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Adapting an industrial automation protocol to remote monitoring of mobile agricultural machinery: a combine harvester with IoT

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Abstract: Remote monitoring of any mobile machine requires radio technology, Internet technology, protocols and applications. Mobile cellular networks provide both radio and communication for Internet services while the protocols for IoT are under development. A protocol used in industrial automation for connecting machine automation to production process control is OPC (Open Platform Communications). The latest version of this technology is OPC Unified Architecture (OPC UA). In this paper, the suitability of this technology for agricultural machinery telemetry application is studied. The case presented is a combine harvester with a yield monitoring system. The paper presents both the server side system in the combine harvester and the client for remote monitoring. The results include the measured latencies of the system. The detected end-to-end latency over the Internet connection was less than 250 ms, which is sufficient for most telemetry applications in agriculture.

Keywords: telemetry applications, OPC, OPC Unified Architecture, CAN bus.

1. INTRODUCTION

Current global trends in engineering involve concepts like *digitalization* and *Internet-of-Things (IoT)*. *Devices* are more connected to each other and to the environment than ever. While in the past the concept was to collect and store *data* in the device for development purposes, today more and more data is transferred using mobile networks and the data is stored in IT systems located in the Internet, or *cloud*. Data storage allows machine developers and other stakeholders to develop additional services and business models for the customer. In case of numerous devices collecting numerous parameters with high frequency, the data set collected into the Internet server grows so large that modern analytics tools are required to handle this *big data*.

Moving the data from a mobile device to the other incorporates a couple of challenges. First of all, the data must be formatted in a way that it has some common representation. This involves both units and definitions like positive directions. The more parameters or variables the data set contains, the more important the data model is. The second challenge is related to the communication technology in general: which physical media is used to transfer the data from the mobile device to the Internet. Today, mobile networks are the obvious answer in case there is coverage in the area where the mobile devices are operated. Other options include satellite communication, or proprietary radio systems. The third challenge, which this paper discusses, is to find a protocol over the communication technology to enable the data flow in a robust and secure manner.

Several communication protocols are proposed for IoT. Partially the wide divergence of the protocols is related to different requirements set by radio technologies. A device with long time operation with an irreplaceable battery requires the radio technology of low power consumption as well as simple protocols for a light microprocessor. Some protocols proposed for IoT originate from IT systems, developed for other purposes.

Our approach to solve the protocol issue was to see how it was done in industrial automation. In industrial automation, many of the requirements have been the same – before the trends of IoT. Would it be possible to use available protocols in industrial automation without reinventing the wheel? Unfortunately, industrial automation has a long history of divergent technologies, like industrial field busses. However, the case is similar than in IoT, different systems developed by different vendors have to communicate with each other in a robust way.

The traditional workhorse to interconnect production machine automation, like programmable logic controllers (PLC), to the production process systems is OPC. Originally, OPC stands for OLE for Process Control, referring to underlying Microsoft technologies COM and DCOM for data exchange. Today, OPC stands for Open Platform Communications and the new version, known as OPC Unified Architecture (OPC UA), is not any more bind to Microsoft systems (OPC, 2013). The technology is currently well standardized and recently multiple SDK's (software development kit) are released for various programming languages which makes it timely potential to put into

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operation. OPC UA is based on client-server architecture and the design pattern proposed the devices are servers (with data) any client may connect to request or set the parameters and variables of the server, with the support of authentication, authorization and encryption.

In this paper, we study how to use this technology for remote monitoring of a combine harvester in the field. A combine harvester with a yield measurement system is a typical device used in agriculture for remote monitoring of the process data of interest. For instance, monitoring a fleet of combine harvesters operating in the same field enables a better view on the task progressing. Furthermore, the yield and the properties like the moisture of grain can be recorded for further processing of the material.

2. TELEMETRY SYSTEMS

Öhman *et al.* (2004) presented a concept for the remote maintenance of ISO 11783 compatible machines. The prototype system consisted of a PDA in a tractor with a GPRS connection. The system was used to monitor fault indicators in ISO 11783 network. Another prototype system for transferring process data from the ISO 11783 network was proposed by Steinberger *et al.* (2009). That system includes the data transfer from ISO 11783. The system covers also analysis and aggregation, which were made available as a web service. In that prototype system, a PDA was used to sync the collected data to a PC. Rusch *et al.* (2014) presented a telematics system, compatible with ISOBUS. The main idea was to utilize a database of CAN messages to configure the mobile end, to interconnect the vehicle data to the server. The database was converted to program code automatically. Oksanen *et al.* (2015) studied how to use OPC UA to transfer ISOBUS process data for telemetry purposes. In that study, a new Data logger functionality of ISOBUS was used to request process data from the implements.

