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ENERGY CONSUMPTION PATTERNS OF MOBILE APPLICATIONS IN ANDROID PLATFORM: A SYSTEMATIC LITERATURE REVIEW

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ABSTRACT

Studies related to resource consumption of mobile devices and mobile applications have been brought to the fore lately as mobile applications depend largely on their resource consumption. The study aims to identify the key factors and holistic understanding of how a factor influences Consumption Pattern (CP) effectiveness for an android platform mobile application. The study presents a Systematic Literature Review (SLR) on existing studies that examined factors influencing the effectiveness of CP for android mobile application and measured the effectiveness of CP. Therefore, the current SLR is conducted to answer the following questions: (1) What is the evidence of CP factors that drain the battery of a mobile device? (2) What are the energy conservation techniques to overcome all the factors that drain battery life? and (3) How can developers measure the effectiveness of an energy conservation technique?. The SLR investigated factors affecting the effectiveness of CP for android platform mobile application. The analyses of forty papers were used in our synthesis of the evidence related to the research questions above. Therefore, the analyses showed 22 studies that investigated how to measure the energy conservation technique effectiveness while 18 studies focused on better understanding of how the resources of mobile devices are actually spent. In this sense, 2 studies show the effectiveness of early analysis of software application design. Additionally, five factors i.e., architecture, interface, behavior of the application, resources, and network technologies that affect CP effectiveness were identified. This study investigated a SLR targeting at studies of CP effectiveness in android platform. The total of 40 studies were identified and selected for result synthesis purpose in this work (SLR). The evidences show there are five factors affecting the CP's effectiveness. Three of them have received a little attention among developers regarding choosing the most suitable: software architecture, application interface and behavior of the application in terms of resource consumption.

Keywords: *Energy Consumption Patterns, Energy Conservation Technique, Android Mobile Application, Systematic Literature Review.*

1. INTRODUCTION

The usage of smartphones and mobile apps have been increasing [1],[2]. The Zettabyte Era et al. reported that the traffic of global mobile data is estimated to surpass that of wired devices in 2016 due to the sustainability of those functionalities in terms of the resources of mobile devices [3]. However, the popularity of a mobile application depends on its resource consumption such as battery consumption [4],[5]. Therefore, mobile applications that require huge resources are not recommended [6],[7]. Resources of mobile devices are generally limited due to the major energy-consuming components in a mobile device which are the display, CPU, network, and GPS [8]. This challenge has drawn a significant research attention for many researchers to design and develop new energy conservation techniques and methods. Therefore, a lot of strategies have been devised to optimize the energy usage at hardware and software levels. The most relevant work in this area is summarized, with a focus on the optimizations proposed to reduce battery consumption [9]. Some of the commonest approaches to battery optimization have already been discussed in the present work. For example, numerous studies propose off-loading resource-consuming tasks to cloud servers. This technique has been adopted by commercial mobile applications. However, it is not applicable for an application that is processing data stored locally (not on server). Besides that, managing resource consumption at the level of the device's operating system has been proposed; however, most developers found that it is challenging to perform this task.

Studies such as [10],[11] focus on the battery consumptions of different mobile networking technologies including Wi-Fi and 3G and the authors have proposed a new communication protocol to reduce energy consumption by delaying some communications or increasing data traffic through pre-fetching information.

Various energy-saving methods such as scheduling data transmission between mobile devices and cloud servers are reported in [12],[13]. In order to characterize the energy consumption, energy demands of mobile devices are determined from both hardware and software [14]. Their study has led to the creation of an energy-aware operating system for mobile devices designed to reduce the energy consumption of mobile applications.

The resource consumptions within specific applications are studied in [15]. As reported, a fine-grained energy profiler for smartphone applications is applied in order to measure the energy spent within an application in performing tasks such as rendering images on the screen or building an internal database for the application. While this information is beneficial for developers seeking to improve resource consumption, the application must be built before the analysis can be executed. Thus, this strategy is not useful at the design stage of a mobile application.

The resource consumption of a wide array of sensors embedded in mobile applications has been studied by Moamen and Jamali [16]. They have proposed a solution to manage the sensing requirements of all the applications running on a mobile device in order to reduce the energy consumption. However, detailed information is not provided on how to design the least-consuming application.

