IEEE 1451.0 Sensor Interoperability Experiment

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I. Motivation

Interoperability is the ability of two or more heterogeneous systems to exchange information and use this data in a reasonable way. For oceanographic data acquisition several approaches exist, how interoperability between different sensor systems can be achieved. A promising interoperability protocol for sensor networks is IEEE 1451.0. Up to now no practical experience exists in using the protocol in the field.

To truly evaluate the use of an interoperability standard it is necessary to really implement it in a demonstration with numerous involved parties and different software implementations of the specification. Only then it is possible to find hidden ambiguities and obstacles that hinder the data exchange in a given specialist area.

An interoperability experiment together with MARUM Bremen, Universitat Politècnica de Cataluny, Monterey Bay Aquarium Research Institute (MBARI) and National Institute of Standards and Technology (NIST) should clarify to what degree IEEE 1451.0 is applicable for oceanographic observations. At the end of the experiment a live demonstration of the system was presented at the Ocean Innovations Workshop in Saint Johns in October 2008. The parties involved in the experiment are shown in figure 1.

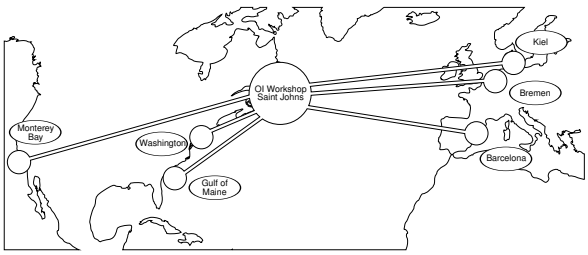

Fig. 1. Parties involved in the interoperability experiment

II. IEEE 1451 Protocol Family

IEEE 1451 is a family of interface standards. It is developed with the aim to access transducer (sensor/actor) data through common open and network-independent communication interfaces. For the user it should not be noticeable whether the transducers are connected directly to a system or accessed via networks – wired or wireless. A key component is the so called *Transducer Electronic Data Sheet* (TEDS) that contains meta data about the transducer including device identification, manufacturer information, calibration curves, measurement ranges etc.

IEEE 1451.0[1] defines common operations for transducers and also protocols how to access transducer data via network using the HTTP. IEEE 1451.0 uses a client/server model. A *Network Capable Application Processor* (NCAP) with one or more *Transducer Interface Modules* (TIM) – these are sensors or actors – attached takes the role of the server. Clients can send requests to the NCAP to retrieve measured values. The server answers with XML documents (figure 2). As an alternative a simpler ASCII format for responses is specified in IEEE 1451.0.

```
<?xml version="1.0" encoding="utf-8" ?>
<TransducerDiscoveryHTTPResponse>
   <errorCode>
      0
   </errorCode>
   <ncapId>
      1
   </ncapId>
   <timId>
      3
   </timId>
   <numberOfChannels>
      3
   </numberOfChannels>
   <channelIds>
      1,2,3
   </channelIds>
   <transducerNames>
      pressure,
      temperature,
      conductivity
   </transducerNames>
</TransducerDiscoveryHTTPResponse>
```

Fig. 2. XML document containing the response of a TransducerDiscovery query

In addition to the IEEE 1451.0 standard the IEEE 1451 family also contains other specifications that describe the communication of transducers connected directly to the NCAP:

- **IEEE 1451.2** – point-to-point connections including RS232, I^2C and USB
- **IEEE 1451.3** – multi-point connections
- **IEEE 1451.5** – wireless communication including IEEE 802.11 (WiFi), IEEE 802.15.1 (Bluetooth) and IEEE 802.15.4 (ZigBee)
- **IEEE 1451.6** – CANopen network interface
- **IEEE 1451.7** – Radio Frequency Identification (RFID) systems

Some of these specifications are still under development or revision. Therefore they were not part of the interoperability experiment in which we only tested the communication between IEEE 1451.0 capable nodes. In the context of this experiment five operations have been evaluated (figure 3).

