Mobile Application Verification: A Systematic Mapping Study

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Abstract. The proliferation of mobile devices and applications has seen an unprecedented rise in recent years. Application domains of mobile systems range from personal assistants to point-of-care health informatics systems. Software development for such diverse application domains requires stringent and well-define development process. Software testing is a type of verification that is required to achieve more reliable system. Even though, Software Engineering literature contains many research studies that address challenging issues in mobile application development, we could not have identified a comprehensive literature review study on this subject. In this paper, we present a systematic mapping of the Software Verification in the field of mobile applications. We provide definitive metrics and publications about mobile application testing, which we believe will allow fellow researchers to identify gaps and research opportunities in this field.

Keywords: Verification, Software Testing, Mobile Application, Systematic Mapping, Literature Review

1 Introduction

Software Testing is the most frequently utilized software verification technique, which aims to ensure bug-free and reliable software products on the market. That's why, it is one of the most important topics in software development and quality assurance. Craig and Jaskiel describe software testing as "A concurrent life cycle process of engineering, using and maintaining test ware in order to measure and improve the quality of the software being tested." [24]. The purpose of testing is to improve software quality by finding bugs before these bugs cause serious effects [25].

In today's world, all sorts of mobile devices including mobile phones and personal digital assistants (PDAs) changed the way we use technology and live our daily lives. Such a world-wide network of uniquely addressable, interconnected objects (Cisco predicts 50 billion connected objects by 2020) [27] are heading into a new era of ubiquity, where the "users" of the Internet will be counted in billions and where humans may become the minority as generators and receivers of traffic.

Mobile Application Testing is defined as "Mobile application testing is a process by which application software developed for hand held mobile devices is tested for its functionality, usability and consistency."[30] Thus, mobile application testing is equally critical as the verification of general purpose computer programs; moreover, it is a trending topic as shown by Google trends in Figure-1 [21]. Figure 1 shows us number of searches on Google for a specific term in a period of time. One can see in Figure-1, the number of searches for "Mobile Application Testing" is increasing over time.

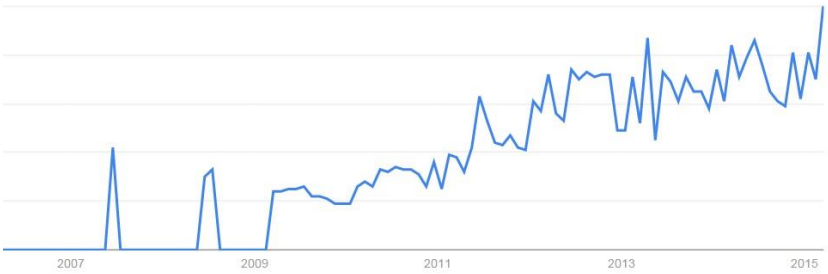

Fig. 1. Search Volume Index for "Mobile Application Testing" [21].

When we scan literature for secondary studies, we found a survey study for model-based GUI testing[22] and another survey study for usability testing[23]. As opposed to the importance and popularity of the topic (Figure-1), we couldn't find any literature review study that covers mobile application (software) testing in general.

In this paper, we provide the results of our review on the subject matter in order to identify gaps, trending opportunities and facilitate future research directions by presenting them in the form of a systematic mapping. We provide definitive metrics and publications about mobile application testing, which we believe will allow fellow researchers to identify gaps and research opportunities in this field.

The rest of the paper is structured as follows: Section 2 Systematic Mapping Process where we defined our steps while doing this literature review study. Section 3 answers the research questions with synthesized data that extracted from primary studies. Section 4 describes the threats to the validity for the mapping study, and Section 5 presents a conclusion and future work of the study.

2 Systematic Mapping Process

A primary study is defined as a firsthand empirical work in an area, where secondary study is defined as "A study that reviews all the primary studies relating to a specific research question with the aim of integrating/synthesising evidence related to a specific research question." [29]

We have applied systematic mapping study method to our secondary study research[3][29] on topic of Mobile Application Verification: A Systematic Mapping Study.

2.1 Definition of Research Scope

We asked specific questions to define body of knowledge about related literature. Research questions and their main motivations to research are shown below.