A set of indicators has been proposed by Keong et al. to measure power consumption. The authors concluded that McCabe cyclomatic complexity, weighted methods per class, nested block depth, number of overridden methods, number of methods, total lines of code, method lines of code and number of parameters have strong bivariate correlations with the power consumption. Therefore, these metrics can be adopted as indicators to estimate the power consumptions of mobile applications [17].

So far, various techniques have been proposed to measure energy consumption such as external power monitors [18],[19]. Also, the consumption information from the battery and the modified kernel has been evaluated by Yoon et al. [20]. In general, consumption information obtained from the devices is reliable for different types of analyses and experiments such as those proposed in the present work. A conceptual framework has been proposed by Berrocal et al. to help mobile developers during the architectural decision making process. By estimating the energy consumption of mobile applications constructed under different software architectures, the proposed framework allows developers to analyze the resource consumption and its variations as the applications are scaled up. To that end, the framework analyzes the consumption of a set of primitive operations that can be used to compose complex social applications [2].

In short, a topic such as consumption patterns (CP) of mobile devices has garnered significant attention in recent years [21].However, to perceive how CP can contribute crucially as an effective android platform mobile application, a suitable investigation needs to be carried out. Thus, the important part is to identify the main factors that significantly contribute effectively towards mobile application in terms of consumption patterns, i.e. factors that make battery endurance more sustainable.

In this research a systematic literature review was done to identify the key factors and holistic understanding of how a factor influences Consumption Pattern (CP) effectiveness for an android platform mobile application and measured the effectiveness of CP. Through aggregating the evidence of CP, one will be able to understand the CP when it is applied to an

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android platform mobile application context. Thus, it can better inform the developers to combine CP into android platform mobile applications. Thus, the total of 40 studies were identified and selected for result synthesis purpose in this work (SLR). The evidences show there are five factors affecting the CP's effectiveness. Three of them have received a little attention among developers regarding choosing the most suitable: software architecture, application interface and behavior of the application in terms of resource consumption. Additionally, the energy consumption patterns are evaluated in order to understand the current resource consumption factors. The remainder of this paper is organized as follows: Section 2 describes the research questions and Section 3 explains the research methods and protocols. Sections 4 reports the SLR results and Section 5 discusses some key findings, implications, and threats to the validity of the current review. Section 6 concludes the current work and offers some recommendations for future work.

2. RESEARCH QUESTIONS

A Systematic Literature Review (SLR) includes identifying, evaluating and interpreting the existing research works that are related to a particular research question [22]. The research questions context (PICOC) structure, the Population, Intervention, Comparison, and Outcomes shown in (Table. 1). All the empirical studies that investigated CP within an android platform mobile application are included in SLR. Therefore, the PICOC did not include any comparison. The main concentration of this SLR was on understanding and then identifying the factors that can influence the CP effectiveness for an android platform mobile application in order to enhance the effectiveness of the Android platform mobile app performance in terms of energy consumption.

Employing CP in industry can ensure better battery endurance, better application quality, minimal development effort, etc. These benefits are the main motivations for modern developers. We organized the CP's effectiveness measurement into four categories: Android platform mobile application performance, technical productivity, application design quality, and satisfaction. Therefore, the current SLR is conducted to answer the following research questions:

1. What is the evidence of CP factors that drain the battery of mobile devices?
2. What are the energy conservation techniques to overcome all the factors that drain battery life?
3. How can developers measure the effectiveness of energy conservation techniques?

Table 1: Summary of PICOC

Population	Android Mobile Application.
Intervention	Energy conservation techniques/ method/ approach.
Comparison	None.
Outcomes	Energy conservation techniques/method/approach effectiveness.
Context	Review(S) of studies of energy conservation techniques/ method/ approach within the domain of android mobile application.

3. REVIEW PROTOCOL

3.1 Relevant Literature Identification

The strategies below are adopted to establish the search string [22],[23]:
1. Identify the major terms appearing in the questions of the review.
2. List the keywords aforementioned in the articles (studies).
3. Search for alternative words and the synonyms (with the help of the subject librarian).
4. Adopt the "AND" Boolean operator to link the major terms.
5. Adopt the "OR" Boolean operator to link the major terms.
6. All relevant papers are reviewed manually.

The initial search string used in the current work is: (mobile application OR android application) AND (Energy Consumption patterns OR factors) AND (energy conservation technique OR method OR approach).

