Profiling Context Awareness in Mobile and Cloud Based Engineering Asset Management

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Abstract. This paper presents an analysis of the potential and a methodology for handling context events and adaptations in maintenance services. A significant number of industrial IT systems employ data models and service frameworks whose design specifications where drafted on the basis of functional requirements for non context-aware systems. Such systems were modular in nature but little care was taken for providing data fusion in a context-aware manner. Though system intelligence might have been a feature for a subset of such systems, two major requirements kept implementations away from wider adoption: (i) refactoring and reengineering of the system's base services (ii) customising and modifying the structure of a data model tightly connected with inter-process organisation. This paper discusses a methodology for injecting industrial asset management systems with modelling semantics and software mechanisms that enable context awareness via portable clients and application-agnostic data fusion services.

Keywords: Context Awareness, Asset Modeling, Mobile & Intelligent Services.

1 Introduction

Increasingly computational logic is aggregated inside IT systems that serve industrial processes to enhance their capacity for offering adaptive services. Their corresponding platforms exhibit an aggressive shift to embody and exploit intelligent mechanisms for the organization, correlation and fusion of field data into application knowledge [1]. Both tasks introduce high-capacity processing and require a capable infrastructure to serve them. Such requirements become a costly overhead especially when involving scaled semantics and rich parameter-lists for capturing highly focused contexts. Engineering asset management constitutes a domain containing several systems that already benefit from such mechanisms, many of which currently advertise services ranging from smart condition monitoring to enterprise-level decision support. The question at hand is whether such complexity can be easily handled by rigidly implemented systems and how recent software trends that decouple intelligence from the application context, can facilitate a more modular implementation.

This paper proposes an operational shift of focus for the above systems, addressing the feasibility and potential of adopting components that exploit the dynamics of modern IT technologies. After building a case for the versatility and scalability of

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contextualized services, we explain how a simple semantics framework can facilitate legacy systems to annotate their existing model and compose functionally beneficial contexts. This simple enrichment can fuel mobile components that track and detect context events, and respond to them with application oriented calibration of maintenance services. Such a modeling evolution can lead to the identification of simple context patterns and binding rules that offer elevated knowledge of the process. At the same time, a new meta-context can emerge and become available for monitoring and system-adaption. Computational and operational challenges of multi-site and multi-industry contexts point at the exploitation of cloud services. The features of modern cloud frameworks are discussed and specific interfacing components are analyzed to provide a conceptualization of how cloud's adoption is feasible by maintenance IT.

2 Context Awareness in Engineering Asset Management

From a system's design perspective, the semantics of context awareness in engineering asset management, though tightly connected with the data model, essentially derive from functional and non-functional specifications of the information system. Positioning assets and personnel, as well as any ICT smart agent, in a scaled manufacturing shop-floor, constitutes part of the asset management context. Indirect and direct localization options offer effective detection, introducing highly capable components within tools already available in mobile maintenance practice [2]. Location awareness brings added value to positioning events and translates their impact in the system. This impact may involve a wide range of functional adaptations and reconfigurations, irrespective of the flat semantics defining the underlying legacy system.

As with most context aware systems, the design of a maintenance-oriented one should follow a few essential steps. As a first step, serving a practical understanding of the maintenance context, its semantics should be associated with three core concepts: location (spatial locality), identity (actor locality), and time (time locality). In order to build a more focused context and extend its semantics, an extraction of functional dynamics must result from defining the desired system's response.

Context awareness is not limited to location awareness, nor is it bound by limitations to sensed parameters. The concept of context is addressed by semantics of any direct, computed or inferred factors [3]. The practice of data analytics on large volumes of maintenance records has gradually revealed that the fusion of new parameter sets may result in discovering new meta-contexts [4][5]. The importance of each new context is assessed by the correlation of events with maintenance semantics. The fusion of machinery condition parameters can fuel the identification of new context instances, such as the machinery states. On a different level, fusion of a maintenance plan's Key Performance Indicators (KPIs) with maintenance personnel expertise, can lead to discovering contexts that optimally balances performance with utilization of human resources. Scenarios of context awareness addressed in our research include:

- A technician's route during inspection tracked directly or indirectly through GPS or RFid beacons. Machinery proximity can be inferred, enabling system to adapt the mobile interface, providing instant access to maintenance history and a list of pending tasks associated with the specific units.

