An Internet of Things Approach for Intelligent Monitoring of Conveyor Belt Rollers

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Abstract

This article presents an Internet of Things (IoT) architecture suitable for large scale sensor networks for condition monitoring. The developed technology has been applied and demonstrated for rotating conveyor belt rolls.

Wireless sensor networks is a relatively new and emerging technology, not only capable of addressing a large number of applications in industry but is also applicable for home automation, medical monitoring, sports monitoring, etc. The presented architecture consists of a sensor platform running the Contiki operating system capable of simultaneous monitoring of several important parameters such as RPM, ball bearing temperatures, total operating hours, total laps, vibrations, and others.

Electric energy is continuously scavenged from the roller's rotation and the platform is hence operating perpetually without the need of any additional power source. All necessary components are embedded in the roller making its appearance and functionality no different from traditional rollers. This approach enables simple, automatic, and straightforward condition monitoring of conveyor belt rollers throughout their entire operating life span without any major investments in monitoring equipment and maintenance systems.

The contribution of the paper is twofold: Firstly, the advantages and possibilities of using a low-power Internet-enabled sensor network for condition monitoring, with seamless integration with upper layers such as SCADA, MES and ERP are presented. Second, the use of highly-efficient EXI for CoAP is presented together with a comparison with traditional text-based XML. Comparatively, EXI show several advantages for large-scale operation of wireless sensor networks with potentially hundreds or thousands of nodes due to its bandwidth efficiency.

1. Introduction

The work presented in this paper originates from the EU-INTERREG IVA COBS project [1] which is a cooperation between Sweden and Norway. The COBS project is currently researching and developing technology for efficient transportation of raw materials, such as ore, on conveyer belts. Conveyer belts are used extensively by several industrial segments for transportation of bulk material and are in many cases crucial components to uphold production in continuous processing or loading of trains or ships.

The main objective of the COBS project is to make traditional conveyer belt rollers intelligent by embedding sensors, processing capabilities and wireless communication. Internet of Things (IoT) [2] provide several advantageous compared to legacy systems for realizing this objective. Specifically, regarding developments of necessary hardware and software as well as implementation of the technology in an industrial environment. In principle, IoT consists of small embedded devices with wired or wireless communication capabilities. The use of the TCP/IP protocol suite enables each sensor node, and in our case, each roller, to be monitored in near real time. Another key feature of the proposed architecture is the extensive use of SOA technologies for IoT in industrial applications, SCADA system integration [3], and condition monitoring and maintenance [4].

In [17], Amankwah et al. demonstrated a vision based system for monitoring of the content of a conveyer belt in order to estimate the level of fines being transported. Online monitoring a conveyer belts have been studied to some extent previously, for example by Pang in [18], where a magnetic matrix was embedded within a belt and used sensors to monitor the belt. Also ball bearings have been subject for vibration monitoring etc. However, very little can be found on the subject of making conveyer belt rollers intelligent in the previous research. The rotating nature of a roller prohibits the use of cables, and the steel shell of an industrial roller prevents radio signals to penetrate. Using optical communication is also very difficult due to the harsh environment a roller is exposed to in mining and continues production. In [19], a system for monitoring vibrations in industrial machines was presented. However the use of non-standard communication protocols limits interoperability and makes integration with standard IP-based maintenance systems difficult.

The approach presented in this paper can be used to manage infrastructure and perform condition monitoring and maintenance. Since each roller has a unique identification number (ID), a company can automatically generate and keep a real-time database over rollers in use. By enabling each roller to monitor ball bearings, RPM etc., a maintenance system can be used to track the need of maintenance of each individual roller. This can mitigate problems with down time of a belt due to unplanned maintenance stops.

This paper is outlined as follow: Section 2 provides a background and related work. Sections 3 and 4 provide a presentation of the intelligent conveyer belt roller and its properties and some results from experimental tests. Section 5 outlines suggestions for future work followed by conclusions in Section 6.

2. Related work

This section provides background and related work to the core technologies used in this paper. The technologies used are conveyer belts and conveyer belts rollers, low-power wireless sensor and actuator platforms (Internet of Things).

