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Research paper

Regression Testing Systematic Literature Review – A Preliminary Analysis

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Abstract

Software needs to be modified and frequently maintained by what is called *regression testing*. Regression testing is a costly but necessary maintenance activity in the software development lifecycle (SDLC), which can be performed to revalidate modified software to make sure that changes did not adversely affect software behavior. Several studies have been carried out regarding regression testing domain in the literature. However, these studies need to be classified, summarized and ordered in a systematic manner to spot on the current state of the art of regression testing field. Previously, a protocol for conducting systematic literature review for regression testing was carried out. Therefore, this paper will carry out a systematic literature review (SLR) to illustrate the current state-of-the-art of regression testing domain. In this SLR, a manual search has been conducted to obtain related studies from four various sources where those studies were classified under journal, conference proceeding, and book chapter categories within specific criteria. Consequently, the initial search resulted in 1261 unfiltered studies, which then decreased according to certain predefined criteria up to 246 selected relevant studies. For the next stage, primary and secondary studies were identified. As a result of this stage, major regression testing concepts such as: approaches, frameworks, models and tools were briefly presented, analyzed and discussed in related with selected studies. In the future, regression testing approaches, techniques and tools will be further discussed in more detail.

Keywords*: *Regression testing; software maintenance; systematic review; software testing.

1. Introduction

Software needs to be modified based on change demands mostly obtained from: users, managers, or other stakeholders, within the aim of improving software functionality in the form of adding new features, modifying existing features, or eliminating others. However, these changes naturally lead to introduce new faults [1], [2], and validating software after these modifications to ensure there is no faults were introduced is what called a *"regression testing"*[3]. Such "regress", i.e.: failure or faults, is necessary to be uncovered after modifications to ensure the quality of modified system under test (SUT) [4]. Regression testing practice increased due to the growth in software demand on the software industry around the world. In software industry, studies indicate that more than 50% of software maintenance cost is related to testing activities. Moreover, regression testing activities alone costs up to 80% of those costs, i.e.: more than one-third of the software production total costs [5]–[9]. However, this process is getting costly, and time consumed especially when size and complexity of systems increased [10]. Increasing cost of regression testing leads the researchers and practitioners in this field looking for further ways not only to decrease the cost of regression testing, but also to increase its effectiveness and performance in terms of ensuring high quality achievements.

Regression testing is an important part of software testing which specifically applied during software project development and maintenance[11], [12], and it has many published studies in the literature. To the best of our knowledge, However, these studies need to be classified, summarized and ordered to spot on the current state of regression testing field, since there is no general and comprehensive systematic literature review has been conducted to highlight regression testing domain in terms of approaches, frameworks, models and tools. To address these issues, this paper presents a systematic literature review that studying the regression testing systematically. In this paper, next section briefly described the related studies, and the aspects of the Regression Testing Systematics Literature Review (SLR) are discussed in more detail in the next section. In addition, the preliminary findings section highlights and briefly discusses the findings of the SLR. This paper ends with a summary and future study directions of the regression testing.

2. Literature Review

Not only a few systematic review studies were published in the literature, but also these studies were concentrated on specific approaches of regression testing such as test case selection approach or test case prioritization approach but not combination, whereas models, frameworks, process and tools have not been highlighted in such studies to give a complete picture about regression testing. Some of these studies were specific for empirical evaluations as emphasized in the following sub-sections.

2.1. Definition and Problem of Regression Testing

Formally, IEEE standard glossary of software engineering terminology defines regression testing as follows: "Selective retesting of a system or component to verify that modifications have not caused unintended effects and that the system or component still

complies with its specified requirements."[6], [11], [13]. In other words, regression testing can be defined as a "software maintenance task performed on a modified program to instill confidence that changes are correct and have not adversely affected the unchanged portions of the program"[4]. According to [14], regression testing problem is described as:
"Given program P, its modified version P', and test set T used previously to test P, find a way, making use of T, to gain sufficient confidence in the correctness of P'."[15].

