Context-Awareness in Internet of Things - Enabled Monitoring Services

Ali Al-Shdifat, Christos Emmanouilidis and Andrew Starr

July 23, 2018

Context-Awareness in Internet of Things - Enabled Monitoring Services

Ali Al-Shdifat[1], Christos Emmanouilidis and Andrew Starr

Abstract Remote monitoring services are required to meet the very high demands on availability and efficiency of industrial systems. The fast evolution of technologies associated with the deeper penetration of Internet of Things in industry creates considerable challenges for such services. These are related to the whole data lifecycle, encompassing data acquisition, real-time data processing, transmission, storage, analysis, and higher added value service provision to users, with adequate data management and governance needed to be in place. The sheer complexity of such activities the need to ground such processing on sound domain knowledge emphasises the need for context information management. The aim of this paper is to survey and analyse recent literature that addresses internet of things context information management, mapping how context-aware computing addresses key challenges and supports delivering appropriate monitoring solutions.

Keywords: Internet of Things, Context Management, Remote Monitoring Services.

1 Introduction

In recent years, research into context management for Internet of Things (IoT) has received increased attention in academia, aimed to address the increasing complexity challenges of IoT-enabled data value chains (Perera et al., 2015). When considering IoT usage in industrial environments, the term Industrial Internet of Things (IIoT), or simply Industrial Internet, is often employed, and is being considered synonymous to Industrie 4.0 (Jeschke et al., 2017). IoT brings together many functionalities such as identification, sensing, communication, computation,

---

Al-Shdifat (✉)
Cranfield University, United Kingdom
e-mail: ali.alshdifat@cranfield.ac.uk

C. Emmanouilidis
Cranfield University, United Kingdom
e-mail: christosem@cranfield.ac.uk

A.Starr
Cranfield University, United Kingdom
e-mail: a.starr@cranfield.ac.uk

services, and semantic information management (Al-Fuqaha et al., 2015). Although it offers many benefits and solution enablers, substantial effort is required to manage and exploit the data generated by things. Among the key instruments to tackle such complexity is the concept of context information management. The term context in computing, originally employed in computational linguistics and later adopted in web-based information management, refers to establishing the background circumstances or specific situation regarding specific data or computing service requests. Context-awareness is the ability of a system to give appropriate information or services to consumers utilising context information (Abowd et al., 1999).

With the deeper penetration of IoT technologies in monitoring tasks, the need for context information management increasingly manifests itself as a requirement for industrial applications. Context gathering, modelling, reasoning and dissemination are needed for the efficient handling of vast amounts of data, produced by numerous devices, and their efficient integration in enterprise systems. This is further fueled by the accelerating shift to service-based business models, wherein service level agreements must be ascertained, supported by adequate monitoring systems.

This paper offers a survey and analysis of recent literature that addresses context management in IoT. It maps how context-aware computing techniques have contributed to delivering solutions and identifies key challenges that IoT-enabled monitoring services need to address. The rest of this paper is organised as follows: Section 2 provides a review of context-awareness, including a critical analysis of their strengths and weaknesses. Section 3 deals with context information lifecycle management, offering also a mapping view of context-awareness in IoT for remote monitoring services. The analysis results in identifying some key challenges to be addressed by further research in the field, as summarised in conclusion.

2 Context Awareness in IoT

Context-awareness has an increasingly significant role to play in deploying IoT solutions in complex industrial environments. Many different definitions of context are reported in the literature. Abowd et al. (1999) have argued that context is used to give necessary information and services to the consumer, where relevance depends on the consumer's task. According to Dey et al. (2001), some definitions relied on examples and therefore could not be utilised to identify a new context, proposing instead to employ synonyms of context, such as environment and situation. Five W’s (Who, What, Where, When, Why) were identified as the basic information that is required to understand context (Abowd and Mynatt, 2000). The management of large-scale sensing was recognised as a prime target for context management, as such data need to be gathered, modelled, analysed, fused, and interpreted (Raskino et al., 2005). The data produced by sensors may not supply the useful information that could be utilised to understand the whole situation. Consequently, additional knowledge and context-relevant information may have to be fused with sensor data for successful context identification. In order to address this, middleware solutions have been proposed, addressing various aspects of IoT data management, such as context-awareness, interoperability, device management, platform portability, as well as security and privacy (Perera *et al.*, 2014). Several surveys have been conducted in this area. The viewpoint of such surveys is mapped in chronological order from left to right in Figure 1.