Table 1. Research Questions

Research Questions	Main Motivation
RQ1: What are the most frequently used test types for mobile applications? (Compatibility, Concurrent, Conformance, Performance, Security, Usability)	Identify trends and opportunities for mobile application testing.
RQ2: Which research issues in mobile application testing are addressed and how many papers cover the different research issues? (Test Execution Automation, Test Case Generation, Test Environment Management, Testing on Cloud, Model Based Testing)	Identify which research areas are widely used in mobile application testing papers.
RQ3: At what test level have researchers' studies most frequently? (Unit, Component, Integration, System, Acceptance)	Provide information for most frequently studied test level
RQ4: What is the paper-publication frequency?	Provide a trend analyze graph
RQ5: Which journals include papers on mobile application testing?	Identify journals which researchers may publish their studies

2.2 Search for Primary Studies

As a first step of a literature review study, we searched digital databases to get primary studies [3]. We selected keywords: mobile, application and test, then used their synonyms to construct search strings (Table 2).

Table 2. Search Strings

(Mobile)
AND
(Application OR Software)
AND
(Test OR Testing OR Validation OR Verification)

After deciding search strings we applied same search strings to 4 digital library and collected the results without any time constraint (Table 3). In order to monitor popularity increase of the topic, we did not limit search by year. In turn, we get the results those are published until June 2014. Thus; we did not include studies that published after June 2014. Downloading, managing and working on collection of papers are complex tasks that cannot be done with manual techniques using spreadsheet applications. Hence, we used several reference management tools such as Zotero [4] and JabRef [5]. We used Zotero to download references automatically from digital databases, and used JabRef to manage all downloaded studies, to merge them, to apply filter and to apply exclusion criteria.

Table 3. Search Result in Digital Libraries

No	Name	Result
1	IEEE	8.157
2	ACM	1.908
3	Science Direct	1.218
4	Springer Link	1.516
	Total	**12799**

We collected search results and merged them with eliminating duplicate studies that were downloaded from different digital databases. We applied three filters (Figure 2) to get primary studies. The filters that we applied to search results (12799 papers) described in Table-4. At the end of the filtering process, we got 123 primary studies (see Appendix A).

Table 4. Filters Applied to Search Results

Filters	Description
Filter-1	We excluded studies from irrelevant journals and conferences.
Filter-2	We read the study title and abstract and to eliminate clearly irrelevant papers.
Filter-3	We read abstracts deeply and some cases full text to apply our inclusion and exclusion criteria.

Fig. 2. This figure illustrates the changing number of target papers as the filters, described in Table-4, applied.

2.3 Inclusion and Exclusion Criteria

In systematic mapping studies, we need to select some papers in purpose of answering the research questions. We use inclusion and exclusion criteria to have an objective study selection process. We define these criteria at the beginning of the selection process, to avoid selection bias.[1][28]

We applied inclusion and exclusion criteria to filter two results on purpose of select studies as our primary studies.

Inclusion Criteria: We included studies that contribute mobile application (software) testing in a particular way such as a theory, a solution, a practice, a strategy or an approach. In addition to regular research papers, we also took into account short papers. When a study has several versions, we accepted the new one, except the case that if there was any extension to the original study. In that case, we included both versions.

Exclusion Criteria: We excluded studies that do not clearly linked to mobile application testing, and do not clearly investigate the topic. Book chapters, secondary studies, thesis, and experimental studies, those do not propose a solution or an approach, were also excluded. Studies on testing mobile devices, hardware of mobile devices or hardware used by mobile application were also excluded, because we limit our mapping study only with mobile software testing.

2.4 Classification Schema

We grouped 123 studies, which we had after filtering process, with a view of software testing as test levels [19] and test types [20]. In order to classify researchers' contribution areas [20] we also categorized the research issues. We classified studies according to Table 5.

Table 5. Classification Framework

Category	Subcategory	Definition
Test Levels	System Testing	"Testing conducted on a complete, integrated system to evaluate the system's compliance with its specified requirements." [12]
	Acceptance Testing	"Formal testing conducted to enable a user, customer, or other authorized entity to determine whether to accept a system or component." [13]
	Unit Testing	"Testing of individual hardware or software units or groups of related units." [12]
	Component Testing	"Testing of individual hardware or software components or groups of related components." [12]
	Integration Testing	"Testing in which software components, hardware components, or both are combined and tested to evaluate the interaction between them." [12]
Test Types	Compatibility	"The ability of two or more systems or components to perform their required functions while sharing the same hardware or software environment." [12]
	Concurrency Testing	"Testing to determine how the occurrence of two or more activities within the same interval of time, achieved either by interleaving the activities or by simultaneous execution,