- When abnormal readings are taken and unknown conditions are inferred, the monitoring agents switch to "alarm" status. A gateway reports to personnel, while sensor monitoring is adapted/ calibrated to a new collective operation profile.
- When an engineer edits the maintenance plan with a corrective task, he may also allocate spare parts and assign a task to personnel. The system captures the session path and presents equipment parts, recommending available personnel and actions.

There are three basic constituents in the described cases: (a) the context, (b) the context event and (c) the system's response. The data schema should define the participation of each maintenance data type in context-related events, as well as map a response or response rule to the identified context. The internal components should incorporate or facilitate processes and services responsible for compiling the context states, detecting the events and executing the system's adaptation. These context interpretation and calibration services are integrated in mobile and server side components respectively, providing the final set of "smart" maintenance services.

3 A Context Aware E-Maintenance Architecture

The majority of recent IT architectures are developed with the modularity required for fast and effective adoption of the aforementioned mechanisms. The service-oriented nature of modern condition monitoring, asset tracking and maintenance management systems enables context awareness to be achieved by the hosting of a supplementary pool of services and data entities. Our research studies the extent at which legacy and modern systems can facilitate and tune federated services for mobile and cloud-based context awareness. We propose the semantics of a context-organizing sub-schema template that can be easily customized and imported in existing models of industrial systems. We discuss how mobile applications can serve a context identification/adaptation engine that captures and responds to context events, occurring in a complex shop-floor or a multi-site enterprise. Finally the role of cloud computing is assessed by evaluating emerging frameworks offering application-agnostic services for data clustering and classification [7].

3.1 WelCOM Maintenance Platform and Piloting Testbed

The conducted research constitutes part of the WelCOM (Wireless sensor networks for Engineering asset Life-Cycle Optimal Management) project [8]. The WelCOM platform utilizes a smart sensor infrastructure for machinery condition monitoring, while interfacing with a CMMS (Computerized Maintenance Management System), to deliver a context aware asset management tool (Fig. 1). An Intelligent Maintenance Advisor client handles context aware operations by exploiting the mobility of portable devices with mechanisms able to record the user's location, environment and system session. The client adapts visually and functionally to changes in the apparent context of a service request. The same client enables maintenance staff to select parameter semantics that profile new monitored contexts. These contexts are processed by the

Knowledge Management sub-System, utilizing a set of local or remotely accessed data fusion services. The Intelligent Maintenance Advisor offers an abstraction layer between maintenance practice and computations, by providing a profiling tool that translates maintenance engineering and management specifications into appropriate method invocation for modeling services. Context modeling and identification, as well as context-based adaptation are key elements in the WelCOM approach.

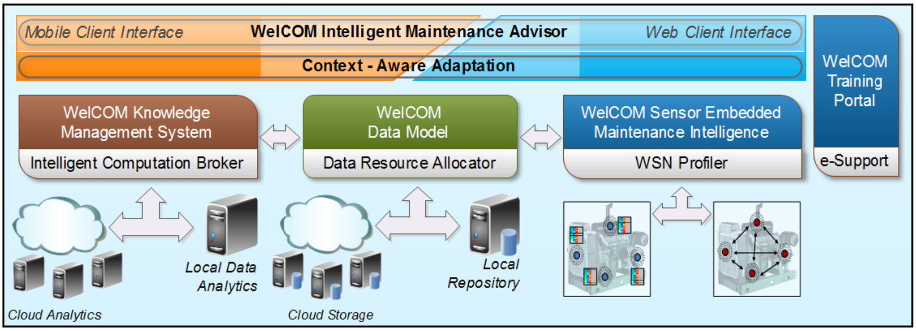

Fig. 1. WelCOM e-Maintenance Architecture

The development of WelCOM's mobile client drives an assessment of direct and indirect methods for inferring maintenance related contexts. One of our main testbed sites is the Kleemann's lift testing tower. This tower is equivalent to a seventeen floor building, and comprises four testing units. The WelCOM intelligent advisor should be able to monitor, map and analyze a set of condition parameters related to lift operational parts and components (Fig. 2). The lift testbeds themselves are technical structures composing an integrated lift machinery installation.