2.2. A Brief History

In the past, regression testing simply has been carried out as a type of retesting the modified software within the existing test suites and test data. However, this way is a very costly and time consumed [1]. After that, testers start to optimize test suites by selecting test cases randomly, unfortunately this way is not effective in accordance with coverage and fault detection ability [16]. In 1981, the first systematic approach for selecting test cases to perform regression testing effectively was proposed by Fischer, Raji and Chruscicki[17], [18], and this improvement establishes a new trend towards regression testing effectiveness called selective retest approach or regression test selection approach as others prefer. In 1997, another approach of regression testing was introduced by proposing [19] their technique, establishing by that a new regression testing direction, which specifically called test case prioritization approach[20].

2.3. Related Studies

Engström et al. [21], conducted a systematic review on regression test selection techniques for the period between 1969 to 2006. Their study focuses on empirical evaluations and selection approach for regression testing, where 28 papers were selected and reviewed among 2923 from seven databases. However, this study ignores test prioritization and hybrid approaches of regression testing, and their focus concentrated only on evaluated techniques meanwhile frameworks and models were neglected. Another study by Engström et al. [22] was published in 2010, where 27 studies were selected and among them 36 empirical studies, 21 experiments and 15 case studies were reported.

3. Methodology

In order to conduct a systematic literature review in any software engineering discipline, Kitchenham et al. [23] provided comprehensive guidelines to facilitate this process and these guidelines were used in this review. Thus, our review process consists of three phases: planning, conducting and reporting the review. For the first stage, we formulated a set of research questions and prepared a review protocol to be a basis throughout data collection process. Next, we conducted a manual search through various sources and selected relevant papers based on the protocol. Accordingly, the selected papers were read thoroughly, and data were extracted in a tabular form as stated in data extraction section. Finally, we analyzed results and prepared them for reporting. This review addresses two main questions and each question has sub-questions. The questions were emphasized as:

1. How many regression testing articles published up to 30th June 2016?
   1.1. How many regression testing *SLRs*?
   1.2. How many regression testing *Reviews / Surveys*?
   1.3. How many regression testing *Primary Studies*?
2. What are the highlighted core concepts of regression testing in these published articles?
   2.1. Approaches.
   2.2. Process.
   2.3. Frameworks.
   2.4. Models.
   2.5. Tools.

3.1. Search Process

The search process is the approach of how primary and secondary studies will be obtained. We conducted a manual search using specific terms in specific databases as following:

- **Terms of Search.** The terms that were used in this search are those related to regression testing keywords generally, with the aim of including many published papers in this domain. Thus, the search string was formulated in general keywords as: ["Regression Testing" OR "Regression Test"].
- **Search Databases.** We conducted a manual search in various online sources and those databases were emphasized in Table 1 as follows:

Table 1: Search Databases

Library	Website
IEEE Xplore	http://ieeexplore.ieee.org/Xplore/home.jsp
ACM digital library	https://dl.acm.org/
Science Direct	http://www.sciencedirect.com/
Wiley Online Library	http://onlinelibrary.wiley.com/

Furthermore, the selected studies take a form of journals, conference proceedings or book chapters, which represented in following sections.

3.2. Paper Selection

To select relevant studies throughout the search process, selection criteria must be defined. Primary and secondary studies which represent the key words in title, written in English and published in completed form were selected, otherwise such studies were missed out. Furthermore, Table 2 presents the inclusion and exclusion criteria for this review.

Table 2: Paper Selection Criteria

Inclusion criteria	Published articles in the following themes were included: ✓ Systematic Literature Reviews (SLRs) articles of Regression Test/Testing. ✓ Review or Survey articles of Regression Test or Testing. ✓ Primary Studies of Regression Test or Testing.
Exclusion criteria	Articles with the following issues were excluded: × Articles have not addressed "Regression Test" or "Regression Testing" in the main title. × Articles have not written in English. × Not completed articles (only abstract or part of the article). × Workshop articles.

3.3. Data Extraction

Data obtained from selected studies takes two dimensions: publication data which include information about each single study such as title, authors and year; and highlighted concepts regarding regression testing. We organized the data obtained from selected studies in a tabular form as emphasized in Table 3:

Table 2: Data Extraction Form

Item	Description
1. Publication Details:	
• ID	Publication identifier.
• Title	The title of the study.
• Author(s)	The writers of the study.
• Publication year	The year when the primary study was published.
• Publication Type	Determine the type of publication (e.g.: journal, conference, etc.).
• Source	The source where paper found.
• Study Type	Determine type of study (e.g.: primary, SLR, etc.).
2. *Highlighted Concepts:*	

• Approaches	The existing approaches used in regression testing.
• Process	The different processes where used during regression testing.
• Frameworks	The existing frameworks applied for regression testing.
• Models	The existing models built for regression testing.
• Tools	The outcome or used tools during regression testing.