2.1 Conveyer belts

Conveyer belts are widely used within the industry. Traditionally, they are comprised of a (large) number of rollers aligned in a line. The rollers are in turn attached to a framework using ball bearings. An electric motor is used to drive the belt. Conveyer belts are used on a large number of different configurations, ranging from small belts for paper boxes to kilometre long belts that transport hundreds of tonnes per hour. The latter type is often used by the mining industry to transport iron ore and pellets between the mine, process plants, trains, and ships.

2.2 Internet of Things

Internet of Things (IoT) is a relatively new approach for distributed monitoring and control [12]. The core aspect of IoT is that properties from reality, or the *physical world*, can be readily available on the Internet, or the *virtual world*. This enables humans and machines to be able to sense, process, and control physical properties over the Internet. One example is by having a web service for controlling heating and ventilation in a domestic building. By connecting temperature sensors, IR-detectors and motor controlled valves to the Internet, the web service can analyse data regarding the out- and indoors temperatures and determine if there are any humans in the building. Based on the acquired information, the heating and ventilation systems can be controlled and thereby optimized.

Two main operating systems are normally used in research regarding IoT. The TinyOS system from Berkeley and Contiki from SICS have been ported to a large number of sensor platforms. Both systems have support for 6LoWPAN with RPL, IPv6 and CoAP. 6LoWPAN is a method of transmitting IPv6 datagrams over low-bandwidth links such as IEEE 802.15.4 or Power line communication (PLC). RPL is multi-hop routing protocol with tight integration with 6LoWPAN. RPL enables formation of mesh networks, where node forward packet for each other in order to allow a greater area to be covered. CoAP is a protocol for resource-constrained devices using low-bandwidth links. It is by design compatible with the commonly used HTPP protocol, which enables traditional methods for access, such as URLs to be used.

3. Intelligent Conveyer Belt Roller

This section presents detailed information about the design of the intelligent belt roller. The main components are; a composite roller, embedded electronics, a wireless network and backend-system.

3.1 Composite roller

The composite roller is comprised of a steel axis, ball bearings and a body made of composite materials. The roller, which weighs about one firth of the weight of a steel roller, allows radio signals to penetrate the outer shell. This allows radio-based communication to be used. The shell also prevents dirt and water to reach the embedded sensors and electronics.

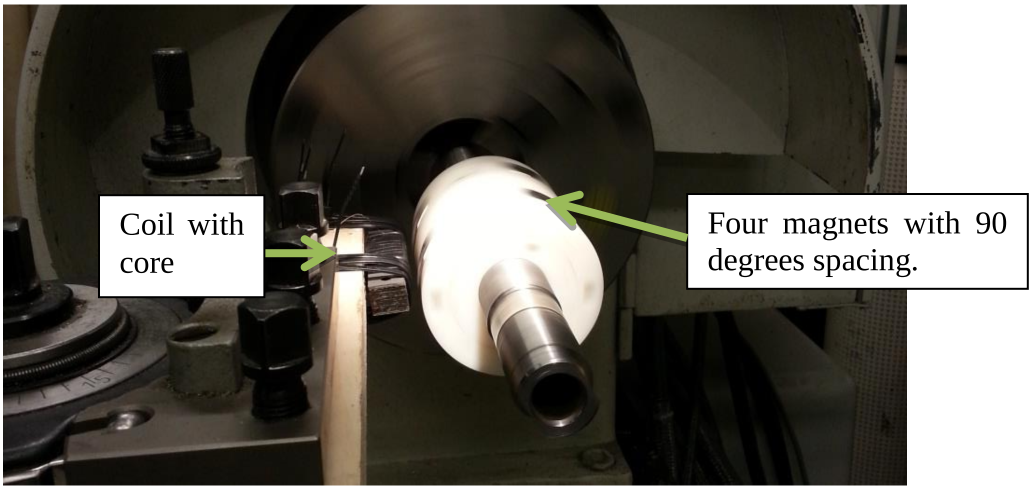

Figure 1: Experimental roller

The roller is manufactured by Narvik Composite A/S [15] in Norway.