		is handled by the component or system." [12]
	Conformance Testing	"Conformance testing is testing to see if an implementation meets the requirements of a standard or specification." [15]
	Performance Testing	"Testing conducted to evaluate the compliance of a system or component with specified performance requirements." [12]
	Security Testing	"Testing to determine the security of the software product." [14]
	Usability Testing	"Testing to determine the extent to which the software product is ATA understood, easy to learn, easy to operate and attractive to the users under specified conditions." [12]
Research Issues	Test Execution Automation	"The use of software, e.g. capture/playback tools, to control the execution of tests, the comparison of actual results to expected results, the setting up of test preconditions, and other test control and reporting functions." [14]
	Test Case Generation	"A computational method for identifying test cases from data, logical relationships or other software requirements information." [17]
	Test Environment:	"An environment containing hardware, instrumentation, simulators, software tools, and other support elements needed to con-

	duct a test." [12]
Cloud Testing	"Cloud Testing uses cloud infrastructure for software testing. Cloud computing offers use of virtualized hardware, effectively unlimited storage, and software services that can aid in reducing the execution time of large test suites in a cost-effective manner." [18]
Model-based testing	"Testing based on a model of the component or system under test, e.g., reliability growth models, usage models such as operational profiles or behavioral models such as decision table or state transition diagram." [14]

2.5 Data Extraction and Mapping of the Literature

After selecting primary research papers we extracted data from studies, on purpose of analyze them. We used a data extraction form shown in Table 6. During extraction process, if a paper did not clearly define research issue or testing type, we left this section blank, to avoid making any assumptions.

Our data extraction methodology is as follows: Before starting data extraction process for 123 studies, we randomly chose a small dataset. Then, I extracted data according to Table-6. A different author also did the extraction process for same data set. I did a cross-check. When I found a conflict, I went back to this study to make an inspection, and identified the reason caused to conflict. After I satisfied all these points worked on the dataset, I applied data extraction process to 123 papers to get the results.

Table 6. Form for Data Extraction

No	Data Extraction Columns
1.	Study ID (example: S1)
2.	Title: Paper's title (example: Big Data Processing Research: A Systematic Review)
3.	Author: Author's name
4.	Year: Publication year (example: 2014)
5.	Conference or journal name: Any conference or journal name (ex: IEEE Big Data 2014)
6.	Test Levels: System testing or unit testing
7.	Test Type: Performance, conformance

8.	Research Issues: Test automation, Test environment management
9.	Test Environment: Real Device, Target System
10.	Contribution Type: Process / method / model / framework / metric
11.	Research Method: Theory / Survey / Experiment / Own Experience / Review
12.	Study Context: Student or simple projects / Professional Projects / None

3 RESULTS

This section discusses outputs of the data extraction process that are described in Section 2.3. Each research question was answered and evaluated separately but, in order to improve understanding, we grouped the results according to the Table.5.

3.1 RQ1: What are the most frequently used test types for mobile applications? (Compatibility, Concurrent, Conformance, etc.)

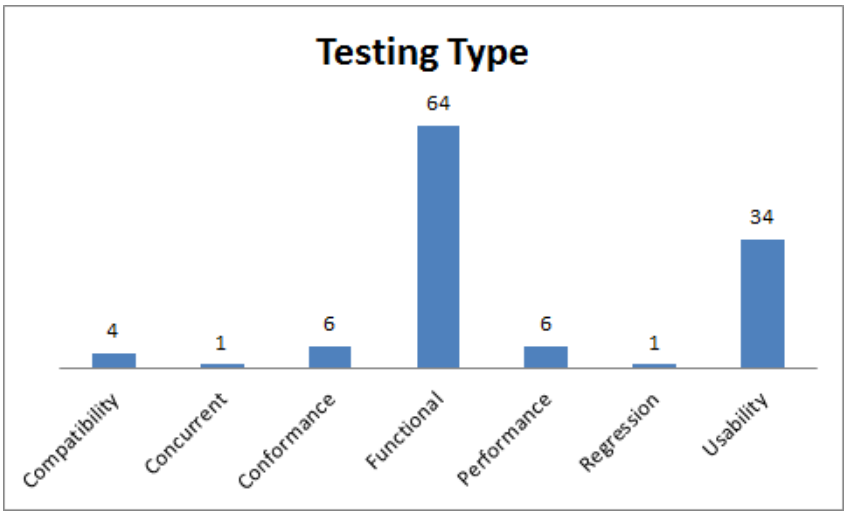

Fig. 3. Frequency of mobile application testing type in published papers

The distribution of publications according to testing type/technique is shown in Figure-3. The most frequently researched testing techniques are functional testing and usability testing.