4. Preliminary Findings

The preliminary findings of this conducted review were presented in two various levels: results of the conducted search process and results of initial data extraction.

4.1. Search Process

Conducting the search process has been staged in three phases which emphasized as:

- Initial Stage – the initial search performed through specified sources has obtained 1264 papers in general. This amount of papers was filtered in the next phase.
- Title Exclusion Stage – in this stage, we excluded studies that did not demonstrate the specified keywords in the main title. The obtained studies after this step minimized to 287 papers.
- Full-Text Exclusion – at the end of this phase, the full-text of the remaining 287 papers was read and a further 41 studies were excluded by consensus. To be obvious, we found some papers were published in two incorporated databases, i.e.: IEEE and ACM, so these studies were considered and classified according their original sources were published.

Regarding the abovementioned search process, Table 4 presents a summary of the selected studies during each stage of the manual search conducted. Sources of these studies also presented in regards with their percentage of selected studies.

Table 3: Search Process Summary of Relevant Articles

#	Library	Initial Search		Second Stage		Final Stage	
		#	%	#	%	#	%
1	IEEE	174	13.79	129	44.95	124	50.41
2	ACM	331	26.25	102	35.54	73	29.67
3	Science Direct	420	33.31	32	11.15	29	11.79
4	Wiley	336	26.65	24	8.36	20	8.13
	Total	1261	100	287	100	246	100

From the table above, most of the selected studies, 50.41%, has been obtained from IEEE, whereas 29.67% of them obtained from ACM. Science Direct and Wiley databases respectively are the lowest databases that selected studies have obtained from. The overall search process has illustrated in Figure 1 as bellow.

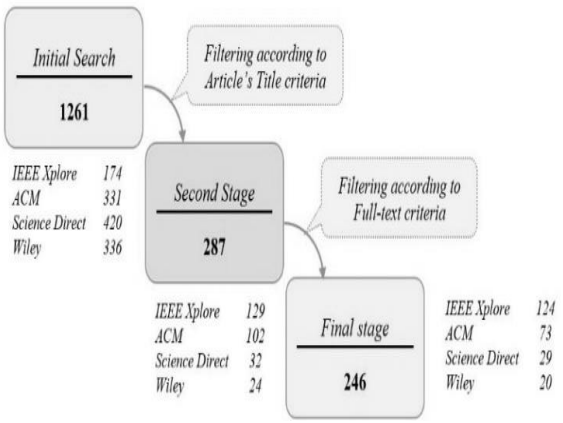

Fig. 1: Phases of the Manual Search Process

4.2. Initial Data Extraction

In this review, we organized the selected studies in two forms: historical and publication type form. Historically, the first research paper has been published in regression testing was in 1981 where placed in ACM database. Table 5 presents the historical growth of publishing in regression testing till this review conducted.

Table 4: Selected Papers According to Publish Year

Year	IEEE Xplore	ACM	Science Direct	Wiley	Total
1981	-	1	-	-	1
1989	1	-	-	-	1
1990	-	-	1	1	2
1991	1	-	-	-	1
1993	3	1	-	-	4
1994	3	-	-	-	3
1995	-	-	1	-	1
1996	1	1	1	-	3
1997	1	1	-	-	2
1998	3	3	1	-	7
1999	1	2	-	-	3
2000	-	2	-	-	2
2001	3	3	1	1	8
2002	2	3	1	-	6
2003	2	3	1	1	7
2004	2	2	-	-	4
2005	4	3	-	1	8
2006	1	3	1	1	6
2007	5	3	1	2	11
2008	4	9	-	1	14
2009	4	3	2	2	11
2010	14	2	1	1	18
2011	15	1	1	3	20
2012	12	4	3	1	20
2013	18	4	2	-	24
2014	6	11	3	1	21
2015	16	6	2	3	27
2016	2	2	6	1	11
Total	124	73	29	20	246

In this table, we can see that there is an increased growth of research in the last ten years. Moreover, most of these studies published in IEEE Xplore and ACM, while the rest in Science Direct and Wiley respectively.