3.2 Sensor platform

The sensor node, which was chosen for this project, is equipped with a Renesas M16C/65 microcontroller and an IEEE 802.15.4 transceiver (868 MHz). It has 47 kB of RAM and 512 kB of flash memory. The nod also features an on-board 2 MB flash memory, thereby enabling storage of relatively large amounts of sensor- and configuration data. The used sensor node, Mulle, is available from Eistec AB [16], under the commercial brand name Mulle, and is based on research results from Luleå University of Technology. The Mulle is in the COBS project further equipped with a sensor board with a number of different sensors, an energy harvesting unit and a super capacitor for energy storage. The sensors currently used are:

- Ball bearing temperature
- Ball bearing vibration
- RPM
- Energy status

Other sensors could also be added later on for sampling of even more parameters. The sensor board is used to enable real-time monitoring of the status of a roller. If a ball bearing's temperature starts to increase in an unnatural manner, ore if severe vibrations start to occur an alarm condition can be raised. Energy is provided by a small generator that scavenges rotation energy. This allows the system to operate perpetually, as long as the roller is rotating. The generator is also used as a sensor, thus indicating to the Mulle each time one round has occurred. The Mulle captures this and keeps track of current RPM, and the total amount of revolutions that the roller has performed.

The Mulle supports two of the most commonly used operating systems for wireless sensors: TinyOS and Contiki. In the work presented here, Contiki was selected due to its good support for Internet of Things related protocols. IEEE 802.15.4 was selected, using 868 MHz, and 6LoWPAN with RPL was deployed. The use of RPL enables formation of multi-hop (mesh) networks.

3.2 Network Architecture

The network architecture used in this work is based on R&D results from the IMC-AESOP project [14]. This EU FP7 project aims at addressing issued concerning the use of Service Oriented Architecture (SOA) for industrial monitoring and control. The network is comprised of a number of low-power sensor nodes communicating using 6LoWPAN and RPL. IPv6 is used between nodes, gateways and services of the Internet or in a company cloud. To mitigate bandwidth requirements and enhance low-power operation, the Constrained Application Protocol (CoAP) has been used. Sensor data is expressed using XML for better compatibility with higher layer enterprise systems and encoded using binary XML (EXI) in order to reduce the amount of data flowing through the network.

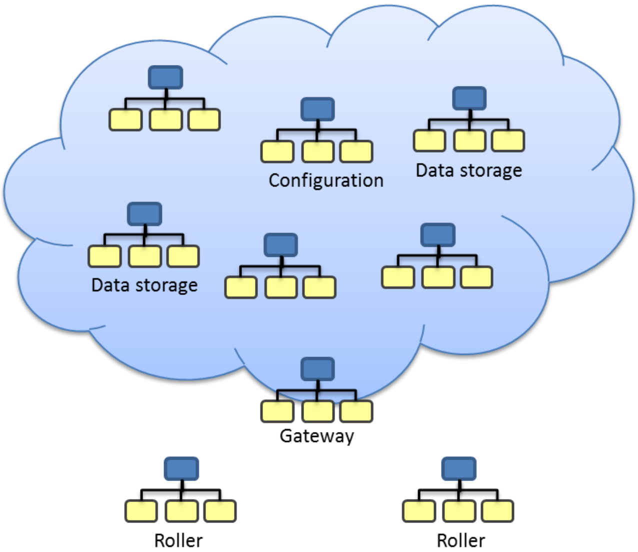

Figure 2: Service cloud

All sensors embedded in a roller are expressed as services, shown in Figure 2, thus allowing easy access to the data. By using the CoAP protocol, event based communication is enabled. A change in ball bearing temperature, or sudden change in RPM will cause an event to be transmitted from the roller to any service that is subscribing to it. This drastically reduces the amount of traffic that the network must support since very little traffic will be generated during normal operation of the belt rollers. Only heart beat messages will be occasionally be sent in order to verify network and roller operation.