Russo and R. Camanho have addressed the importance of elements such as sensitivity and specificity during the SLR search. So, sensitivity accounts for retrieving numerous relevant studies and specificity aims at retrieving the least number of irrelevant studies [24]. Initially, only a few articles were retrieved when the above search string was used. For example, science direct and IEEEXplore databases retrieved only 5 and 6 studies, respectively. Therefore, we consulted a

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librarian on the appropriateness of our search string. According to the librarian, a much simpler string must be used to retrieve more results. Therefore, keywords such as (Energy Consumption pattern OR factor) were used and more papers have been retrieved from the online databases. All identified papers were then reviewed. The online databases that were used in our search process were five: the ACM digital library database, Science-Direct, IEEEXplore, Scopus, and SpringerLink. The online databases used in the current research were subscribed by the library of University of Putra Malaysia. Following the recommendation of B. Kitchenham and S. Charters, it is important to specify a list of relevant online databases in order to facilitate the search process [22].

3.2 Selection of Studies

The criteria comprise all CP empirical studies targeting an android platform mobile application. Literature published within years 2007-2017 are covered in the current literature review. Studies related to factors that affect the effectiveness of CP for android platform mobile application and ways used to measure the effectiveness of CP are emphasized. The main exclusion criteria consisted of CP papers not targeted at android platform mobile applications. In addition, papers of the following natures were considered as well:

1. Papers that reported claims with no supporting evidence;
2. Papers involving CP but outside android platform mobile application;
3. Papers that were not written in English.

3.3 Data Extraction and Study Quality Assessment

To facilitate the data extraction process, a checklist form was used to gather evidences of research questions and measure the quality of studies. When the quality checklist was designed, some questions reported in the existing literature [25],[26]and[27] were adopted. The checklist contained six general questions (see Table. 2).

The qualities of both quantitative and qualitative studies were evaluated according to the scale: Yes = 1 point, No = 0 points, and partially = 0.5 point. The quality score ranged between 0 (Very poor) and 7 (very good).

Table 2: Study Quality Checklist

	Item	Answer
1	“Was the article refereed?” [26].	Yes/No
2	“Were the aim(S) of the study clearly stated?” [25].	Yes/No /Partially
3	“Were the data collections carried out very well?” [25],[27].	Yes/No /Partially
4	“Were potential confounders adequately controlled for in the analysis?” [24].	Yes/No /Partially
5	“Were the approach to and formulation of the analysis well conveyed?” For example, rational for choice of method/tool/factors [25],[27].	Yes/No /Partially
6	“Were findings credible?” For example, the study was methodologically explained so that we can trust the findings; findings/ conclusions are resonant with other knowledge and experience [26].	Yes/No /Partially

We organized the extraction of knowledge from each study by performing intensive reading. Once the extraction was completed, the result was passed to one of the authors (Hasan). For validation purposes, a random sample including 20% of the total number of selected studies was extracted by the first and the third authors. Subsequently, a review meeting was conducted to review and compare the results. Whenever the difference of extracted data was less than 10%, discussion was continued until consensus was achieved. Nevertheless, the inter-rater agreement was not measured [28]. For the remaining 80% of the selected studies, it was hoped that the experience gained from conducting the review meeting would reduce the data extraction bias. If the information in any study was ambiguous, we would contact the author(s) for more information.

Table 3: Quality Score

Quality Scale	Very poor (<2)	Poor (2 - <3)	Fair (3 - <5)	Good (5 - <= 6)	Very Good (>6)	Total
Number of Studies	0	0	12	22	6	40
Percentage (%)	0%	0%	30%	55%	15%	100%

The synthesis of the SLR evidence presented in this section starts with the analysis from the literature search results. The science-direct database was chosen as the baseline database during the selection process due to its reputation as the largest abstract and citation database. In order to avoid duplication, each article that was retrieved from the other databases was compared with the existing list of ScienceDirect accumulated papers.

The searching result of the first round of our search processing identified 388 empirical studies using the "android platform mobile application AND energy conservation" search terms. Out of this number of studies, only 105 were possibly relevant to our terms based on the inspection of titles and abstracts. The inclusion and exclusion filtered criteria were used for each of these studies before being accepted for the evidence synthesis. If titles and abstracts showed the irrelevance of a paper, full articles were used. The duplicated studies or fundamentally the same studies which were published in more than one paper were considered if any. The synthesis bias would surface inevitably if a study were to be duplicated [22]. Based on the search results, 40 studies (38 percent of 105 studies) were accepted for the evidence synthesis after performing a thorough evaluation of abstracts/full texts and excluding duplicates (see Fig. 1). Therefore, 40 studies were included in the SLR for the evidence synthesis (see Appendix A for the included study list).