Module	Operation	Parameters	Task
TimDiscovery	reportTims	NCAP id TIM id	*list of sensors attached to the NCAP*
	reportChannels	NCAP id TIM id Number of channels Channel id Channel name	*list of channels of one sensor*
TransducerAccess	readData	NCAP id TIM id Channel id Transducer data	*read the current measurement value of a channel*
TedsManager	readTeds *(GEO TEDS)*	NCAP id TIM id TEDS type *(=14)* TEDS data	*read the geographic position (latitude, longitude, height) of the sensor system*
	readTeds *(Meta−Id TEDS)*	NCAP id TIM id TEDS type *(=2)* TEDS data	*read vendor, model, version, serial number, description of the sensor system*

Fig. 3. The five operations from IEEE 1451.0 used in the experiment

III. IEEE 1451.0 Server

For the experiment a Java implementation of an IEEE 1451.0 server has been developed in Kiel. It receives IEEE 1451.0 requests via HTTP from clients. If necessary it triggers attached sensors to perform measurements and read the results. Other kinds of sensors constantly report values to the NCAP – in that case it is only necessary to select the latest values. The measured values are prepared and returned to the client in IEEE 1451.0 format. An overview of the system in Kiel is shown in figure 4. Attached to the central NCAP are three TIMs having several *channels* each. The weather station at IfM-Geomar, the weather station at Kiel lighthouse and measured values from a CTD[1] were used as data sources.

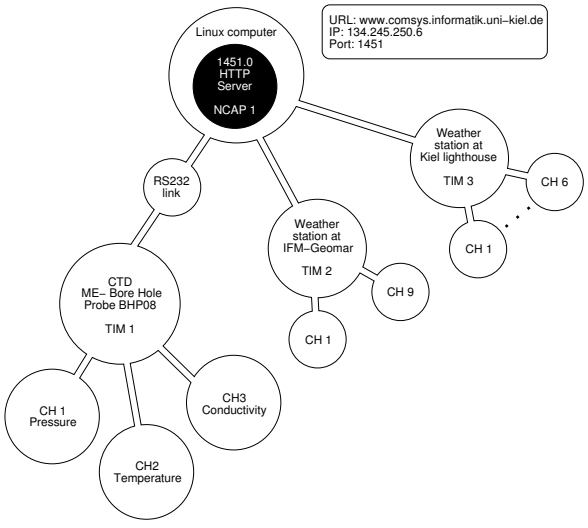

Fig. 4. Overview of the IEEE 1451.0 system in Kiel

[1]a oceanographic instrument measuring conductivity, temperature and depth/pressure

The Java source code for the server developed in Kiel was also used by the partners in Bremen and Barcelona as basis for their software development. They wrote their own code for the communication between NCAP and instruments and the conversion of measured values into IEEE 1451.0 format. MBARI on the other hand used a completely own implementation including the IEEE 1451.0 command interpreter. These parallel developments made it possible to compare different servers and to find and fix software bugs but also helped finding ambiguous text passages in the IEEE 1451.0 specification.

Several IEEE 1451.0 clients written by the participants of the experiment were used to query the various IEEE 1451.0 servers. A simple but quite useful client with a graphical user interface (fig. 5) has been developed in Kiel. It was used frequently during the experiment to check the responses from the servers.

Fig. 5. GUI of the IEEE 1451.0 client

IV. Results of the Experiment

During the experiment, several flaws of IEEE 1451.0 became visible. It appeared that further studies are necessary, for example on how to deal with low bandwidth links and links with discontinued operation – both limitations of satellite links, which are often used in the communication with oceanographic instruments. Other problematic points are the treatment of units of measurement and timestamps for measurements.

This shows how important interoperability experiments are: They help to assess the usability of specifications for the in-the-field use in a given specialist area.

References

[1] IEEE STD 1451.0-2007, Standard for a Smart Transducer Interface for Sensors and Actuators – Common Functions, Communication Protocols, and Transducer Electronic Data Sheet (TEDS) Formats, IEEE Instrumentation and Measurement Society, TC-9, The Institute of Electrical and Electronics Engineers, Inc., New York, N.Y. 10016, SH99684, October 5, 2007.