Figure 3 shows the basic IMC-AESOP architecture that has been the base for the roller belt sensor network architecture. All features are exposed as services, either at node, gateway or cloud level. The rollers are at the lowest level, but by utilizing standard SOA technologies even at that low level seamless integration with higher layer systems such as SCADA, maintenance or Enterprise resource planning (ERP) systems. Figure 3 shows the IMC-AESOP architecture. The EU FP7 project IMC-AESOP is performing R&D activities in the field of industrial monitoring and control, SOA-enabled sensor networks and seamless integration between legacy systems and state-of-the-art SOA-based systems and services.

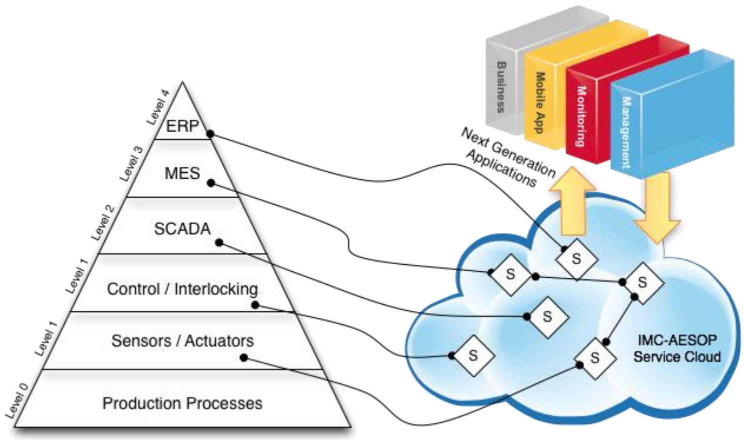

Figure 3: IMC-AESOP Architecture

The IMC-AESOP architecture is designed to allow shop-floor devices such as vents, valves, sensors, actuators etc., to directly communicate with higher layer services and systems. This service cloud enables seamless integration of resource-constrained devices with high-end business and maintenance systems. The current status of the project is that small sensor nodes with, i.e. embedded in composite rollers. The rollers can be integrated with upper layers with the SOA approach, using a combination of protocols such as CoAP, DPWS, OPC-UA, and others.

4. Evaluation

The test setup consists of a Mulle device that is embedded in a conveyor belt roller and communicates diagnostic information to a base station. The monitored parameters include current rotation speed, total amount of revolutions for the roller, current temperature on the left and right bearings, battery level and signal strength to the base station. This information is delivered in an event base communication pattern where only the values above predefined threshold are sent to the base station.

In order to plot the diagnostic parameters over period of time and guarantee that the connection to the node is working properly the base station requests "heartbeat" readings from the Mulle node that include all the monitored parameters and a timestamp. The "heartbeat" messages have a certain frequency that can be controlled during runtime. These periodic readings subscribe or renew the existing subscription to the parameters of interest.

The event-based communication is achieved by using light-weight RESTful web services that are implemented using the Constrained Application Protocol (CoAP). This web services guarantee interoperability with enterprise systems and seamless integration of other nodes and services as described by Shelby [6]. In order to meet the low-power requirements and hardware constants of the wireless sensor node system, the Mulle node is equipped with Contiki OS and light-weight CoAP implementation evaluated in [10].The base station on the other hand runs Linux and uses libcoap library configured for version 12 of the CoAP specification. For efficient data representation, the service payload that carries the diagnostic information is represented using Efficient XML Interchange (EXI) format [7] for binary encoding of XML. EXI is increasing the compactness as well as the processing speed of XML structured information as shown by the evaluations performed by W3C [8]. The XML structure of the messages is shown in the example below:


```
<cobs nodeId="111">
  <timestamp>2012-12-31T12:00:00</timestamp>
  <rpm>222</rpm>
  <accRounds>8989</accRounds>
  <temp>
    <left>22.2</left>
    <right>33.4</right>
  </temp>
  <RSSI>
    <min>100</min>
    <max>200</max>
    <avg>120</avg>
  </RSSI>
  <battery>3.1</battery>
</cobs>
```


Figure 4: XML data format

The size of the sample message shown in Figure 4 in text representation is 321 bytes. Our prototype uses EXI in schema-less mode of operation to represent this data in just 152 bytes. For supporting the resource constraints of the target platform we used EXIP library for processing the binary XML streams. EXIP is specially designed for very constrained embedded platforms as presented in [9].