Mobile applications tend to prevail as the dominant computing platform for the upcoming decades; because, proliferation of internet with the Internet of Things concept shall entail employing much more mobile applications in very diverse domains. Thus, performance issues will be of great interest in resource constrained embedded devices.

RQ1 seeks to identify research trends and opportunities in testing techniques. As one can tell from Figure-3, functional and usability testing types have already been studied in many research papers. We think that performance testing may provide opportunities in terms of research in mobile application testing research field.

3.2 RQ2: Which research issues in mobile application testing are addressed and how many papers cover the different research issues?

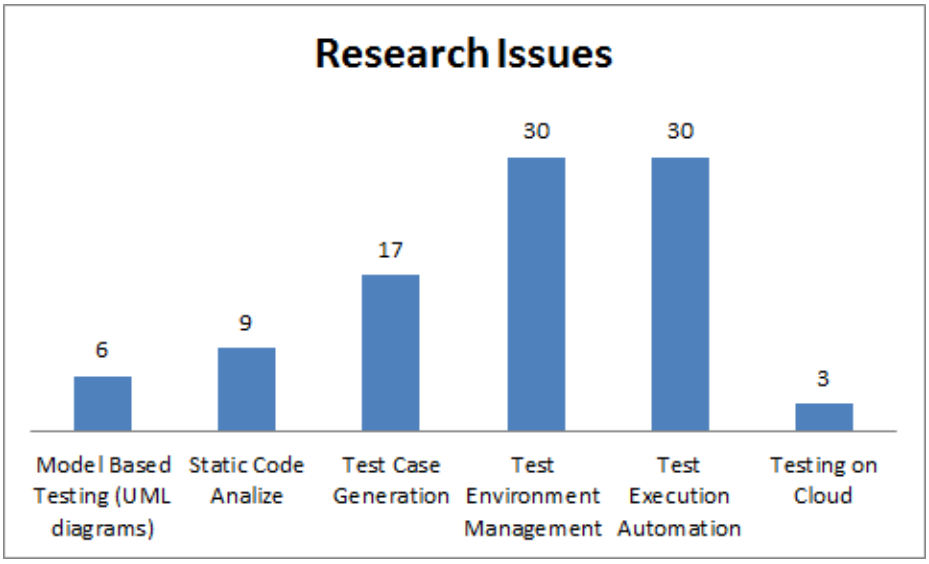

Fig. 4. The distribution of publications according to research issues

We have described several research issues that relate to research in mobile testing. The literature review we conducted yielded the results shown in Figure-4. After careful inspection and applying inclusion-exclusion criteria, a total of ninety five (95) publications are classified into six (6) different research issues.

RQ2 seeks to identify the opportunities for open research issues. The results indicate that test environment management, test execution automation and test case generation are the top three issues that are most frequently addressed in research community; whereas, model-based testing and testing on the cloud are the least challenged issues. Thus, we define testing on the cloud and model-based testing as the most promising research issues for the years to come.

