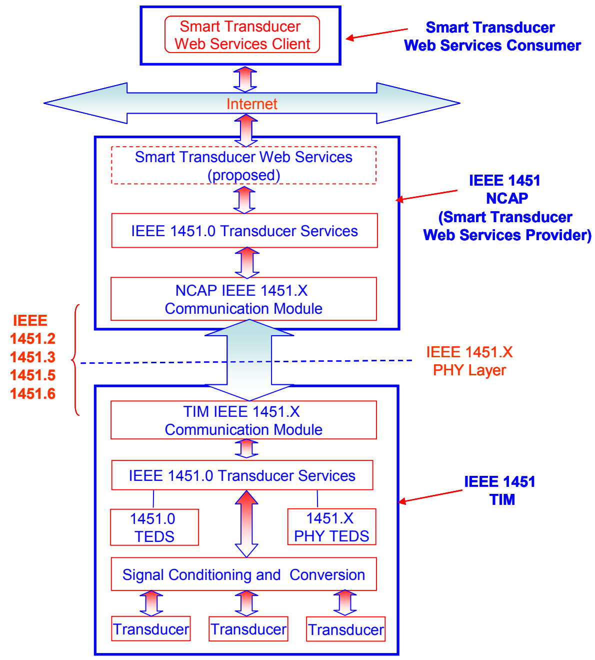

Figure 6. Client Access to IEEE 1451 Transducers via Web Services.

NETWORKED SENSOR APPLICATION IN CONDITION-BASED MAINTENANCE OF MACHINES

The IEEE 1451 is based on a distributed architecture, which means intelligence is decentralized and is pushed down to the sensor module level. This arrangement is well suited for remote control and monitoring applications, such as equipment automation and condition-based maintenance (CBM), respectively. Machinery condition and health could affect machine performance and remaining life. Machinery Information Management Open Systems Alliance (MIMOSA) was organized to establish an open architecture and a set of protocols for exchanging complex sensor information between Condition-Based Maintenance (CBM) systems. Similarly the Open System Architecture for Condition Based Maintenance (OSA-CBM) program, which is associated with MIMOSA specifications, aimed to develop an open architecture and standard for distributed CBM software components.

However, neither the MIMOSA nor the OSA-CBM specification defines a sensor interface and communication protocols for acquiring sensor data. The missing link is the IEEE 1451 smart transducer interface standard, which can play a key role in completing the process from the acquisition of data at the sensor level to the transfer of the sensor information to the enterprise level, where MIMOSA and OSA-CBM are set up to manage the information. It was determined that it is feasible to establish a link between the IEEE 1451 standard and MIMOSA and OSA-CBM architecture [12]. The OSA-CBM data model can be readily used as the *entry points* for the interfacing requirements of an IEEE 1451.1 NCAP as shown in Figure 7.

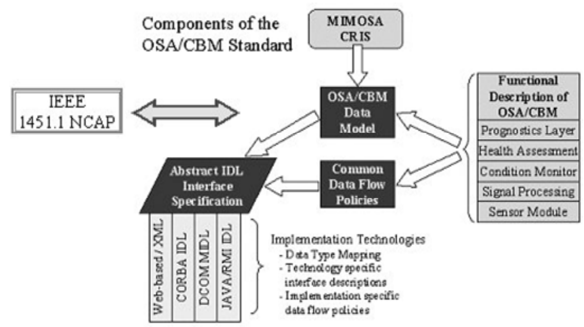

Figure 7. Conceptual link between IEEE 1451 and MIMOSA/OSA-CBM system.

