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TRILHA PRINCIPAL

Requirements Specification of Context-Aware Systems: A Systematic Mapping

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***Abstract*—Context-aware computing covers research on computational systems which adapt their behaviour so as to provide services or information to users according to their context of interaction. The literature has reported the complexity of development of such systems in the light of their features such as adaptation and heterogeneity of devices and information. This paper describes the execution of a systematic mapping on the requirements specification activity of context-aware systems, which is one of the early stages of software development. The main result includes the identification of gaps and/or research trends on requirements specification of context-aware systems.**

***Index Terms*—Requirements Specification, Context Aware, Systematic Mapping.**

I. Introduction

CONTEXT-aware computing is a knowledge area in which we study using information gathered from the user interaction context or from the environment he is in. The goal is to personalize and adapt computational services provided to the user through the modification of the behavior of those services during their execution [1] [2].

The literature has reported the complexity of the development of context-aware systems, which is due to their characteristics such as adaptation, device and information heterogeneity [3], among others.

Hence, there are growing efforts in the Software Engineering area to propose methods and processes that support the complexity of context-aware systems. The Requirements Engineering area, specially, has reported several difficulties in this field [4] [5] [6] [7].

Traditional methods of Requirements Engineering focus on the resolution of the inherent ambiguity of requirements and defend the specification of those requirements with a level of detail that is enough for the verification of the conformity of the implementation to this specification.

Context-aware systems are able to adapt their behaviour in an autonomous and dynamic way in response to changes in external conditions. One difficulty associated to requirements engineering of this type of system is that the traditional methods are not enough to deal with requirements whose changes cannot be foreseen in project time. The main challenge is to keep them updated as a reflection of the changes in the context-aware systems.

The main goal of this paper is to create an analysis on requirements specification for context-aware systems in order to extract information on this field, which are the main tools and modelling techniques used, the way the specification document is usually described and which are the most used techniques to specify context requirements, so that we can understand which topics are well defined and the gaps in the research.

In order to reach the desired goal, we used the systematic mapping method, which consists on a study on a series of papers found in research bases based on a search string. The study followed the protocol that guides the whose systematic mapping [8] [9].

At the end of this paper, we present and analyze the quantitative data found on research questions that are related to requirements specification in context-aware systems. Hence, the result of this work can be used as a starting point to future works in the field.

This paper is organized as follows. Section II discusses the methodology used to execute this work. detailing what is a systematic mapping, how it works and the protocol used. Section III presents the results found during the systematic mapping. Finally, Section IV presents the conclusions based on the results found and their analysis.

II. Methodology

IN this section we present in details the methodology used to perform this research.

A. Systematic mapping

A systematic mapping, as well as all other review studies, is a form of research that uses as data sources the literature on a specific topic [9]. It is a way to identify, evaluate and interpret all the research found and defined as relevant to a specific research question, theme area or phenomenon of interest [8]. It is a bibliographic review method, in which the data extraction focuses on classification and categorization of the results, without a qualitative analysis of the primary studies [8] [9].

The main characteristics that differentiate between a systematic mapping and a conventional bibliographic study are the following:

- Systematic mapping begins with the definition of a protocol, which specifies the research question and the methods used during the mapping;
- Systematic mapping is based on a search strategy that intends to detect the maximum amount of information on a specific topic;
- Systematic mapping documents the search strategy, so that readers can evaluate the rigor, completeness and repeatability of the process;
- Systematic mapping requires the definition of criteria that can justify the exclusion of papers considered to be outside the mapping scope.

Hence, a systematic mapping is very useful, because it allows to summarize the existing evidences which are relevant to several situations, such as fata gathering on the state of the art of the requirements specification for context-aware systems.

A systematic mapping also allows us to identify eventual gaps in the knowledge about the research topic, suggesting new investigation areas and offering a direction and positioning properly new research activities in a research area.

B. *Systematic mapping protocol*

The protocol followed during this systematic mapping is made of five phases, which are: planning, execution, selection, extraction and conclusion.