Furthermore, each selected study takes a form of journal, conference or book chapter type; while most of these studies takes the form of conference proceeding, only 3 of them were published as book chapters as well as they were published only in Science Direct database as illustrated in Table 6.

Table 5: Selected Papers Classification According to Publish Type

Library	Journals	Conference Proceedings	Book Chapters	Total
IEEE Xplore	12	112	-	124

ACM	15	58	-	73
Science Direct	26	-	3	29
Wiley	20	-	-	20
Total	73	170	3	246

4.3. Primary Studies

The numbers of selected primary studies were 212, and these studies have presented different concepts and those concepts were classified in this study as: techniques, models, frameworks and other concepts as illustrated in Table 7.

Table 6: Selected Primary Studies

	Techniques	Models	Frameworks	Others
IEEE	82	4	10	14
ACM	40	4	4	12
Science Direct	20	-	-	4
Wiley	13	-	2	3
Total	155	8	16	33

The aforementioned table emphasizes that techniques were proposed in 155 studies which distributed among three regression testing approaches; test case selection, test case prioritization and hybrid approach. Models have been proposed in regression testing mostly for maintaining the cost such as: [24]–[26] in general and one model, [27], was specific for maintaining the cost of selection approach. Besides the previous model, three models were proposed also in regression test selection approach; [28] a model for test generation which implemented as a tool called *Sleuth*, and the other two models [29], [30] were proposed for test case reduction. Regarding test case prioritization approach of regression testing, only [31] model proposed for code coverage of regression testing. Furthermore, there are 16 frameworks proposed, 8 of them were general frameworks as: multi-level regression testing framework [32], DART *(Daily Automated Regression Tester)* framework for GUI [33], framework for database applications [34], open-source framework for hybrid regression testing (reduction and prioritization) [35], testing framework for database and code changes [36], regression test automation framework [37], SimRT automated framework [38], and RECONTEST framework for concurrent programs [39]. Moreover, there are 6 frameworks for test selection approach [14], [40]–[44], and two frameworks for prioritization approach [45], [46]. The remaining studies (about 33 studies) were unclassified and they have discussed general aspects of regression testing such as general concepts [10], [47]–[50], specification [51], tools [52]–[59], applications [60]–[66], case studies [67]–[70], and others [71]–[78]. Table 7 emphasizes a summary of those primary studies.

4.4. Secondary Studies

Secondary studies, which contain data obtained from primary studies, in this study includes: SLRs, systematic mapping, reviews, surveys and empirical studies that discuss regression testing and presented in Table 8.

Table 7: Selected Secondary Studies

	IEEE	ACM	Science direct	Wiley	Total
SLR	1	-	1	-	2
Systematic Mapping	-	1	-	-	1
Review	1	-	1	-	2
Survey	1	1	1	2	5
Empirical Study	12	10	2	-	24
Total	15	12	5	2	34

There are two SLRs, [21] and [22], which have discussed empirical evaluations for test selection approach. However, there is no SLR study has been gained in this study which discusses test case prioritization or hybrid approaches of regression testing. In regards with mapping study, there is only one systematic mapping which has been stated and this study discussed web services regression testing [79]. Another form of secondary studies which is review and surveys studies have been reported. Two surveys have explored regression testing approaches (minimization, selection and prioritization), the first one discussed 168 techniques [80], and the other surveyed discussed 25 techniques [81]. Program slicing, code changes and UML Diagrams have a space in regression testing were reported in [82]–[84] respectively. The rest of surveys were conducted to discuss regression test selection approaches [85], [86]. In terms of empirical studies, 24 papers were reported; 13 of them for test selection [87]–[99], 7 for test case prioritization [100]–[106], and the rest are general [107]–[110].

5. Conclusion

Regression testing is a costly but necessary activity which performed to conform the changes made to software were not adversely affected its quality. In this paper, we conducted a comprehensive systematic literature review to explore different areas in regression testing domain. As a result, we selected 246 studies out of 1261. After that, extracted data were presented in tabular form in terms of published studies. Furthermore, preliminary findings were presented including discussion of major related concepts of regression testing such as: frameworks, approaches and models. For future, the researchers intend to discuss approaches and techniques of regression testing in more details in regards with related processes and tools.

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