The quality scores for all studies are shown in Table 3. The qualities of 6 studies (15 percent) are considered as "very good" while those of 22 studies (55 percent) are "good". 12 studies (30 percent) achieved fair quality, and there is no study which attained very poor or poor quality; at the end, the number of studies that were included in the evidence analysis is 40.

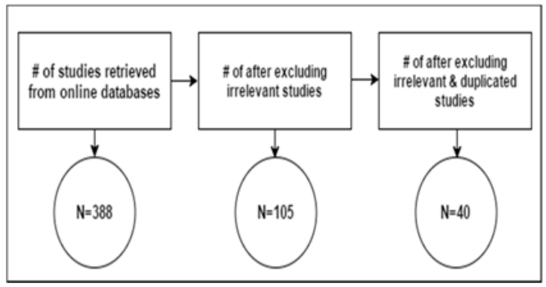

Figure 1: Identifying Relevant Literature

In the subsequent section, the results of the SLR, four research questions are presented. We identified each study as Sn, where n denotes the study's number (see Appendix A for the studies list used in the SLR).

4. RESULTS

A systematic literature review (SLR) investigates factors affecting the effectiveness of consumption pattern (CP) for android platform mobile applications. Forty papers were used in our synthesis of evidence, and 5 factors that can affect CP effectiveness. The analyses of these studies answered the following research questions:

4.1 What is the Evidence of CP Factors that Drain the Battery of Mobile Devices?

The SLR identified 40 CP studies conducted in android platform mobile applications that investigated energy conservation. The investigation of the studies varied via the techniques/method/approach of CP. The ultimate goal of this SLR was to understand and then identify the factors that can influence the CP effectiveness for an android platform mobile application in order to enhance the effectiveness of Android platform mobile app performance in terms of energy consumption. The 40 studies analyzed 22 studies which investigated how to measure the energy conservation technique effectiveness. In this sense 18 studies focused on better understanding of how the resources of mobile devices are actually spent, so that better techniques could be developed to reduce consumption, while 2 studies show the effectiveness of early analysis of software application design (see Table 4).

Table 4: The SLR's Evidence Synthesis

Evidence synthesis	Significant effect
20 studies (50 percent) investigated how to measure the energy conservation technique effectiveness.	S3,S6, S7, S10, S12,S14, S16, S17, S18, S19, S20, S22, S23, S24, S26, S28, S29, S32, S34, S37, S38, S39
18 studies (45 percent) focused on better understanding how the resources of mobile devices are actually spent.	S1, S2, S4, S5, S6, S8, S11, S13, S15, S21, S25, S27, S30, S31, S33, S35, S36, S40
2 studies (5 percent) show the effectiveness of early analysis of software application design.	S9, S14

4.2 What are the Energy Conservation Techniques to Overcome all the Factors that Drain Battery Life?

A total of 18 studies focused on better understanding of how the resources of mobile devices are actually spent, so that better techniques could be developed to reduce consumption. In this area, studies such as [14], [29] use surveys to find software solutions (approach and methods) that can help to reduce energy consumption. While [10], [12], [13], [19], [30] and [31] developed modeling tools to help software developers to improve their application power consumption, such as Balasubramanian et al. who presented a model for the power consumed by the activity of network for each of 3G, GSM and WiFi. Using this model the authors developed TailEnder, a protocol to reduce power consumption of common mobile applications [10]. Terefe et al. presented a model to identify the energy consumption of multisite applications that used a discrete time Markov chain (DTMC) to model the fading wireless mobile channels [12]. Similarly, A. A. Moamen et al. presented the ShareSens approach to manage the energy consumption through custom filters to send the required data to each application [16]. In same sense, [32],[33] and [34] focused on using methods to minimize the overhead energy, such as by developing a new method to determine the energy-aware optimal delta consistency level (d) and Multi-Criteria Decision Making (MCDM). The TOPSIS method and the LARAC method were adopted to approximate the optimal solution.