1) Planning: In this phase we define the protocol to be followed in the next phases of this mapping. The definition of the protocol takes into account the *definition of the research questions*, the *selection of research sources* and the *study selection.*

The definition of the research questions was made taking into account the focus of this study: "identify the state of the art of the requirements specification activity for the construction of context-aware systems". Hence, we defined the research questions relevant to the research, which are:

- Which are the main artifacts generated during requirements specification for context-aware systems?
- Are there requirements specification models for context-aware systems?
- What are the main challenges for the creation of artifacts for requirements specification for context-aware systems?
- Which are the open questions in requirements specification for context-aware systems?
- Which are the main tools or standards used to support requirements specification for context-aware systems?

In order to perform a systematic mapping, we need reliable research sources. Hence, we defined criteria for the selection of the research sources, as suggested by Kitchenham et al. [9]:

- Offer search mechanisms through strings with support to logic expressions;
- Offer the same results whenever the same string is inserted;
- Offer a web-based search mechanism;
- Include papers on Computer Science, Information Systems or Software Engineering; and
- Allow selection by publication year.

Based on the criteria defined above, we selected seven research sources that satisfied all the criteria. The selected sources are the following:

- ACM Digital Library
- Biblioteca Digital Brasileira de Teses e Dissertações (BDTD)
- Engineering Village
- IEEEXplorer
- Scopus
- Springer
- Web of Science

Still in the planning phase, we defined that we would only consider studies published either in English or in Portuguese, from the year 2005 until 2014.

After defining the research question, the selected sources and the selection criteria, the next step was to define the search strings to be submitted to all the selected research sources; the search strings would be also applied to the tile and abstract of each paper under consideration.

Following the recommendation of Kitchenham et al. [9], the definition of the strings must be preceded by tests with different options. The goal is to analyze the search results found and verify the precision of the results from each of the used strings. This work was performed by three researchers, for greater refinement of the strings, until the results approached the goal proposed for this research. Hence we defined two search strings:

String for English-written papers: *("requirements specification" AND "context-aware" AND software)*

String for Portuguese-written papers: *("especificação de requisitos" AND ("sensível a contexto" OR "sensível ao contexto") AND software)*

We also defined the criteria for exclusion of a study, which are:

- papers not written in the languages defined in this protocol;
- papers whose full text is not available freely at the web or at the CAPES Journals Portal;
- papers with no relation to the Requirements Engineering field;
- papers that do not deal with requirement specification;
- papers not related to context-aware applications.

We also defined that we would considered that we would also accept thesis, dissertations, book chapters with abstracts, journal and conference papers which satisfied the inclusion criteria and did not meet the exclusion criteria defined in this protocol.

2) Execution: This phase consisted of submitting the search strings to the research sources that were already defined and prepare all the received information.

We defined that the results returned by the search tools would be stored into an electronic spreadsheet, using the software *LibreOffice Calc*. In order to store the data, we needed to export the results from the search tool and for this task we used the mechanism that is already available in most tools, which generates a file in the *CSV* format.

In those tools where this exportation mechanism was not available, we used the external plug-in *Zotero* to properly perform this conversion.

3) Selection: This phase consisted in selecting the studies based on the title and abstract of each paper, taking into consideration the inclusion and exclusion criteria already presented in this paper.

A new column was created in the table and after reading each paper, it was marked with the adequate status (I - included; E - excluded).

For each paper marked with the Excluded status, we attributed one of the exclusion criteria, as follows:

1) It does not answer the question on requirements specification;
2) It is not about a context-aware application;
3) Neither about requirements specification nor context-aware application (combination of 1 and 2);
4) Duplicated paper;
5) It is not a paper, thesis or dissertation; and
6) Document not available.

The process of paper inclusion and exclusion was performed by three persons: the student, the advisor and the co-advisor. The authors know that this process should include more persons to decrease the distortion in the criteria and undue exclusions of papers that are relevant to this research.

4) Extraction: In this step we fully read each included paper. hence, we were able to clear any doubts and get a less biased decision about its maintenance or exclusion from the selected set, considering the established criteria.

In this step we also extracted the data relevant from each paper in order to try to answer the five research questions defined in the planning phase of this protocol.

5) Conclusion: In this phase we were able to create reports and graphs based on the results found by the search tools and create a few conclusions.