3.3 RQ3 : At what test level have researchers studies most frequently?

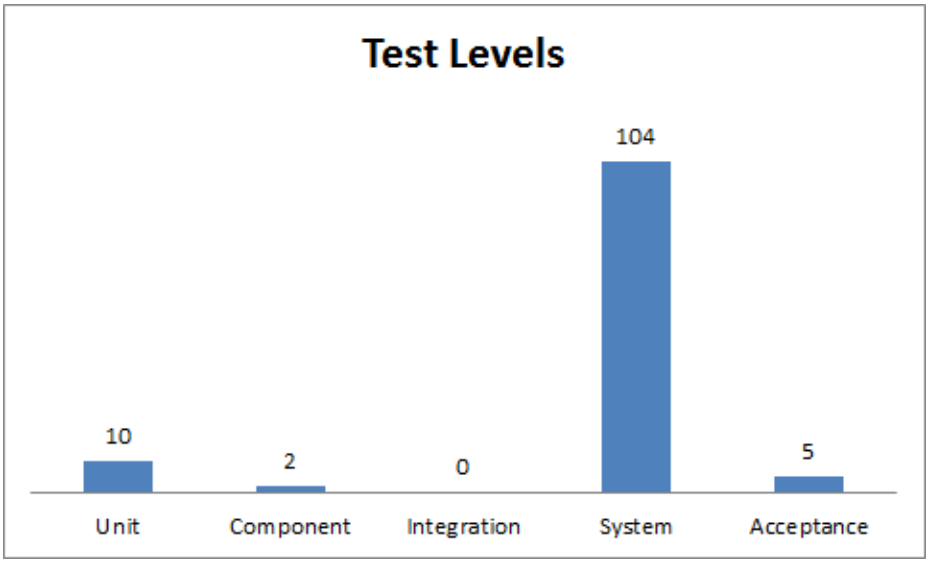

Fig. 5. The distribution of publications according to Mobile Application Test Levels

The majority of the research literature concentrated on system level testing as shown in Figure-5. This is not surprising, because software testing generally deals with system level challenges. This infers that any new research to be conducted should concentrate on system level testing problems.

3.4 RQ4. What is the papers publication frequency?

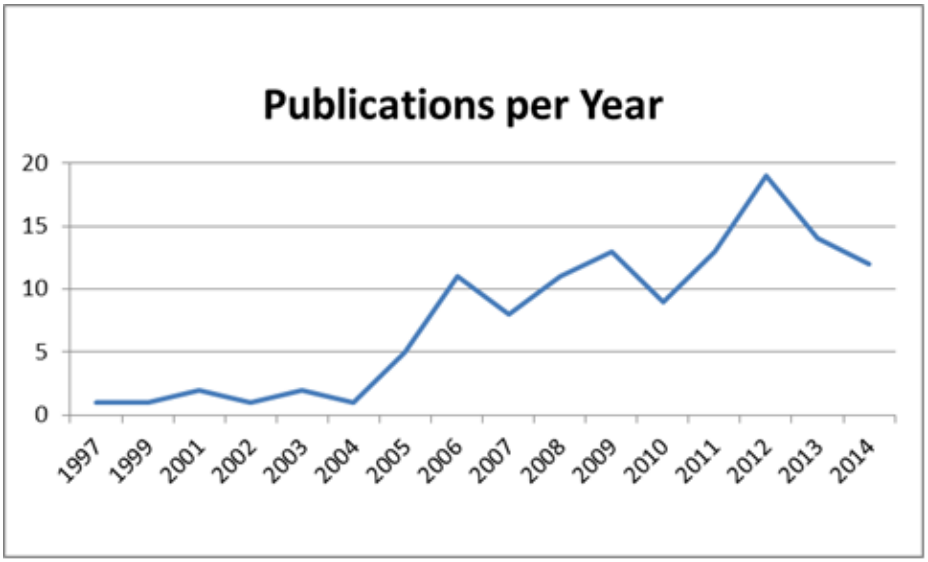

Fig. 6. Publication frequency per year

We have identified that the literature on mobile application domain picked up an upward momentum with the proliferation of mobile devices in everyday life (Figure-6). The results shown in Figure-6 indicate that the total number of publications per individual year. We think that this is revealing a correlation with the maturity of the subject domain.

3.5 RQ5: Which journals and conferences include papers on mobile application testing?

Table 7. Journal Names

Journal No	Journal Names
1	Computer
2	Information and Software Technology
3	IT Professional
4	Procedia Computer Science
5	Procedia Technology
6	Software Engineering, IEEE Transactions on
7	Software, IEEE
8	Advances in Computers
9	Software Engineering Notes
10	Universal Access in the Information Society

11	Computing
12	Systems and Service-Oriented Engineering
13	Journal of Interaction Science
14	Software Testing, Verification & Reliability
15	Mobile Networks and Applications
16	Personal and Ubiquitous Computing
17	Multimedia Tools and Applications
18	Interactions
19	Software Quality Journal
20	The Journal of Supercomputing
21	Tsinghua Science & Technology

4 Threats to validity

In general, we may consider wrong decision-makings in the followings as threats to validity for the mapping study: research questions, publication selection, and data extraction. We describe each possible treat below and give our methodology to eliminate them.