A step further is taken in [35],[36] regarding proposals for new schemes that reduced the energy consumption of a mobile application. While various studies have focused on different techniques for maintaining energy conservation, some such as [37],[38] and [39] proposed direct read (DR), Phone2Cloud, and Integer Linear Programming (ILP), respectively, to overcome the factors that drain battery life. Others, such as M. Tawalbeh et al., wenr a step further, and suggested a technique to reduce the energy consumption by smart phones [40]. The power consumption is measured experimentally for different components of two common brands of smart phones, namely, Galaxy Note3 and Sony Xperia Z2 and the obtained results are presented to get more accurate understanding of how these components participate in the overall power consumption of the smart phone.

In this sense, two studies show application design. Keong et al. have developed various software metrics to estimate the energy consumption of a mobile application, and they have concluded: there is urgent necessity to design a model that can be used to measure energy consumption in the early design stage [17], while Berrocal et al. propose a conceptual framework to help mobile developers during the architectural decision making process. By providing consumption estimates of mobile applications constructed under different software architectures without the need to actually implement them, the proposed framework allows developers to analyze the applications' resource consumption and its variations as the applications scale. To that end, the framework proposes analyzing the app's consumption from the consumption of a set of primitive operations that can be used to compose complex social applications [2].

4.3 How Can Developers Measure the Effectiveness of an Energy Conservation Technique?

Four categories were specified by the total of twenty two studies that investigated how to measure the energy conservation effectiveness, as follows:

4.3.1 Power profiling approach

Several software metrics have been used to estimate the energy consumption of a mobile application [41], and they have concluded that: there is urgent necessity to design a model that can be used to measure energy consumption in the early design stage. In [15], [35] and [42] they used the power profiling approach to determine energy-consuming events. Xiao et al. described the practice of model-based energy profiling employed in Android phones, Symbian and Maemo. They evaluated the accuracy by measuring the physical energies consumed by applications such as web browsing, file transfer, instant message, and video streaming [43].

4.3.2 Frameworks

Rice and Hay used the framework to yield fine-grained annotated traces of energy consumption of a phone [11], while Kwon et al. presented Mantis, which was a framework used for estimating the resource consumption of Android mobile applications [44].

4.3.3 Techniques/Approaches

Many studies such as [18], [20], [41], [45], [46] and [47] used different techniques like : AppScope, the battery-based automatic model construction technique, Powersaver, Ternary Decision Maker (TDM), multi attribute decision making (MADM) and PowerPedia. These techniques are developed to measure and monitor energy consumption of applications on Android devices. Similarity, based on a Mobile full system Simulation framework called MofySim with power models, Pitticrew et al. introduced the power consumption and performance analysis method [48].

4.3.4 Analysis of Energy Conservation

Numerous studies have analyzed different aspects of these devices' energy conservation. The energy conservation of mobile devices, in particular, is of great interest for the research community since it is one of the most limited resources of these devices. Studies such as [2], [48], [49] and [50] focus on analysis of applications in term of architecture, interface and behavior of a typical context-aware application, while N. Vallina-rodriguez et al. was using a small set of volunteers to collect data on handset usage. They argued that system workload, resource utilization and energy demands are diverse and dynamic in time and space, depending on the contextual information and pattern of usage [14]. One area that has attracted close attention in this domain is that of mobile networking technologies, including Wi-Fi Studies such as [40], [51] and [52] which focus on Wi-Fi Direct power management schemes, which is a self-organization based power management method used in mobile network, energy consumption, modeling, and simulation from the viewpoint of a heterogeneous network.S. D'Ambrosio et al. explored how energy savings in mobile devices can be effectively tackled by switching on/off filtering techniques [53].

5. DISCUSSIONS

5.1 Evidence on CP's Effectiveness

The 40 studies were conducted in the android platform mobile application that investigated energy conservation. The investigation of the context varied via the techniques/ method/ approach of CP. The SLR's goal was to understand and identify the factors that can influence the CP effectiveness for an android platform mobile application in order to enhance the effectiveness of Android platform mobile app performance in terms of energy consumption.