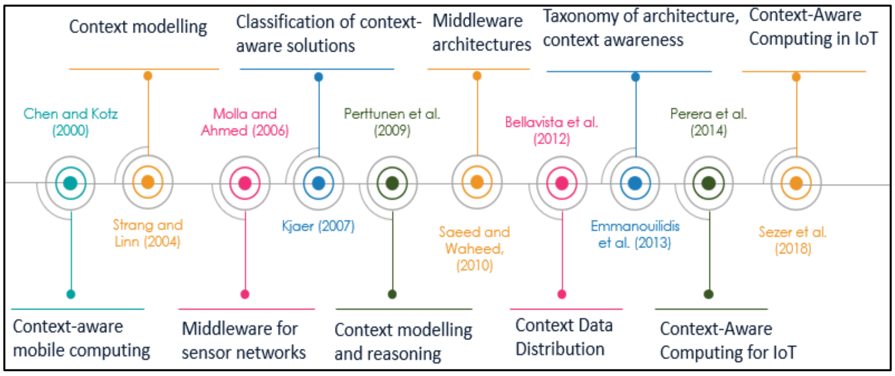

Figure 1: Summary of surveys on context awareness

Surveyed worked shows that context management has largely dealt with the challenges of ubiquitous environments, as well as the data heterogeneity and services scalability. It plays a central role in defining what data needs to be collected and how to be processed, as well as in determining what information and services that require being presented to the consumer. Context management issues increasingly progressed from dealing with context acquisition and modelling to context reasoning and dissemination. Early context information management literature targeted mobile computing and web-based information processing. IoT has expanded the range of applications with substantial needs for context management, and this was reflected in the focus of relevant surveys. Nonetheless, while substantial research efforts have been devoted to context lifecycle management in web-based, mobile, and ubiquitous computing, including IoT-enabled computing, little attention has been given to translate these advances to tangible progress in remote monitoring services. Various types of context have been identified by researchers based on different perspectives. Abowd et al. (1999) distinguished context between primary and secondary, as well between conceptual and operational. Operational context can be further classified as sensed, static, profiled, and derived. Chen and Kotz (2000) distinguish between passive and active context, depending on whether context is directly actionable or not, considering the way it is used in applications. Liu et al. (2011) classify context into user, physical, and networking. An overview of different context categorisation schemes in chronological order is shown in Figure 2.

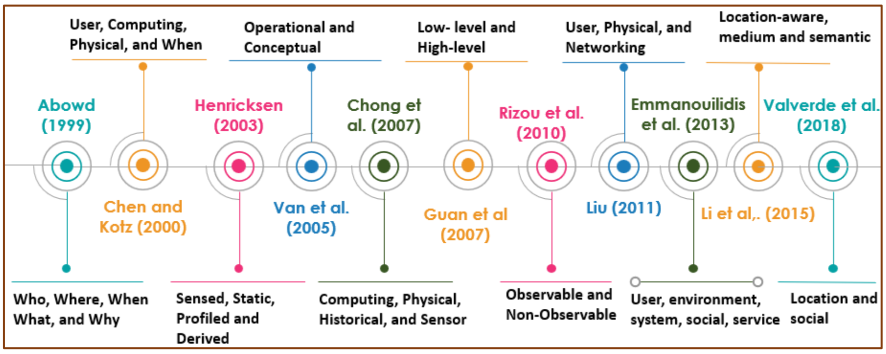

Figure 2: Different context categorisation schemes

An outline of strengths and weaknesses of typical context classification approaches are depicted in Figure 3.