Telemetry application for agricultural machinery is available in several products in the market. Commercial systems providing telematics services (a.k.a. telemetry) for their vehicles are: AGCO AgCommand, John Deere JDLink, Claas Telematics, Raven Slingshot and Trimble Connected Farm. These are considered as closed systems for telematics applications, due to the link between the mobile device and manufacturer servers.

The telemetry data can be utilized in several ways in analytics. Steckel *et al.* (2015) presented an anomaly detection and performance evaluation system for combine harvesters. With data mining tools, the system was benchmarked with a fleet of eight combine harvesters for unsupervised and supervised anomaly detection. Pfeiffer & Blank (2015) used telemetry data for the real-time operator performance analysis of combine harvesters. The real time system evaluates the performance indicators and at all skill levels the system tries to help the operators to learn how to improve their performance. Another application for telemetry data comes from fleet management. Kluge (2015) presented a tablet application for crop harvesting operations. This application helps the drivers of the combine and transport vehicles to coordinate actions, by providing the presentation of the key variables of the vehicles in the field.

3. MATERIALS

3.1. Combine harvester

The combine harvester (Figure 1) used in this study was Sampo Comia C6 (manufacturer: Sampo-Rosenlew Oy, Pori, Finland). The header of the combine harvester is 4.1 m wide. The combine harvester has a built-in control system using CAN bus. Most of the parameters in the bus are related to the diesel engine made according to SAE J1939 standard.

The yield monitoring system RDS Ceres PS8000 with 8000i display is an add-on for the combine harvester (manufacturer: RDS Technology Ltd, Gloucestershire, United Kingdom). The yield monitoring system was a stand alone system without the connection to the CAN bus. The yield monitoring system has a dedicated GPS receiver with RS-232 connection (Garmin GPS 19x). The external interface to get data of the yield monitoring system is another RS-232 link.

Figure 1. Sampo Comia harvester.

3.2. Automation system

The positioning system is based on marine GPS receiver with NMEA2000 interface (Garmin GPS 19x). This receiver is compatible with J1939 protocol.

To integrate the data from the CAN bus and RS-232, a rugged laptop computer (Panasonic Toughbook CF-19) was installed onboard with a CAN bus adapter (NI USB-8473). The software was developed using NI LabVIEW and the main functions of the software are: reading the CAN bus data, reading RS-232 data, logging the data for internal storage and writing the fused data to the CAN bus. Besides these functions, the system provides an interface for the user to enter metadata and monitor the status of the system, see Figure 2.

The server for OPC UA data access is another software that communicates with the former by using the CAN bus, plugged in to the standard CAN bus connector used ISO 11783-2 (2012) in the cabin. This allows running the software either on the same computer, or in another onboard computer. In the tests, a dedicated miniature computer (Intel NUC with a CAN bus adapter) was used to run this software with 3G mobile network modem. The software was developed using C++ language and a SDK (provided by Unified Automation) was used. The data is received from the CAN bus, in SAE J1939 format. The server internally handles received CAN messages at 10 ms sample rate. The yield monitor data was encapsulated into proprietary CAN frames while the engine data and GPS are according to the standards SAE J1939 and NMEA2000.

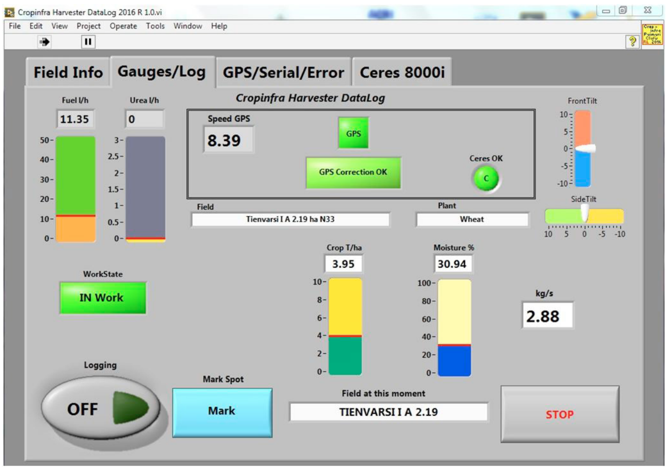

Figure 2. User interface of LabVIEW software.

3.3. Remote client for combine harvester

A desktop client for remote monitoring of the combine harvester was developed to present the process data of the combine harvester. The software was developed using C# language and the data link was done using another SDK (provided by Unified Automation). Most of the user interface components are from NI Measurement Studio library and GMap was used to draw the map. The client can read the mobile server in Internet, see Figure 3.