III. Analysis of the Results

In the section we will present and analyze the results found in each step of the systematic mapping.

As a result of the execution step, in which we executed the different search engines with the strings selected, a total of 462 papers was found, as seen in Tables I and II.

Table I: Papers found during the Execution phase classified by Search Engine.

Search engine	**Papers Found**
ACM DL	101
Engineering Village	4
IEEExplorer	100
Science Direct	34
Scopus	79
Springer	144
Web of Science	0
BDTD	0
Total	**462**

Table II: Papers found during the Execution phase classified by publication year.

Year	**Papers Found**
2005	25
2006	38
2007	36
2008	48
2009	48
2010	65
2011	67
2012	52
2013	64
2014	19

In the Selection phase, papers were marked with the status of Included or Excluded and for each paper marked as excluded, an exclusion criterion was attributed. Table III shows the occurrences of each exclusion criterion during the Selection phase.

Table III: Paper exclusion criteria and their respective occurrences during the Selection phase

Exclusion criterion	**Excluded papers**
1	109
2	50
3	134
4	88
5	15
6	17
Total excluded	**413**

Analyzing Table III, it is possible to realize that most papers were excluded based on criteria 1 to 4, which suggests a problem in the search string. Exclusion due to criteria 1 and 3 (70%) happened because papers mention either *"requirements specification"* or *"context-aware"*, but not both of them in the abstract. There was also a high number of exclusions due to criterion 4(21%) due to paper repetition (same title, authors and publication year) in the returned set from different search engines.

At the end of the Selection phase, there remained 49 papers which are presented in the Tables IV and V: Table IV presents them grouped by search engine, while Table V groups them by publication year.

Table IV: Papers remaining after the Selection phase, classified by search engine.

Search Engines	Remaining papers
ACM DL	10
Engineering Village	0
IEEExplorer	17
Science Direct	3
Scopus	9
Springer	10
Web of Science	0
BDTD	0
Total	**49**

Table V: Papers remaining after the Selection phase, classified by publication year.

Year	Remaining papers
2005	3
2006	5
2007	4
2008	6
2009	4
2010	9
2011	8
2012	4
2013	5
2014	1

After reading the remaining 49 papers, it was possible to determine whether a paper whether a paper was relevant to the research.

It was defined that a paper would be considered irrelevant to this research if it did not propose a specification support document or tool, or if it did not use any tool to support specification, international standards or even provided details on how the requirements were specified.

After the elimination of the non relevant papers, 17 out of the initial 49 were discarded. Hence, we had 32 papers with information relevant to our research. Based on these papers, it is possible to extract some useful information.

Table VI presents the remaining papers after the Extraction phase classified by search engine, meanwhile Table VII presents the same papers grouped by publication year.

Figures 1 to 4 present the data shown in Tables VI and VII in order to make it easier to understand the results and to better structure them.

Figure 1 present the result of the remaining papers at the end of the Execution, Selection and Extraction phases grouped by search engine. Figure 2 presents the same results grouped by publication year.

Table VI: Papers remaining after extraction phase classified by search engine.

Search engine	Remaining papers
ACM DL	8
Engineering Village	0
IEEExplorer	12
Science Direct	1
Scopus	6
Springer	5
Web of Science	0
BDTD	0
Total	**32**

Table VII: Papers remaining after extraction phase classified by publication year.

Year	Remaining papers
2005	3
2006	5
2007	4
2008	6
2009	4
2010	9
2011	8
2012	4
2013	5
2014	1

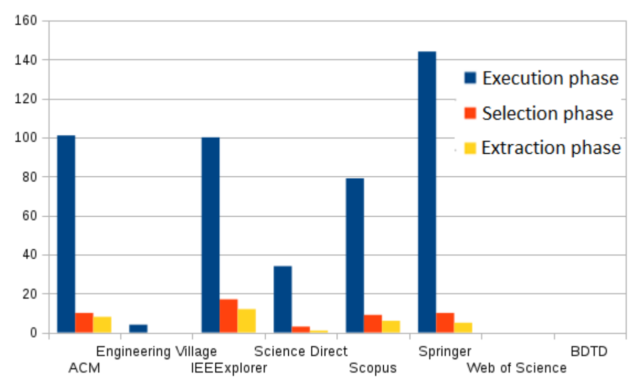

Figure 1: Papers remaining after the three phases, classified by search engine.