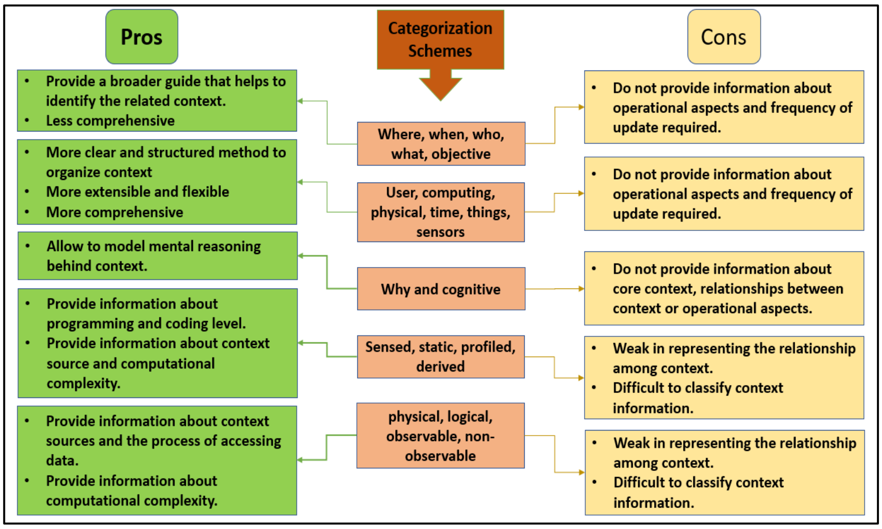

Figure 3: Comparison of context categorisation schemes adapted from Perera et al., (2014)

Based on the assessment of context classification, it is clear that existing context classification schemes have weaknesses and it is particularly unclear to what extent they meet needs for monitoring services. Therefore, in order to design an appropriate framework to manage context for IoT-enabled monitoring services efficiently, further analysis is needed. In order to do so, an outline of how the lifecycle of context information can be managed is first introduced.

3 Monitoring Services Context Information Life Cycle

Context lifecycle refers to how data is gathered, modelled, processed, and how knowledge is deduced from the obtained data (Sezer et al., 2018). The context lifecycle management generally consists of four steps, namely context acquisition, modelling, reasoning, and dissemination (Perera et al., 2014). However, a more detailed handling and analysis of what these steps actually involve when considering monitoring services are largely missing in the relevant literature. Figure 4 offers an illustration of the different stages of context information management, placing them against the monitoring services functionality.

Context acquisition involves acquiring and bringing together data from physical objects in different ways, based on sensor types, responsibility, acquisition process, frequency, and source (Aguilar et al., 2018). From a remote monitoring perspective, it would be of contextual relevance to understanding what type of measurement data need to be collected (e.g. temperature, vibration, and pressure) by using IoT devices and sensors, making also sure that these are indeed acquired.

At context modelling level, is further generally referred to as representation and formalization of the context, through certain modelling approaches (Cabrera *et al.*, 2017). Context modelling techniques have been surveyed by (Chen and Kotz, 2000; Strang and Linnhoff-Popien, 2004), and include Ontology-Based, Key-Value, Logic-Based, Markup Scheme, and Graphical ones. From an IoT perspective, service management enables to work with heterogeneous objects, and it also concerns the operations to manage and orchestrate the services exposed through it. From a remote monitoring perspective, information handling is the process of converting digital data into real quantities of working conditions of machines to produce meaningful information, while filtering out perceived outlier data.

Context Reasoning can be defined as a process that contributes significantly to the collection of new knowledge based on the acquired contextually relevant data (Bikakis et al., 2008). Typical context reasoning techniques include Rule-based approaches, Supervised learning, Fuzzy logic, Unsupervised learning, and Ontology-based ones (Bikakis et al., 2008) (Perttunen et al., 2009). The importance of this layer of context management lies the ability to provide high-quality intelligent services to meet end-user needs. In remote monitoring ser-vices, this can enable not only fault detection, diagnostics, and prognostics, but also action recommendations consistent with the inferred context of the analysed situation.

Context Dissemination. This is where actionable context is made available to other applications and services, or users. Two methods are typically used for context distribution 1) Query: The user requests the context, such that the context management system answers to that query. 2) Subscription also called publication (Perera *et al.*, 2014). This constitutes the high-end of the IoT-generated data process chain and can fuel added value services, such as visual or other types of analytics, as well as decision support. From the end-user's perspective, this stage is actually the most important, as the initial data are now disseminated in enhanced form and are essentially converted to visual information, insights and action recommendations.