For the schema-less processing the run-time RAM usage on the Mulle platform is 3870 bytes. The statically allocated memory is 14.6 kB and the programming memory needed for the EXIP library is 94 kB. These measurements are done for the fully-fledged EXIP library that is not optimized and includes features that are not used by the application. Significant reductions of the resource requirements (RAM, programming memory, radio usage) can be achieved by using EXI in schema-enabled mode where the sample message shown in Figure 4 is compressed to 99 bytes. Using strict interpretation of the schema and stripping the EXI processor from unnecessary features as suggested by Doi et al. [11] can further optimize the resource utilization.

The current status is that the hardware, e.g. sensors, nodes, gateways, has been successfully tested in a laboratory environment. Wireless communication between a rotating roller and a gateway has also been proven to be robust and dependable. A number of services, such as data acquisition, conversion between binary XML and plain text XML, data storage, visualization, etc. has been verified. By using EXI, some data messages can for example be compressed from 250 bytes down to 8 bytes. This mitigates performance issues when low-bandwidth wireless communication is used and increases scalability, especially in mesh networks. A test bench has been built in order to perform lab tests of a single roller and to test the wireless communication and integration with the service cloud. More tests are needed though in order to fully validate the approach.

In order to increase productivity during software development, work is being prepared to utilize a holistic network simulator from Riliskies et al. [13]. This simulator can simulate hardware devices, sensor network behaviour and allows the IoT approach to be completely simulated before deploying a wireless sensor network.

5. Future work

In this paper, we have demonstrated the use of Internet-connected embedded devices capable of measuring key parameters for performing condition maintenance of industrial conveyer belt rollers. In the next steps, we will focus on enabling large-scale installations by using mesh-enabled networking and advanced routing. For this a network simulator will be used as a tool to identify important network parameters. We will also aim at making an installation at one or more mining-related sites. Other parameters, such as belt speed or weight of transported material, to monitor then the ones currently supported will also be investigated. More work is also needed in order to develop a low-cost generator that can scavenge energy in a very efficient manner.

One important feature of the system is to enable operations and maintenance personnel to easily access data. For this reason, web based visualization is currently being implemented.

Security issues are of course important since a productions plant's operation might be disturbed if a malicious intruder could inject false massages in order to trick the maintenance system that a conveyer belt malfunction is eminent. For this reason, IPsec will be evaluated as a security solution. The performance provided by CoAP's DTLS encryption will also be investigated.

6. Conclusions

In this paper, a novel approach for conveyer belt monitoring has been proposed. The approach is comprised of a new type of composite belt roller with embedded electronics. Since the rollers are rotating at a relatively high speed, communication using cables of course not applicable. The use of composite materials enables radio signals to penetrate the roller's shell which is not feasible when using traditional rollers made of steel. The system is thereby based on the Internet of Things approach. Sensor nodes are embedded inside a roller with a number of sensors, such as measurement of ball bearing temperatures, vibration, RPM, etc. The information provided by the sensors are processed by the sensor node, in this project a Mulle v6.2 was chosen. The Mulle runs Contiki and uses standard IoT protocols such as CoAP and XML/EXI for communication. The communication architecture is completely services-based, where all functionality of the system is exposed as services. The use of a Service-oriented architecture (SOA) enables new features to be added to the system, and new services can be composed by orchestration of existing ones.

The results from this work show that it is feasible to embedded wireless Internet technology in each individual belt roller. The use of IoT enables sensor information about the condition of each monitored roller to be transmitted wirelessly to the Internet for alarm generation, storage and visualization.