According to Figure 3, observe that more than 60% of the relevant papers come from the IEEE and ACM digital libraries, a fact that suggests that conferences and/or journals with those brands attract more researchers on Requirements Engineering for context-aware systems.

We can also observe that there was a increase in the number of papers along the last two five-year periods: 44% (14 papers) published between 2005 and 2009 and 56% (18 papers) published between 2010 and 2014. Since this result occurred in the middle of 2014, it did not include all papers published that year. Hence, this growth in numbers may suggest that Requirements Engineering for context-aware systems is still an interesting research theme (Figure 4).

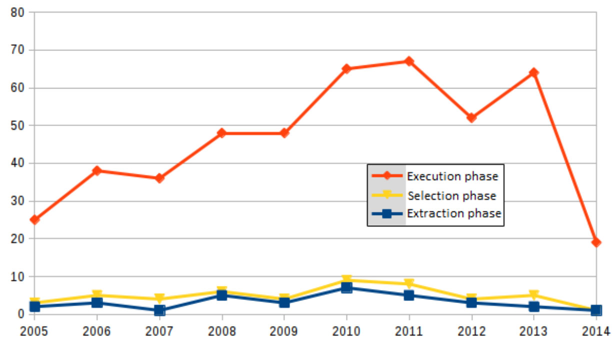

Figure 2: Papers remaining after the three phases, classified by publication year.

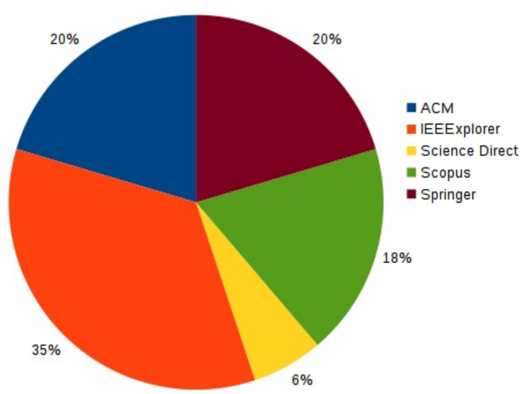

Figure 3: Relevant papers classified by digital library.

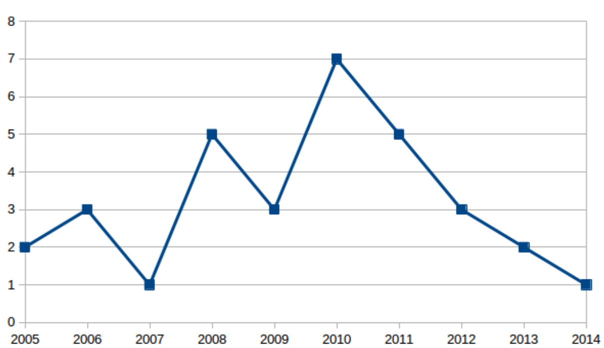

Figure 4: Relevant papers classified by publication year.

According to Figure 5, only 13% of the papers present a proposal for a requirements specification artifact model and 13% of the papers do not present an artifact, but use an international standard to specify requirements. These data may suggest that these researches do not propose artifacts and/or innovative standards to specify requirements, using only those already known in Requirements Engineering.

The international standards used by the authors of the selected papers include the following:

- ISO/IEC 9126-1: standard for software product quality, it establishes quality models for process, external product and quality of use [10]. It was replaced in 2007 by ISO/IEC 25000 [11];
- ISO/IEC 25020: it provides reference models and a guideline to measure and evaluate the quality requirements for a software [12];
- ISO/IEC 25030: it provides requirements and recommendations for the specification of software quality requirements [13];
- IEEE 830: it describes recommendations for the specification of software requirements [14]. It was replaced by IEEE Std 29148 [15];
- ISO 10303 - 233: it defines requirements, scope and information for several development stages during the project of a system [16].