With the wide availability of the Web, any sensor connected to a wired or wireless network can be accessed anywhere via the network or Internet. This will greatly enhance the effectiveness and application of machinery health maintenance. An application model of IEEE 1451 is shown in Figure 8. In this model, three NCAP/TIM combinations are used to illustrate how IEEE 1451 can be used. In case one, sensors and actuators are each connected to a TIM, which is then connected to NCAP #1. Application software running in the NCAP can perform a localized control function, such as maintaining a constant temperature or spindle speed. The NCAP reports process information and control status to a remote monitoring station or host. It frees the host from the processor-intensive, closed-loop control operation. In case two, NCAP #2 is connected to a TIM with sensors. It can perform remote process or condition monitoring function; for example, monitor the vibration level of a set of bearings in a turbine. In case three, based on the broadcast data received from NCAP #2, NCAP #3 activates an alarm when the vibration level of the bearings exceeds a critical setpoint. In case four, communications between NCAPs are supported by the client-server or publish-subscribe communication method. This provides an environment that supports intelligent collaborative measurement and control functions among a group of NCAPs.

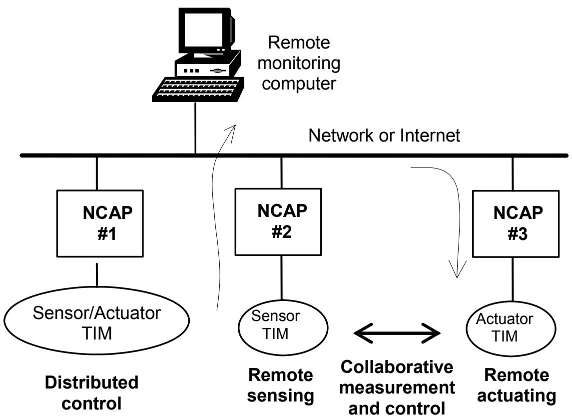

Figure 8. Application Model of IEEE 1451-based Sensor Network.

Figure 9. Application of IEEE 1451 for remote monitoring of machine conditions.

Based on the IEEE 1451 application model, an application of the IEEE 1451 networked sensor standards and technology is implemented for remote condition monitoring of a machine. The machine and sensor network components are shown in Figure 9. The machine condition monitoring system consists of four sets of IEEE 1451-based Ethernet network nodes, temperature sensors, accelerometers, Ethernet hub, and power supplies. The network nodes, consisting of NCAP and STIM modules and related hardware, were integrated into a protective cabinet for day-to-day operation in a production machine shop environment. Sensors were strategically placed on some key components of the machine such as spindle bearings and axis motors as illustrated in Figure 10. Web capability was developed for remote monitoring of the sensors via the Ethernet and Internet using a common Web browser. A trend chart displaying the temperatures of the vertical spindle (top trace) and Z-axis drive (bottom trace) motors over a 24-hour period is shown in Figure 11.

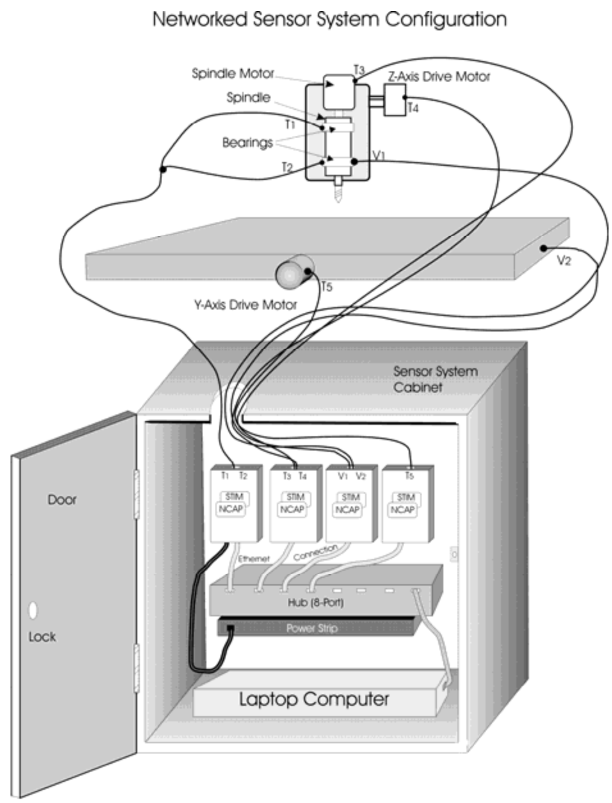

Figure 10. Configuration of the machine condition monitoring system.