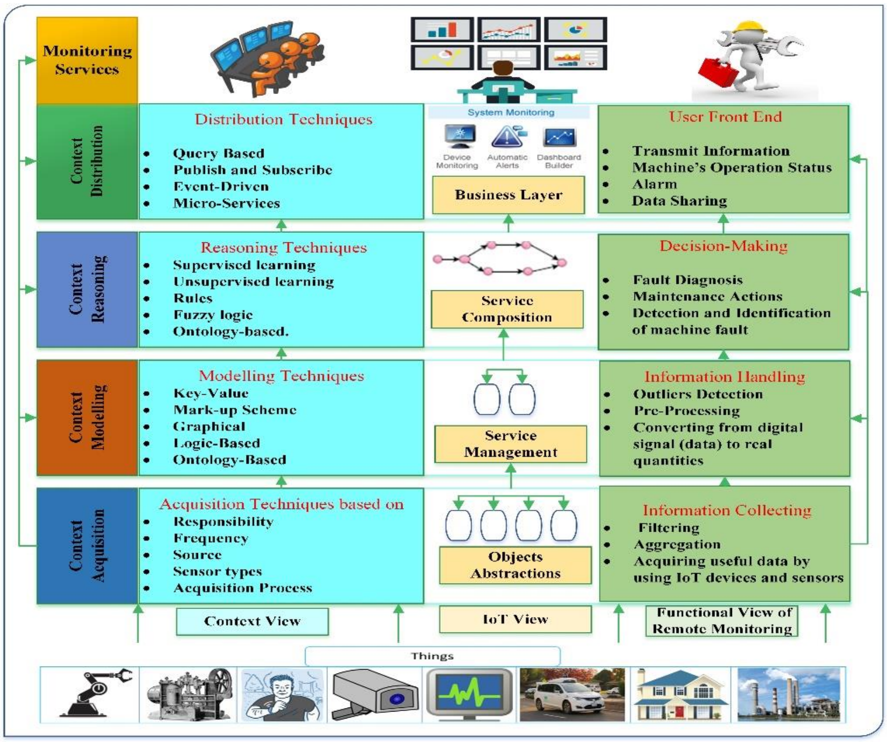

Figure 4: Context management lifecycle in IoT for remote monitoring services

4 Conclusion and further research

This paper's aim was to outline and analyse key issues related to context management for IoT – enabled remote monitoring services. This highlighted the need for handling the whole context information management lifecycle, from context acquisition and modelling, through reasoning, all the way to context dissemination and the relevance that each such phase has to monitoring services. IoT has expanded the range of applications and the scale of involved data, creating a clear need for context management, and this was reflected on the recent focus of relevant surveys. Such research is contributing towards filling the gap in relevant literature, which focused on context lifecycle management in web-based, mobile, and ubiquitous computing, including IoT-enabled computing, while paying little attention to translating these advances to tangible progress in remote monitoring services. Consequently, further research is required to develop context-aware approaches and architectures to deliver more efficient IoT-enabled monitoring services, including non-functional issues, such as IoT security, which constitute a critical adoption barrier in current IIoT – enabled systems.

5 References

Abowd, G. D., Dey, A. K., Brown, P. J., Davies, N., Smith, M. and Steggles, P. (1999) "Towards a better understanding of context and context-awareness," in Proc. 1st international symposium on Handheld and Ubiquitous Computing, ser. HUC '99. London, UK: Springer-Verlag, pp. 304–307.

Abowd. G. D and Mynatt, E. D. (2000) 'Charting past, present, and future research in ubiquitous computing', ACM Trans. Comput.-Hum. Interact., 7(1), pp. 29–58.

Aguilar, J., Jerez, M. and Rodríguez, T. (2018) 'CAMeOnto: Context awareness meta ontology modeling', *Applied Computing and Informatics*. King Saud University, 14(2), pp. 202–213.

Al-Fuqaha, Ala. Guizani, Mohsen. Mohammadi, Mehdi. Aledhari, Mohammed. Ayyash, M. (2015) 'A survey on Internet of Things', IEEE Communication Surveys & tutorials, 17, No 4.

Bellavista, P., Corradi, A., Fanelli, M. and Foschini, L. (2012) 'A survey of context data distribution for mobile ubiquitous systems', ACM Computing Surveys, 44(4), pp. 1–45.

Bikakis, A., Patkos, T., Antoniou, G. and Plexousakis, D. (2008) 'A Survey of Semantics-Based Approaches for Context Reasoning in Ambient Intelligence', Constructing Ambient Intelligence, 11, pp. 14–23.

Cabrera, O., Franch, X. and Marco, J. (2017) '3LConOnt: a three-level ontology for context modelling in context-aware computing', Software and Systems Modeling. Springer Berlin Heidelberg, pp. 1–34.

Chen, G. and Kotz, D. (2000) 'A Survey of Context-Aware Mobile Computing Research', Dartmouth Computer Science Technical Report, 3755, pp. 1–16.

Chong. S. K, McCauley. I, Loke .S. W, and Krishnaswamy. S. (2007) "Context-aware sensors and data muling," in Context awareness for self-managing systems (devices, applications and networks) proceeding. Berlin : VDE-Verlag, pp. 103–117.