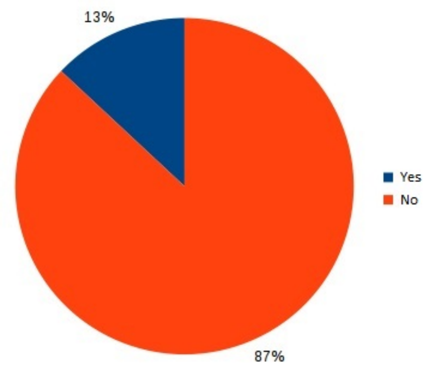

Figure 5: Number of papers that present a new proposal for a requirements specification document.

On the subject of requirements specification and modelling (Figure 6), 47% of the papers use natural language. Formal description corresponds to 30%, and, in a small scale (19%), papers use formal descriptions with ontologies. The smallest part (4%) use UML language to describe requirements.

This suggests that the easiest way to specify requirements in natural language, but with the need to specify requirements unambiguously in execution time, formal descriptions are much used, since both forms of formal description (with a formal language and an ontology), sum up to be the majority (49%).

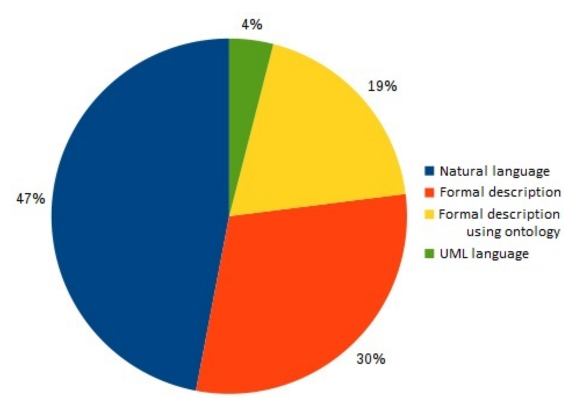

Figure 6: How the papers specify and model requirements.

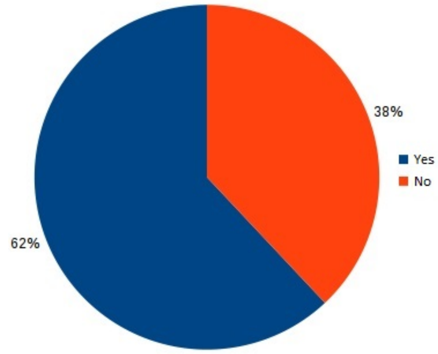

Figure 7: Requirements specification tool support.

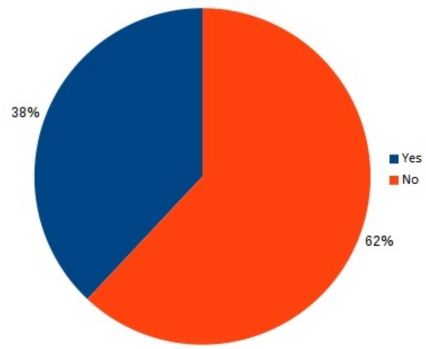

Figure 8: Papers that make use of a tool for requirements specification.

Figure 7 shows that most of the relevant papers (62%) introduces a proposal to support requirements specification for context-aware systems (a tool, a framework, a language, etc), suggesting that the development of new support tools is still an area that requires research.

When analyzing the proposals presented by the authors for specification support tools, we can see that 50% of the papers concern themselves specifically with requirements modelling and 16% of them focus on the definition of non functional requirements. Besides, 33% focus their research efforts on how to allow requirements to be included and updated in execution time for context-aware systems. Hence, we conclude that nowadays the main efforts in the area are to model requirements in the most efficient way and to specify and update the requirements in execution time, which are some of the main challenges of this area.

Figure 8 shows that most of the relevant papers (62%) does not use any support tool for requirements specification for context-aware systems, which is the exact inverse number of the papers that proposes tool. This may suggest that in general that papers that do not propose a new tool use an existing one for their goal.

From the 32 relevant papers, it was possible to find out that approximately 30% (i.e. 9) come from Italian research groups. One particular research from the University of L'Aquila, in Italy, called Paola Inverardi is very relevant, with 3 of those 9 publications found.