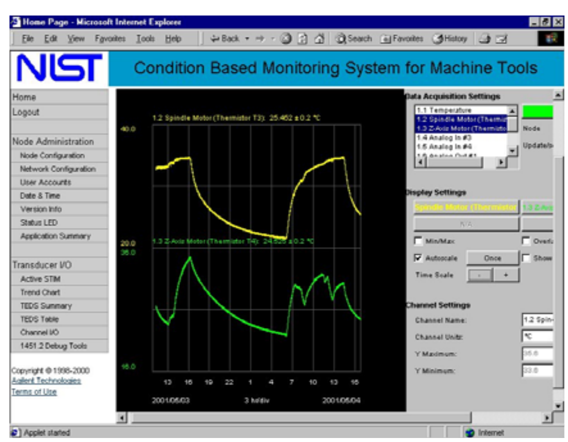

Figure 11. Web display of the temperatures of machine spindle and axis drive motors.

HARMONIZATION OF SENSOR STANDARDS

As sensor network complexity grows and the need to access sensor or sensor-derived information via the network or the Web, a standardized approach may be the only way to achieve globally connected sensor networks in an economic and effective manner. However, there are many existing and emerging standards which are sensor-related. They were originally defined by their respective organizations to serve their customers. Even though they are somewhat sensor-centric, they do not necessarily easily interface, or exchange data or messages with each other. Recognizing this problem, a Sensor Standards Harmonization Working Group was formed in December 2005 to meet quarterly at NIST to address this and other sensor harmonization issues. The aim of the group is to provide a forum for industry, academia, and government to exchange information and improve understanding of the various sensor-related standards programs being advanced by various standards development organizations (SDO) and to identify opportunities to frame the harmonization of sensor-related standards to meet the need of the community.

Various approaches were discussed including modifying each standard to work with each other. This will be an enormous task involving different standards organizations and their committees. Another sensor standards harmonization approach is using Semantic Wiki. Semantic Wiki is a platform for building applications with ontology. It could be used as a framework for harmonizing sensor and related standards, and to demonstrate compliance of a particular sensor with a particular standard. The standards involved are discussed above and shown in Figure 12. At this time, it consists mostly of text-based mappings of sensor metadata with the referenced standards. Discussion will continue to further examine the benefits of this approach.

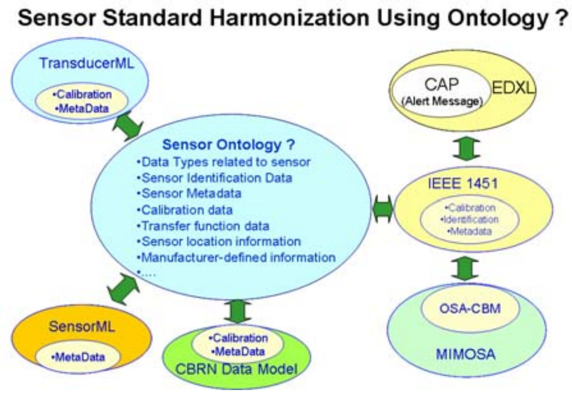

Figure 12. Harmonization of Sensor Standards.

SUMMARY

This paper has presented some approaches to work with open standards to enable seamless sensor interconnection, discovery, access, integration and usage from sensors to networks and to enterprise applications.

Efforts are underway at the Sensor Standards Harmonization Working Group to find ways to harmonize the sensor-related standards, such as IEEE 1451, SensorML, TransducerML, CBRN Sensor Data Model, MIMOSA, and OSA-CBM, to bring sensor data and sensor-derived information to Web-based applications. The feasibility of developing a common data model based on metadata that would allow seamless data exchange to simplify integration was discussed. In addition, the group is exploring ontology as a tool that will identify areas of commonality in these sensor-related standards that can be used to transfer sensor-derived data among various applications or organizations.

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