Interoperability between Domains - Bridging Industrial Control Systems and Geographic Information Systems

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ABSTRACT[1]:
This paper presents the conceptual design and the related implementation of a bidirectional domain interconnection bridging Supervisory Control and Data Acquisition (SCADA) systems and Geographic Information (GI) systems. Due to the numerous common interests and the fact that both realms, SCADA and GIS, have their own central information, namely time-based sensor data and geographical position, a connection between these domains is a benefit for both of them. Therefore, the authors designed and implemented a bidirectional software connector by the use of implementations of the two standards OPC UA and OCG SOS. The presently linked information from a SCADA system can be utilized and further augmented by a GIS, which can then readdress its outcomes to the former and vice versa. The proposed adapter and its components have been validated in a real-world scenario. The data from three different experimental buildings were visualized and exchanged between a SCADA/HMI-System and a GIS using the developed software prototype.

1 INTRODUCTION

A vast amount of data is collected and stored in the process of industrial production. Telemetry is employed to exchange this information - and the necessary commands and programs as well - and to receive monitoring information from local and remote sites. This strategy is already used in a wide variety of industrial branches such as manufacturing, mining, security or leisure. Supervisory Control and Data Acquisition (SCADA) systems comprise these telemetry-based processes as well as data acquisition from sensors within the industrial facility. Based on the gathered data, analyses are carried out and the results are then visually displayed to enable the associated personnel to execute the required actions in due time [1]. However, sensor data do not only feature time-centric facets, they hold location-centric aspects as well (geo-referenced information), which is commonly handled by Geographic Information Systems (GISs). These systems acquire, store, process, analyze and visualize geo-referenced data, which are gained from sensors [2]. GISs can be found in various application domains such as remote sensing [3], water resource management [4], health applications [5], or energy management [6].

Technically speaking, SCADA systems and GI systems, with their respective time-centric and location-centric perspectives, are not intervened *per se* and do operate separately. There are no standardized interfaces between these two domains. However, due to their common data source, namely sensors, various common interests arise. For example, the user of a SCADA system could direct maintenance work in case of a failure detected by the sensors in a pipeline based on the geographic information fetched from a GIS [7].

This paper presents the concept, design and implementation of a software interface connecting production industry and geoinformatics. Namely SCADA Systems and GIS are bridged using standard protocols from both domains. The software adapter translates between the **Openness, Productivity and Collaboration (OPC) Unified Architecture (UA)** [8] for SCADA systems and the **Open Geospatial Consortium (OGC) Sensor Observation Service (SOS)** [9] for GIS.

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After discussing related work in the fields of SCADA and GIS as well as pointing out 'missing links', the sections afterwards focus on the employed communication models, namely *OPC UA* and *OGC SOS*. Then the conceptual design of the developed inter-domain connection and the related prototypical implementation are described on the basis of the data exchange performed through the software adapter. Subsequently, the achieved results are summed up and the paper closes with an outlook on future implementation and standardization work and acknowledges the support given and work done by our partners.

2 RELATED WORK

Over the last years, several research endeavors focused on the integration aspect of SCADA systems and GI systems. Qi et al. [10] explored the benefits of the combination of SCADA systems and GI systems in the realm of distributed network monitoring. The authors argue that existing integration approaches of GIS and SCADA systems often utilize commercial GIS software, which leads to an overhead in terms of license costs and unnecessary functionality. Therefore, they suggest a user interface design that incorporates GIS and SCADA functionalities; however, a major issue still remains present: the interoperability of existing systems. It is rather unlikely that all Small and Medium Enterprises (SMEs) will develop their own software for several reasons: i) the development of a new system introduces additional ii) existing systems that have already be integrated would have to be replaced, and iii) there exists a lack of support and maintenance, normally provided by vendors' specialists.

Kosmac et al. [11] presented a combination of a SCADA system and geo-referenced information, in specific, lighting information of a lighting location system (LLS). The aim was to provide an automated real-time fault localization tool for power lines. However, the authors do not present a clear or detailed description how their components work. Therefore, the presented components and the associated design constitute themselves as black boxes and in consequence remain in a proprietary state.

Alonso et al. [12] focused on simulation of hydraulic models in water distribution systems in GIS and their integration in a SCADA system. The GI system provides the model for the SCADA system, while measurement data from the SCADA system is utilized to calibrate the simulation and the resulting model in the GIS. The authors achieve the desired integration by means of an ArcGIS extension for the GIS domain and EPANET for the SCADA-based simulation control. Again, the issue of interoperability arises. The GIS extension is vendor-specific (Esri) and the main module for controlling the SCADA/EPANET environment is only described as a black box.

Huang et al. [13] developed a system approach to combine a GIS and a SCADA system in order to locate leakage within a pipeline transportation system. The described approach is vague in details and there is no existing description of how to combine GIS and SCADA in general to solve the given problem scenario and beyond.