Fig. 2. WelCOM Testbed Planning

3.2 Context in Mobile Maintenance

A range of context models have been investigated by research initiatives and development processes. While the first seek to explore the depth and breadth of context semantics, the later battle their way through implementations that can deliver functionality to facilitate handling of these contexts. Maintenance related models are connected with indicators of operational performance and descriptive power, providing a solid base for context aware systems. The extensibility of these models is achieved through compliance to established schemas (MIMOSA [9]) and the native importing (multi-inheritance) features of the modeling technology (XML schemas). While earlier and recent models, address context modeling with respect to a single application or application class, engineering asset management constitutes a problem space that allows scaling of semantics at a generic level. This derives from the ranged scope of the corresponding services that start from shop-floor maintenance tasks to strategic level KPI analysis. The WelCOM maintenance advisor is designed to be configured by a context engine that detects and adapts to the following context types (Fig. 3):

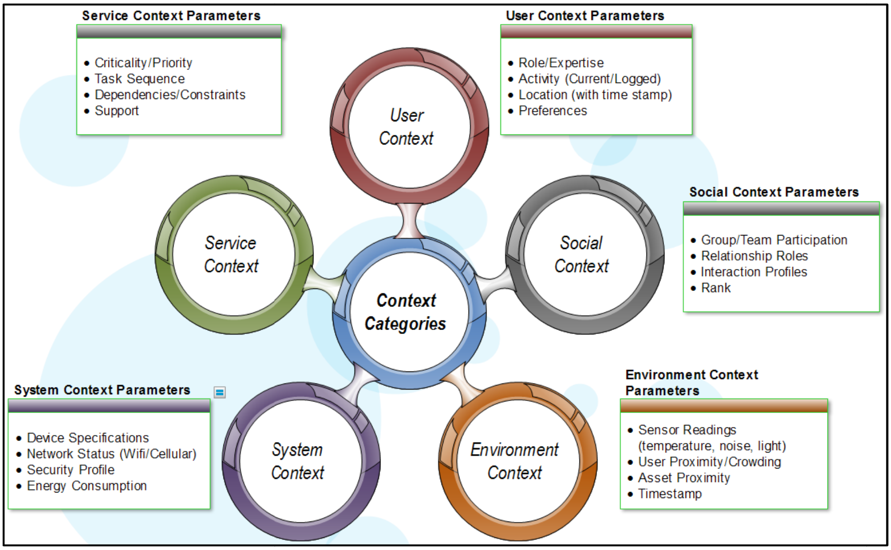

Fig. 3. Context in Mobile Maintenance

- User Context – It maps the semantics behind the information included in user profile, system preferences and logged activity. Profile information designates personnel's expertise, maintenance roles and system credentials. Preferences express a set of property values that allow user-defined adaptation of services and console personalisation. Logged activities contain a list of both completed and pending tasks, along with checked/unchecked notifications.
- System Context – It holds the semantics for describing device features, along with other non-functional information, such as the connection status and network

availability (e.g. availability of Wi-Fi networks and/or 3G signal strength), power level and system performance/status, etc.

- Environment Context – It addresses the location coordinates or code of the personnel proximate position (asset/segment => position), along with a timestamp of his presence there. It also includes a set of property values that describe constituents of the sensed industrial environment (temperature, noise, humidity, light).
- Service Context – The context of the user assigned functions and services. It contains the semantics about the service participation in a larger workflow (sequence number in maintenance plan), its criticality/priority and its dependences with other services/functions. A set of property values that define maintenance specific task parameters, such as constraints and available supporting material.
- Social Context – This context describes the dynamics of group participation and collaboration between industrial agents such as personnel. The semantics here draw a constantly updated linked graph, where flow of knowledge and authority identify individual skills for co-operative efficiency and effective supervision.