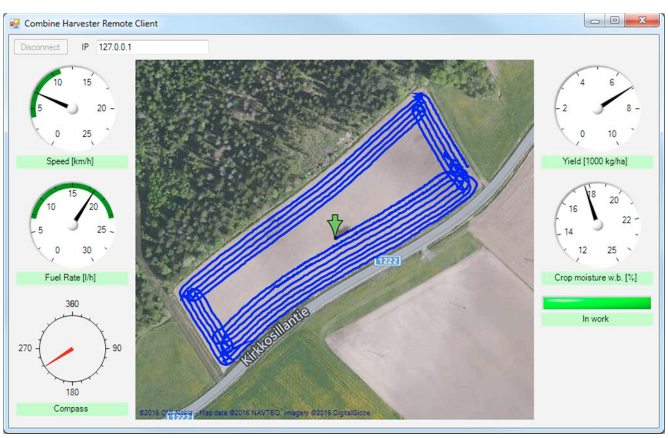

Figure 3. OPC UA Client software for combine harvester.

4. PROTOCOL

4.1. OPC Unified Architecture

OPC UA technology provides means for communication but also for semantics. The information model is a built-in feature of this technology, which enables easier access on the relevant data. The communication protocol is build on TCP/IP stack. Security is another built-in feature of this technology, providing a secure point-to-point link from the client to the server. The security model incorporates authentication with username/password or certificate/private key with OpenSSL certificates. Authorization can be defined in the server to support various use cases, for different access rights – for instance at the manufacturer, dealer and customer levels. The protocol supports 128-bit and 256-bit encryption.

4.2. Information model

The core feature of the OPC UA is information modeling. Without any information model, the data is typically presented as a list of variables without any structure. This kind of approach makes it hard for the integration developers to find the appropriate variables in different servers, e.g. based on their units or based on their properties. This semantics is presented for the client, for browsing the server.

As all the data on the combine harvester was first integrated in the automation system to SAE J1939 format, with some proprietary messages, an information model of SAE J1939/NMEA2000 was developed. This model allows any standard signal on the bus to be presented in the same way. The model includes the type of the attributes (integer, floating, binary), identifiers, units (converted to engineering units) and presentation of the original structure under CAN messages. The server was developed to exclusively present the available attributes on the bus, automatically. This enables both easy browsing of the data and expandability.

4.3. Data transfer

For OPC UA client three basic operations are available: Read, Write and Subscribe. Read operation is used to poll the value of an attribute in the server, Write operation for commanding a new value for settable attribute and Subscribe enables data streaming from the server to the client. In the protocol, Subscribe operation enables data refresh when the data is changed in the server, this saves bandwidth and cumulative data if the attribute occasionally changes.

5. RESULTS

5.1. Process data

The combine harvester with the yield monitoring system has 14 signals on the CAN bus that are monitored. The signals on CAN bus which are attributes in OPC UA server are listed in Table 1. The data contains both current coordinates of the vehicle and the coordinates stamped when the yield was harvested. The latter is due to the processing time in the combine harvester, the yield measurement is delayed by about 12 seconds identified in the machine using the instruction of the yield monitoring system. As this delay is calibrated into the yield monitoring system, the client does not have to know that thanks to time and position stamps.

5.2. Latency of OPC UA link

For any communication protocol, the latency is an important measure. OPC UA is not designed for the sub-second sampling rate though this is possible. To overload the system to the maximum, we set up a test with both the sampling rate and the publishing rate to 50 ms which was considered the smallest. The OPC UA client may set these rates for the server when requesting subscription, the publishing interval is a common variable for the subscription while the sampling rate is per variable.

Table 1. Monitored signals in the combine harvester

Signal / attribute	Source
Current latitude	GPS receiver
Current longitude	GPS receiver
Current speed	GPS receiver
Current course	GPS receiver
Work state (on/off)	Yield monitor
Crop yield	Yield monitor
Crop density	Yield monitor
Crop moisture	Yield monitor
Number of header sections	Yield monitor
Header width	Yield monitor
Yield stamp: time	Yield monitor
Yield stamp: latitude	Yield monitor
Yield stamp: longitude	Yield monitor
Instantaneous fuel rate	Engine

The test was done by using a setup illustrated in Figure 4. Both the OPC UA Test client and the OPC UA Server are connected to CAN bus using USB-CAN adapters. On the other hand, both devices are connected to the Internet, with different Internet Service Providers. The OPC UA server is connected to the Internet by using 3G mobile network and the Test client connects through ADSL connection. The Test client sends a CAN message to the CAN bus, changing the value of a signal stepwise. OPC UA Server monitors this value and finally the change in the monitored item is seen over OPC UA link. In the test setup, no other messages were transmitted in CAN bus, so the latency of this link is less than 1 ms. One round for the new data update is called a ping in the figure.