Wang et al. [14] proposed a vendor-independent Distribution Management System (DMS), which exploits the benefits of the GIS and the SCADA realm. Similar to the research described before, the authors tried to build a whole new system architecture to combine GI systems and SCADA systems. However, their approach introduces a new issue as now the suggested approach features critical dependencies on the type of data-base that is used. A similar issue arises within the work of Soto et al [15]. They built a system to support governmental water support management.

Cavalieri et al. [16] discussed the introduction of a *generalized interface*, which serves as middleware layer in order to access SCADA and GIS capabilities. The overall idea is to present all functionalities of each system component within one architecture. The presented solution is vendor-independent and solves the issue of interoperability of various GISs and SCADA systems. As the communication is XML-based, the issue of the used XML schema arises. If these schemata have to be built specifically for each application scenario, the generic character of the system architecture is lost.

3 STADARTIZATION

The following sections describe the standards OPC Unified Architecture and OGC Sensor Observation Service, which provide the basis for the software implementation.

3.1 OPC Unified Architecture

OPC UA is a standard for machine-to-machine communication protocols in the field of automation technology, developed by the OPC Foundation [17]. Due to the fact that Software Development Kits (SDKs) for the programming languages ANSI C, C\# and Java are available, OPC UA is platform-independent. An implementation of the OPC UA specification typically includes a server and a client, which both consist of three software layers: The *OPC UA Stack*, the *OPC UA Client/Server SDK*, and the *OPC UA Client/Server* [8]. In order to encode messages for transportation, the serialization of data can be either done in binary format or in Extensible Markup Language (XML) format. The implementation for the network protocol can be based on the UA Transmission Control Protocol (TCP), the Hypertext Transfer Protocol (HTTP), or the Simple Object Access Protocol (SOAP). The use of Web services enables the control of facilities and machines that are separated by a geographically large distance. Data models of the OPC UA, or more specifically the address space, are built by nodes and references [17].

3.2 OGC Sensor Observation Service

OGC SOS offers a broad range of interoperability, such as discovering, connecting and querying of sensors, sensor platforms, and sensor networks. Further, it is part of the OGC Sensor Web Enablement (SWE) initiative, launched by the Open Geospatial Consortium (OGC) in order to develop specifications for sensors, their positioning and their communication [9]. OGC itself is dedicated to the development of geospatial standards within the GIS domain [18]. OGC SOS -- one of more than 30 published standards -- represents a Web service, which enables saving descriptions of sensors and their measurement data. In addition, these observations can be queried with optional temporal and spatial filters [9]. By the data exchange format XML, platform independence is enabled [19].

4 BRIDGING SCADA SYSTEMS AND GI SYSTEMS

Building a bridge between two different domains requires knowledge of their main characteristics. In automation technology, time behavior is of great interest in order to guarantee the delivery of information such as alerts or measurement values on time. In contrast, geographic information systems focus on the geographical location and time-related information is merely an add-value in most cases. This results in different point of views concerning observed data. Further, it is important to ensure not to lose information when connecting domains SCADA::GIS aims at establishing a bidirectional connection in order to exchange observation data without loss of information. In addition, after establishing a connection, specific features such as real-time behavior of SCADA systems and tracking of movements in GI systems can be shared by each other. In order to develop a sustainable concept, we propose a standardized interface between the domains.

4.1 Conceptual Design

With the aim to implement a sustainable software adapter for bridging the gap between OPC UA and OGC SOS, therefore it has to have the following attributes: i) independence, ii) reusability, iii) extensibility, and iv) Internet capability. Furthermore, establishing a connection must be possible without any intrusive dependencies, and the effort for configuration of the adapter should be minimized in order to increase usability.

The implemented software adapter, see Figure 1 below, consists of two separated components. The former component -- 'GIS2SCADA' -- is responsible for the data transfer from OGC SOS to OPC UA. The latter component -- 'SCADA2GIS' -- enables the data transfer the opposite direction.

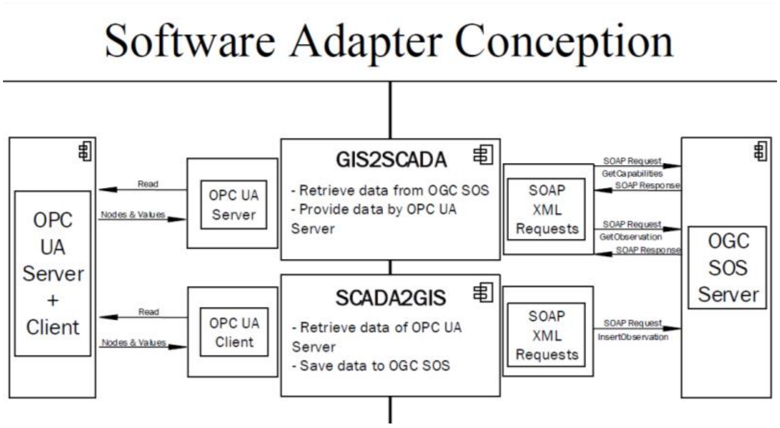

Figure 1. Software Adapter Conception for Bridging SCADA and GIS

Some selected further details and information about data exchange orchestrated by the software adapter are explained in the following subsection.