Research Questions: The research questions may not cover all mobile software testing area in detail. We tried to get only a snapshot of mobile application testing literature. This study is not a subject specific literature review.

Publication Selection: Even though we searched major digital databases we cannot guarantee that we included every related study and applied our criteria.[2] To mitigate that threat we did snowballing.

Data Extraction: Since data extraction depends on personal judgment, there is possibility of incorrect decision. We selected a data set, and two researchers did the data extraction. Then we compared with others answers. When there is a disagreement, we both checked, talked and decide to a settlement.

5 Conclusion and Future Work

Our motivation was to summarize existing studies in mobile application testing area and conduct a gap analysis. The main contribution of this study is to provide a mapping of the current-state of art on mobile application testing.

By analyzing the results shown in Figure-3, Figure-4 and Figure 5, we conclude that software testing research is open to new contributions in general. In particular, research on performance testing of mobile applications may provide more research opportunities as we observe lack of research studies in that area. The results also indicate immerging research needs on ***mobile application testing on the cloud***, which

deal with ***test execution automation*** or ***test environment management*** for ***system level functional testing.*** Analyzing the results, we also observe that previous research gives high importance to system level testing problems.

Work remains in extending this study to conduct a systematic literature review on mobile application testing. As future work, we will also investigate how to devise a framework for mobile system testing framework on cloud computing platforms.

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Appendix A. Selected Primary Studies

Study ID	References
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S02	Amalfitano, D.; Fasolino, A.R.; Tramontana, P.; Amatucci, N., "Considering Context Events in Event-Based Testing of Mobile Applications," Software Testing, Verification and Validation Workshops (ICSTW), 2013 IEEE Sixth International Conference on , vol., no., pp.126,133, 18-22 March 2013
S03	Amalfitano, D.; Fasolino, A.R.; Tramontana, P.; De Carmine, S.; Memon, A.M., "Using GUI ripping for automated testing of Android applications," Automated Software Engineering (ASE), 2012 Proceedings of the 27th IEEE/ACM International Conference on , vol., no., pp.258,261, 3-7 Sept. 2012
S04	Amalfitano, D.; Fasolino, A.; Tramontana, P.; Ta, B.; Memon, A., "MobiGUITAR -- A Tool for Automated Model-Based Testing of Mobile Apps," Software, IEEE , vol.PP, no.99, pp.1,1
S05	Stephan Arlt, Cristiano Bertolini, Simon Pahl, Martin Schäf, Chapter 6 - Trends in Model-based GUI Testing, In: Ali Hurson and Atif Memon, Editor(s), Advances in Computers, Elsevier, 2012, Volume 86, Pages 183-222, ISSN 0065-2458, ISBN 9780123965356
S06	Rebecca Baker, Xiaoning Sun, and Bob Hendrich. 2011. Testing touch: emulators vs. devices. In Proceedings of the 4th international conference on Internationalization, design and global development (IDGD'11), P. L. Patrick Rau (Ed.). Springer-Verlag, Berlin, Heidelberg, 135-142.
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S08	Srikanth Baride and Kamlesh Dutta. 2011. A cloud based software testing paradigm for mobile applications. SIGSOFT Softw. Eng. Notes 36, 3 (May 2011
S09	Ana Correia de Barros, Roxanne Leitão, Jorge Ribeiro, Design and Evaluation of a Mobile User Interface for Older Adults: Navigation, Interaction and Visual Design Recommendations, Procedia Computer Science, Volume 27, 2014, Pages 369-378,
S10	Selin Benli, Anthony Habash, Andy Herrmann, Tyler Loftis, and Devon Simmonds. 2012. A Comparative Evaluation of Unit Testing Techniques on a Mobile Platform. In Proceedings of the 2012 Ninth International Conference on Information Technology - New Generations (ITNG '12).
S11	Birgitta Bergvall-Kåreborn and Staffan Larsson. 2008. A case study of real-world testing. In Proceedings of the 7th International Conference on Mobile and Ubiquitous Multimedia (MUM '08).
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S14	Robert V. Binder and James E. Hanlon. 2005. The advanced mobile application testing environment. In Proceedings of the 1st international workshop on Advances in model-based testing (A-MOST '05)
S15	Jiang Bo, Long Xiang, and Gao Xiaopeng. 2007. MobileTest: A Tool Supporting Automatic Black Box Test for Software on Smart Mobile Devices. In Proceedings of the Second International Workshop on Automa-

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