In order to enhance both maintenance personnel positioning and asset proximity, we explore the potential of using NFC-enabled devices with corresponding tags. Currently the vastly adopted android OS supports the 3rd version of NFC framework, while the mobile market offers a range of tablets with native features for read/write operations on NFC-tags. Facilitation of such technologies can lead certain benefits:

- The utilization of solid and non-fragile portable units, capable of operating in harsh industrial environments and by maintenance practicing hands. Introducing state-of-the-art features, such robust tablets can operate as a final product/service host, without strict handling policies. Former systems lacked casing protection and handling versatility due to connection limitations (tablet + GPS receiver/RFid reader).
- New context aware maintenance clients, developed on-top of a uniform NFC framework. Such implementations ensure:

  – Interoperability: cross device coupling and context data exchange between proximate personnel. Technicians passing reports to engineers, for collaborative authoring and validation, serving and powering the **social context**.
  – Portability: migrating users' session state, such as pending maintenance tasks, alert notifications and system preference, from the tablet to his smartphone. Synchronizing a single rich session between shop-floor tablet, the client pc and the personal smartphone, serving and powering the **user context**.
  – Compliance: exploiting the wide range of supported tags, offered by the NFC framework to program multiple associations. One tag to multiple assets and multiple tags to one asset. Optimal collaboration with the driver-set of other sensors can detect and map a detailed **environment context**.
  – Scalability: NFC framework is integrated with state-of-the-art devices driven by the latest versions of Android (and Windows8) operating system. Such versions include the most recent libraries for data presentation, UI composition and wireless coupling. They effectively incorporate the features capable of performing unique client adaptation for the maintenance **service context**.

3.3 Context Aware Maintenance Cloud

The concept of cloud and its serving technologies have only recently found application in the engineering asset management field. The term "sensor cloud" has emerged to offer the first maintenance cloud tool in modern IT architectures [10]. A sensor cloud is introduced as the method to outsource storage of maintenance data, supported also by proper tools that semantically annotate and organise the collected volumes. A cloud approach comes to offer two main advantages: (i) the provision of scalable storage and service instances, hosted in (ii) third party infrastructures. In maintenance systems, scalable resources may become crucial when multiple diagnostics and modelling services are invoked by different monitoring agents (software/personnel). Aggregating the execution of such complex tasks demands high availability of resources. Few of them can easily dominate the capacity of a limited infrastructure. To address such a challenge many industries overtook the indoor development of custom distributed diagnostics, operating them on top of enterprise-owned/maintained servers/clusters and backup systems. The multifold cost of such an investment is where the second cloud feature comes to serve. Cloud providers enable enterprises to escape the cost of running their maintenance system on top off owned storage and processing facilities. The Quality of Service (QoS) defined in a cloud Service Level Agreement (SLA) has proven to be much more reliable and cost-efficient than most self-maintained centres. The question then is how secure is for a competitive industry to outsource such core functions that support its manufacturing edge, i.e. the maintenance process.

Cloud services have evolved to deal with security issues of data analytics, by supporting the abstraction layer of application-agnostic frameworks. This means that cloud providers can now efficiently host generic modelling services, whose analytic power can be extensively configured to provide highly focused results. In this scenario, apart from the service hosting/handling infrastructure, the development cost of base services is also escaped by the client industry. Such a cloud-based maintenance system only requires the following components:

- The Intelligent Computation Broker – Knowing and analysing the capabilities of the employed cloud services, this subsystem is responsible for orchestrating an appropriate workflow of service invocations that eventually returns the desired results. It operates as an engine that profiles specialised tasks of maintenance intelligence into sequenced calls of application agnostic analytics.
- The Data Resource Allocator – This subsystem handles the encryption, wrapping and exchange of maintenance data. Such tasks ensure that the output of one cloud service is properly formatted and securely passed to lead the input of the next one in the workflow. It is also responsible for monitoring and imposing the data caching, replication and migration policies between the cloud storage sites.

The target of the WelCOM's cloud side is to assess how thin and modular our maintenance advisor can be, by exploiting cloud instead of local resources. Currently, frameworks such as Mahout offer ready-to-use cloud services, addressing core tasks in context analytics (classification, clustering and batch-based collaborative filtering).

Our goal is to calibrate and facilitate such services in order to provide, consume and/or extend maintenance services.

4 Conclusions

Context awareness is a design methodology that promotes adaptation in customised IT services and content. In the last few years, many field adoptions have been studied and evaluated, while enabling technologies and techniques progressed to enable new context dimensions for maintenance management and condition monitoring. By employing them, modern maintenance systems can offer advanced adaptive services build upon application-agnostic cloud frameworks. This paper described the WelCOM-platform's semantics, design and implementation plan for a contextualised mobile client of a distributed model that constitutes a maintenance mobile cloud.

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