4.2 Data Exchange

Based on the concept depicted above, a bidirectional connection between OPC UA and OGC SOS has to be implemented. In order to retrieve data of an OGC SOS, 'GIS2SCADA' has to send an XML-based request to the service. In the first step, general information about queryable offerings, procedures and their respective properties has to be requested. In the second step, the newly retrieved information is used to build a request in order to get measurement data of a specific observation. Additionally, temporal and location-based criteria can be added to the request to filter the results. Beyond that, the return format for the resulting document can be defined. After this process is completed, an integrated OPC UA server starts up to provide the observation data for OPC UA clients. The model of the OPC UA server must be defined in advance and includes the required nodes and references in order to transfer the observation data of the OGC SOS. 'SCADA2GIS' is responsible for the data transfer in the opposite direction and takes observational data of an OPC UA server. Once the data have arrived, the component saves it into the OGC SOS by sending a XML-based request to the Web service. This process of saving is repeated in a defined time interval.

5 RESULTS

Based on the conceptual principles in the fields of automation technology and geoinformatics, an autonomous software adapter was developed, whose functionalities were providing extensibility and reusability. The adapter is based on internationally established standards, namely OGC SWE and OPC UA. It provides the exchange of measurement observations and corresponding meta data between implementations of these two standards. The implementation has been tested, among others, using the official OPC UA client of the OPC Foundation. The software adapter requests the data of the OGC SOS and provides them for an OPC UA client by starting an internal OPC UA server.

In order to validate the functionality of the software adapter in a real world scenario, a use-case with three smart buildings at the "BAUAkademie Lehrbauhof Salzburg" in Austria was built up. These houses were built with different building supplies for testing effectiveness of construction and material. In the interior of the houses, and especially in the walls and bricks, there are many sensors for measuring particularly temperature and humidity. In addition, rain, light, and wind are also measured by these sensors.

To have the ability to analyze the history of measured values over a longer period and to be able to perform also special spatial analyses, the data were stored in a database, which has extensions for spatial data. In this case not only the geographical locations of the houses are of interest, but also the positions of the sensors inside the building, which can be north, east, south, west, and the depth of the sensor inside of the wall.

In relation to the project task of bridging industrial control systems and geographic information systems the goal was to collect the measurement data by retrieving them from the database and to provide it for a SCADA system. An extension for the software adapter was implemented to request the measurement data of the MySQL database. In a next step the measurement data where integrated in a SCADA system. For this purpose the procedure as described above was applied. The internal OPC UA server provides the measurement data available for OPC UA clients. These are then able to request and browse the nodes and values. The transferred measurement data consists of sensor names, timestamps, latitude and longitude coordinates, indoor positions, indoor temperatures, and outdoor temperatures. In order to complete the real world scenario, the SCADA software was employed to retrieve and display the measurement data of the smart buildings.

6 FUTURE WORK

The implementation of the software adapter presented leaves some questions open that are relevant for future work. Regarding flexibility, it would be helpful to be able to provide the adapter functionality not in form of a dedicated bilateral link but in form of a distributed service. It would be possible to employ the adapter service in a cloud environment. By doing so, data could be kept location-independent and could be processed for various purposes that exceed the current approach of near real-time data exchange. Long-term monitoring of measurement data based on data mining techniques is one facet; another facet would be in the field of preventive maintenance or in the field of logistics support for the machine building industry. As a side effect of this approach, a variety of devices could be easily incorporated into the present concept. For example, this would enable on-site production forecasting, local operations optimization, and -- as a vision -- rethinking the way production planning is done today.

Another feature planned for the future is some kind of auto-negotiation in order to connect available OPC UA servers and OGC SOSs automatically.

Related to distributed scenarios there is need for dealing with complex security issues, which is also a major subject of future work in this field.

7 CONCLUSION

In conclusion it can be said that our concept, the developed software-adapter and its validation in a suitable application represent a bridge between the time-centric HMI/SCADA world and the location-centric GI world. Both sides can profit from the data and the visualization possibilities of the other. Utilizing OPC UA and OCG SOS as open standards for the realization of the developed data model and the implementation of the interface offers the easy integration in different frameworks and software solutions. While the use of open XML-based standards and TCP/IP enables easy authentication, encryption and reliable communication, real-time is left over as an issue. A deterministic time frame of message and response still has to be established. While this is not that big issue in GIS, it somehow remains an open question in HMI/SCADA. As this could be easily solved using any real-time Ethernet protocol we did not elaborate on that during the prototypical implementation and validation. Following the best practice established within our project, it would be simple to integrate additional domains to either GIS or HMI/SCADA.

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