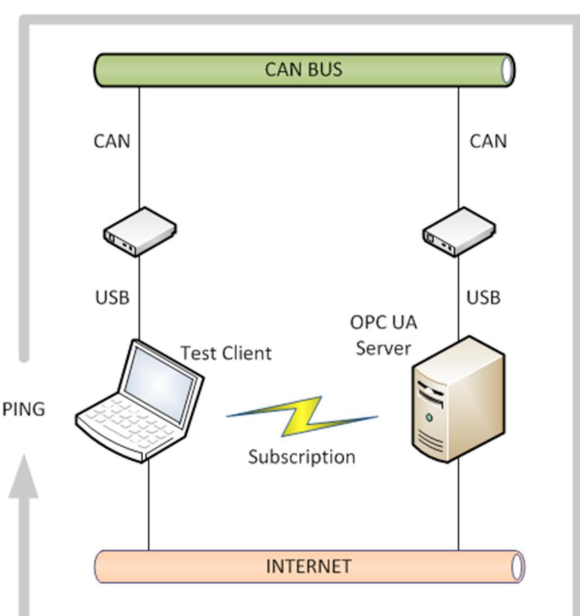

Figure 4. The test setup for latency identification.

At first, to test the latency of the client-server system without the real network, the server and the client were run on the same computer and the Internet was replaced with *localhost*. By using 50 ms publishing and sampling rate, the average latency in 1000 samples was 67 ms and the standard deviation 22 ms. This is considered as the intrinsic latency of the system, due to the CAN message receiver sample rate plus the sampling rate of OPC UA subscription.

With the real Internet connection using 3G mobile on the server side and ADSL on the client side in rural area, the detected average latency was 135 ms and the standard deviation 30 ms. Histograms of the detected latencies are visualized in Figure 5; the test over localhost on the top and over the Internet on the bottom.

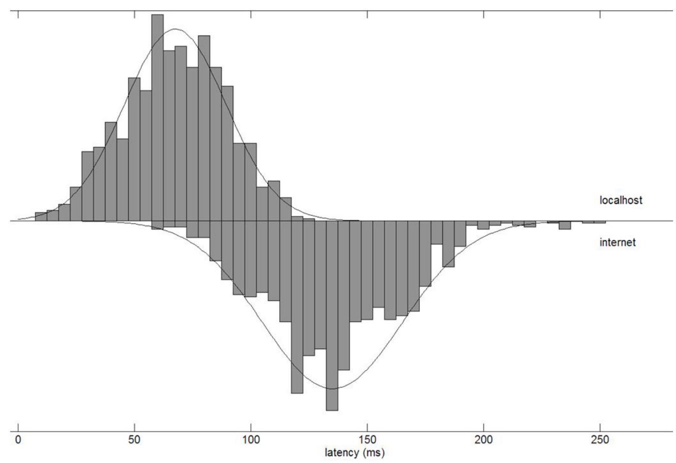

Figure 5. Latency histograms. On the top: localhost, on the bottom: over 3G mobile network connection.

6. CONCLUSIONS

Standards are required for Internet-of-Things devices. We consider OPC UA as one potential technology for that purpose as it fulfills the general requirements of safe and secure communication, thanks to the origins in industrial automation.

In this paper, we demonstrated the use of the technology to access the parameters of the combine harvester remotely. The protocol implementation was done by using commercial SDK's of Unified Automation. The server implementation requires remarkably more effort, as it requires designing an information model, for instance. The client is much more straightforward to implement.

Accessing the data of a combine harvester is easy if all data is directly available in CAN bus. In our case, the combine harvester, yield monitoring system and the positioning device were separate from each other and the first stage was to multiplex this data into single CAN bus.

Based on the latency test, the latency of subscription is less than 200 ms when both the server and the client are located in the same region. The sample rate of most signals in the CAN bus of the combine harvester is either 200 ms or 1000 ms, so this latency is considered sufficient even if the maximum frequency is desired. However, the sample rate of 200 ms over Internet is rare in any telemetry system, in the commercial telemetry systems designed for agricultural machinery, a typical sample rate is 10 or 15 seconds. In case the TCP/IP connection is transferred large distances, like across continents, the network latency will be remarkably more significant compared with the intrinsic latency.

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