North american researchers have 4 relevant publications on the area, with no dominance of any single research group. On the other hand, out of the 5 papers that involve British researchers, two include Italian coauthorship. There are also 3 publications on the topic from Brazilian researchers, one of them also in collaboration with Italian researchers. Table VIII summarizes the results found in this section.

Table VIII: Summary of the research results.

Information	Data found
Papers found during execution phase	462 papers
Papers remaining after Selection phase	49 papers
Papers remaining after Extraction phase (considered relevant)	32 papers
Most relevant search engines	IEEExplorer (38%) followed by ACM DL (25%)
Highlighted researcher	Paola Inverardi, University of L'Aquila, Itália
Evolution of the topic along the years	Out of the relevant papers, 44% were published between 2005 and 2009 and 56% between 2010 and 2014
According to the requirements specification	Natural language (47%), formal description (30%), ontologies (19%) and UML language (4%)
Papers that propose a model of an artifact for requirements specification	13% of the relevant ones
Papers that use international standards for requirements specification	13% of the relevant ones
Papers that propose tools to support requirements specification	62% of the relevant ones
Out of the papers that propose tools to support requirements specification	Requirements modelling (50%); capture, inclusion and update of the requirements in execution time (34%); focus on non functional requirements (16%)
Open questions	Execution time requirements for context-aware systems

IV. Conclusions and future work

THIS paper describes an analysis on the state of the art of the requirements specification for context-aware systems, summarized in the research questions described next and whose answers can be seen in Table VIII:

- Are there models for specification documents?
- How are requirements specified?
- Are international standards used in requirements specification?
- Are specification support tools proposed (or only used)?
- What are the open questions on requirements specification?

In order to achieve the proposed goal, we used the systematic mapping protocol, which is a research technique that uses as data source the literature on a specific topic and follows a protocol with well defined phases.

At the end of this work we found a synthesis on requirements specification for context-aware systems, indicating in a quantitative way, with the help of numbers, tables and figures, which is the state of the art in relation to what is already solidified in the field and to the points the next research must approach.

Out of the 462 papers initially found, a total of 32 were found to be relevant to this research (7%). Among those deemed relevant[1], it was possible to realize that:

- the digital libraries ACM DL and IEEExplorer include most of the relevant papers on the area;
- research on the area of this paper do not focus on the development of specification models or specific standards;
- natural language is still the most frequent way adopted for requirements specification in the papers relevant to this research;
- the development of new tools to support requirements specification is still a topic of interest in the academic community;
- a large part of the current research focuses on manipulating requirements in real-time for the adaptation of the behavior of context-aware systems;
- the main references to the topic requirements in execution time come from Italian universities, but also include research groups from England and Brazil.

As a final contribution, we can observe that the topic of requirements specification for context-aware systems is still relevant, with a trend towards requirement specification in execution time, given the characteristics of the the target systems of this research.

Finally, based on the conclusions presented here and with the goal of giving continuity to the research on this topic, we suggest the following future work:

- an investigation on the treatment of requirements in execution time for context-aware systems, from their capture to the adaptation of the system behavior;
- a tool that supports the capture, inclusion and update of requirement specification for context-aware systems. A tool with this abilities is still a challenge to this area.

It is important to point out that the items above are goals for the research teams in which the authors are included. This research explore the use of ontologies in the specification and modelling of requirements in execution time for self-adapting systems [5] [17].

[1]The articles considered as relevant to the research (title, authors and publication year) can be found in Table IX of this paper's appendix

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Appendix

Table IX: Table with the 32 papers relevant to the research, after the extraction phase.