Dey, A., Abowd, G. and Salber, D. (2001) 'A Conceptual Framework and a Toolkit for Supporting the Rapid Prototyping of Context-Aware Applications', Human-Computer Interaction, 16(2), pp. 97–166.

Emmanouilidis, C., Koutsiamanis, R. A. and Tasidou, A. (2013) 'Mobile guides: Taxonomy of architectures, context awareness, technologies and applications', Journal of Network and Computer Applications. Elsevier, 36(1), pp. 103–125.

Guan, D., Yuan, W., Lee, S. and Lee, Y.K. (2007) 'Context selection and reasoning in ubiquitous computing', Proceedings The 2007 International Conference on Intelligent Pervasive Computing, IPC 2007, pp. 184–187.

Henricksen, K. (2003) 'A framework for context-aware pervasive computing applications', The School of Information Technology and Electrical Engineering, The University of Queensland, pp. 13–20.

Jeschke, S., Brecher, C., Meisen, T., Özdemir, D., Eschert, T. (2017) "Industrial Internet of Things and Cyber Manufacturing Systems", in Jeschke,S., Brecher,C., Song,H., Rawat,D. (eds) Industrial Internet of Things Cybermanufacturing Systems.Springer Series in Wireless Technology, pp 3-19.

Kjaer. K. E. (2007) "A survey of context-aware middleware," in Proc. 25th conference on IASTED International Multi-Conference: Software Engineering. ACTA Press, pp. 148–155.

Li, X., Eckert, M., Martinez, J. F. and Rubio, G. (2015) 'Context-aware middleware architectures: Survey and challenges', Sensors (Switzerland), 15(8), pp. 20570–20607.

Liu. W, Li. X, and Huang.D.(2011) "A survey on context awareness," in Computer Science and Service System (CSSS), 2011 International Conference on, pp. 144 –147.

Molla.M, and Ahamed.S,(2006) "A survey of middleware for sensor network and challenges," in Proc. 2006 International Conference Workshops on Parallel Processing, ser. ICPPW '06. Washington, DC, USA: IEEE Computer Society, pp. 223–228.

Perera, C., Liu, C. H., Jayawardena, S. and Chen, M. (2015) 'A Survey on Internet of Things from Industrial Market Perspective', IEEE Access, 2, pp. 1660–1679.

Perera, C., Zaslavsky, A., Christen, P. and Georgakopoulos, D. (2014) 'Context Aware Computing for The Internet of Things', IEEE Communications Surveys & Tutorials, 16(1), pp. 414–454.

Perttunen, M., Riekki, J. and Lassila, O. (2009) 'Context Representation and Reasoning in Pervasive Computing', International Journal of Multimedia and Ubiquitous Engineering, 4(4), pp. 1–28.

Raskino, M., Fenn, J., and Linden, A. (2005) "Extracting value from the massively connected world of 2015," Gartner Research, Tech. Rep. Available at: https://www.gartner.com/doc/476440/extracting-value-massively-connected-world (Accessed: 13 June 2018)

Rizou. S, Haussermann. K, Durr. F, Cipriani.N, and Rothermel. K. (2010)"A system for distributed context reasoning," in Autonomic and Autonomous Systems (ICAS), Sixth International Conference on, pp. 84 –89.

Saeed, A. and Waheed, T. (2010) 'An extensive survey of context-aware middleware architectures', 2010 IEEE International Conference on Electro/Information Technology, EIT2010.

Sezer, O.B., Dogdu, E. and Ozbayoglu, A.M. (2018) 'Context Aware Computing, Learning and Big Data in Internet of Things: A Survey', IEEE Internet of Things Journal, 5(1), pp. 1–1.

Strang, T. and Linnhoff-Popien, C. (2004) 'A Context Modeling Survey', Workshop on Advanced Context Modelling, Reasoning and Management, UbiComp 2004 - The Sixth International Conference on Ubiquitous Computing, Workshop o(4), pp. 1–8.

Valverde-Rebaza, J. C., Roche, M., Poncelet, P. and Lopes, A. de A. (2018) 'The role of location and social strength for friendship prediction in location-based social networks', Information Processing and Management. Elsevier, 54(4), pp. 475–489.

Van Bunningen, A.H.; Feng, L.; Apers, P.M.G. (2005) 'Context for ubiquitous data management'. In Proceedings of the International Workshop on Ubiquitous Data Management, Washington, DC, USA, 4 April 2005; pp. 17–24.