The work performed in the COBS project has resulted in an intelligent conveyer belt roller, capable of measuring ball bearing temperatures on all bearings, RPM for each individual roller, and count the total amount of hours and laps that each individual roller has been operating. These measurements can be transmitted using a mesh network of Mulle devices and integrated with higher layer SCADA and maintenance systems.

Acknowledgements

The authors wish to thank partners in the INTERREG COBS project, and the IMC-AESOP and Arrowhead projects for cooperation and funding.

References and footnotes

1. http://www.interregnord.com/en/projects/north/1-trade-and-industry-development/cobs-den-intelligenta-bandrullen.aspx , visited 2013-01-25
2. http://www.ipso-alliance.org/wp-content/media/embedded_services-webinar-slides.pdf , Z. Shelby, IPSO Alliance, visited 2013-01-22
3. R Kyusakov, J Eliasson, J Delsing, J Deventer and J Gustafsson, 'Integration of wireless sensor and actuator nodes with IT infrastructure using service-oriented architecture', IEEE Transactions on Industrial Informatics, vol 9, pp 43-51, 2013.
4. G Del Vescovo, M Paschero, A Rizzi, R Di Salvo and F.M.F Mascioli, 'Multi-fault diagnosis of rolling-element bearings in electric machines' in XIX International Conference on Electrical Machines (ICEM), 2010.
5. S Bagnoli, R Capitani and P Citti, 'Comparison of accelerometer and acoustic emission signals as diagnostic tools in assessing bearings', Proceedings of 2nd International Conference on Condition Monitoring, London, UK, pp 117-125, May 1988.
6. Z Shelby, 'Embedded web services', IEEE Wireless Communications,vol 17 pp 52-57, 2010
7. 'Efficient XML Interchange (EXI) Format 1.0', March 2011, http://www.w3.org/TR/2011/REC-exi-20110310/
8. 'Efficient XML Interchange Measurements Note', G. White, J. Kangasharju, D. Brutzman, and S. Williams, http://www.w3.org/TR/exi-measurements/
9. R. Kyusakov, J. Eliasson, and J. Delsing, 'Efficient structured data processing for web service enabled shop floor devices', Industrial Electronics (ISIE), 2011 IEEE International Symposium, June 2011
10. M. Kovatsch, S. Duquennoy, A. Dunkels, 'A low-power CoAP for Contiki', IEEE 8th International Conference on Mobile Adhoc and Sensor Systems (MASS), 2011
11. Y. Doi, Y. Sato, M. Ishiyama, Y. Ohba, and K. Teramoto, 'XML-less EXI with code generation for integration of embedded devices in web based systems', 3rd International Conference on the Internet of Things (IOT), 2012.
12. A. W. Colombo, F. Jammes, J. Delsing, T. Bangemann, 'Towards an architecture for service-oriented process monitoring and control', IECON 2010 - 36th Annual Conference on IEEE Industrial Electronics Society, 2010
13. L. Riliskis, E. Osipov, 'Symphony - simulation, emulation and virtualization framework for accurate WSN experimentation', The International Conference on Software Engineering proceedings, 2013
14. The IMC-AESOP FP7 project. http://www.imc-aesop.eu/ 2013
15. Narvik Composite AS, Norway. http:// http://www.narvikcomposite.com , 2013
16. Eistec AB, Luleå, Sweden. http://www.eistec.se/ 2013
17. A. Amankwah, C. Aldrich, ' Automated Online Estimation of Fines in Ore on Conveyer Belt Using Image Analysis', International Conference on Industrial Control and Electronics Engineering (ICICEE), pp 23-25, 2012
18. Y. Pang, 'A Novel Embedded Conductive Detection System for Intelligent Conveyor Belt Monitoring', IEEE International Conference on Service Operations and Logistics, and Informatics, 2006. SOLI '06.
19. V.M.D Jagannath, B Raman, 'WiBeaM:Wireless Bearing Monitoring System', 2nd International Conference on Communication Systems Software and Middleware, 2007. COMSWARE 2007, vol., no., pp.1,8, 7-12 Jan. 2007