Art.	Title	Authors	Ano
1	A Modeling Language for Vehicle Motion Control Behavioral Specification [18]	Wang, Shige; Birla, Sushil K. & Neema, Sandeep	2006
2	A Multi Level Approach to Autonomic Business Process [19]	Oliveira, K.; Castro, J.; Santos, E.; Fidalgo, R.; Espana, S.; Pastor, O.	2012
3	A Product-line Requirements Approach to Safe Reuse in Multi-agent Systems [20]	Dehlinger, Josh & Lutz, Robyn R.	2005
4	A Representation Model for Reusable Assets to Support User Context [21]	Ben Hadji, H.; Su-Kyoung Kim; HoJin Choi	2008
5	A requirements engineering process extended to context information management [22]	Castelli, V.; Thomas, P.; Bertone, R.; Oliveros, A	2011
6	A Requirements-Led Approach for Specifying QoS-Aware Service Choreographies: An Experience Report [23]	Maiden, N.; Lockerbie, J.; Konstantinos, Z.; Bertolino, A.; DE Angelis, G.; Lonetti, F.	2014
7	A Taxonomy for Identifying and Specifying Non-Functional Requirements in Service-Oriented Development [24]	Galster, M.; Bucherer, E.	2008
8	Assessing web applications consistently: A context information approachL. [25]	Molina H., Olsina	2008
9	Continuous adaptive requirements engineering: An architecture for self-adaptive service-based applications [26]	Qureshi, N.A.; Perini, A.	2010
10	Designing Middleware for Context Awareness in Agriculture [27]	Kjaer, Kristian Ellebaek	2008
11	Engineering Autonomous Systems [28]	Serbedzija, Nikola; Bures, Tomas & Keznikl, Jaroslav	2013
12	Feature oriented evolutions for context-aware adaptive systems [29]	Inverardi P., Mori M.	2010
13	Formal Design of Ambient Intelligence Application [30]	Coronato, A.; De Pietro, G.	2010
14	Formal Specification of Wireless and Pervasive Healthcare Applications [31]	Coronato, A.; DE Pietro, G	2010
15	Model Checking Requirements at Run-time in Adaptive Systems [32]	Inverardi, Paola & Mori, Marco	2011
16	Modeling domain variability in requirements engineering with contexts [33]	Lapouchnian A., Mylopoulos J.	2009
17	Modeling Functional Requirements for Configurable Content- and Context-aware Dynamic Service Selection in Business Process Models [34]	Frece, Ales & Juric, Matjaz B.	2012
18	Modelling with Problem Frames: Explanations and Context in Ambient Intelligent Systems [35]	Anders Kofod-Petersen, Jorg Cassens	2011
19	Ontological Support for Managing Non-Functional Requirements In Pervasive Healthcare [36]	Koay, N.; Kataria, P.; Juric, R.; Oberndorf, P.; Terstyanszky, G.	2009
20	PC-RE: a method for personal and contextual requirements engineering with some experience [37]	Alistair Sutcliffe; Stephen Fickas McKay ; Moore Sohlberg	2006
21	Real-Time Embedded Software Design for Mobile and Ubiquitous Systems [38]	Pao-Ann Hsiung; Shang-Wei Lin; Chao-Sheng Lin	2010
22	Reasoning with contextual requirements: Detecting inconsistency and conflicts [39]	Raian Ali; Fabiano Dalpiaz ; Paolo Giorgini	2013
23	Requirements models at run-time to support consistent system evolutions [40]	Inverardi, P.; Mori, M.	2011
24	Requirements specification for apps in medical application platforms [41]	Larson, B.; Hatcliff, J.; Procter, S.; Chalin, P.	2012

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25	Requirements-aware systems: A research agenda for RE for self-adaptive systems [17]	Sawyer P., Bencomo N., Whittle J., Letie E., Finkelstein A.	2010
26	Semantic web service adaptation model for a pervasive learning scenario [42]	Lau, B-Y-S; Pham-Nguyen, C.; Lee, C-S; Garlatti, S.	2008
27	Specification of failure-handling requirements as policy rules on self-adaptive systems [43]	Pimentel J., Castro J., Franch X	2011
28	Support for situation awareness in trustworthy ubiquitous computing application software [44]	Yau S.S., Huang D., Gong H., Yao Y.	2006
29	Towards a Context Binding Transparency [45]	Tom Broens; Dick Quartel; Marten Van Sinderen	2007
30	Towards service orientation in pervasive computing systems [46]	Bellur, U.; Narendra, N.C.	2005
31	UbiCheck: An Approach to Support Requirements Definition in the Ubicomp Domain [47]	Spínola, R. O.; Pinto, F. C.	2010
32	Using Task-oriented Requirements Engineering in Different Domains Experiences with Application in Research and Industry [48]	Adam, S.; Doerr, J.; Eisenbarth, M.; Gross, A.	2009