The 40 studies analyzed 20 studies (50 percent) which investigated how to measure the effectiveness of energy conservation techniques. In this sense 18 studies (45 percent) focused on better understanding of how the resources of mobile devices are actually spent, so that better techniques could be developed to reduce consumption. While, 2 studies (5 percent) showed the effectiveness of early analysis of software application design, a review of research in android platform mobile application shows that consumption patterns can have an effect on energy conservation achievement. Additionally, the consumption patterns that capture the general categories of research articles are observed, and then the classification in literature taxonomy is refined as shown in (Fig. 2).The several factors which affected energy consumption in the main classes, are easily distinguished, though overlaps do happen. According to the taxonomy there has been no work assisting developers in choosing the most suitable software architecture, application interface and behavior of the application in terms of resource consumption.

5.2 Implications for this Research

This work (SLR) found the most common factors investigated in CP studies were resource managing (see Table 5), and the existing literature shows that resource managing has great importance in estimating energy consumption.

We also identified that most CP studies predict managing resources using the power profiling approach as Indicator. The area that requires close attention in this CP as shown by SLR is that of communications as these operations are particularly hard on battery consumption. Studies such as [10],[12],[40],[51] and [52] focus on the battery consumption of different mobile networking technologies, the authors propose a new communications protocol that would achieve significant reduction in energy consumption.

Numerous studies analyzed different aspects of these devices' energy conservation are scrutinized. The energy conservation of mobile devices, in particular, is of great interest for the research community since it is one of the most limited resources of these devices. Studies such as [2],[49],[50] and [54] focus on analysis of application in term of architecture, interface and behavior of application.

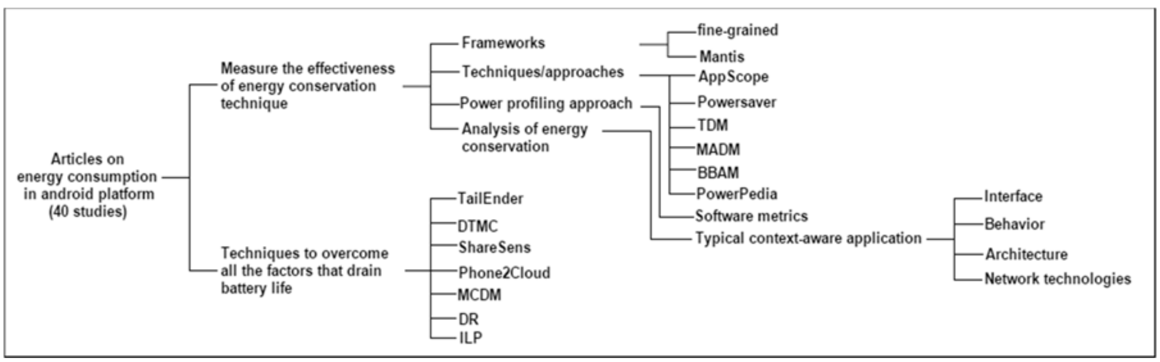

Figure 2: Taxonomy of Research Literature on Energy Consumption

Table 5: List of Factors Investigated in CP Studies

No.	Factor	Total studies	Significant effect
1	Resources	30	S1, S3, S5, S6, S7, S8, S10, S11, S12, S13, S15, S16, S19, S20, S21, S22, S23, S25, S27, S30, S31, S32, S33, S34, S35, S36, S37, S38, S39, S40
2	Architecture	2	S9, S14
3	Behavior	1	S24
4	Network technologies	5	S2, S4, S26, S28, S29
5	Interface	2	S17, S18

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5.3 Threats to the Validity of the Results

There are many considerations when the current SLR results are generalized. By selecting the relevant studies, we considered only those articles published in the period of (2007-2017), thus excluding studies that might have appeared before 2007. Also other threat belongs to the method of conducting the review. The first researcher was assigned to identify the strategy in executing the main tasks involved in each SLR step. Meanwhile, the other researchers provided feedbacks such as study selection, extraction of quality assurance data, and result compilation. Anyway, following the guidelines of SLR in [22], the associated biases in the results were minimized.

6. CONCLUSIONS

The current section described a SLR targeted at studies of CP's effectiveness. The total of 40 studies was used in this work (SLR), five factors that effecting CP's effectiveness was identified. Of these, architecture, interface, behavior of typical context-aware application, resources, and network technologies. However, resources managing an important role in estimating energy consumption and regarded as one of the critical factors in determining the popularity of an application.

Many metrics have been employed to measure the effectiveness of CP such as Android platform mobile application performance, technical productivity, application design quality, and satisfaction. Also we found out that the most metric used often to measure energy consumption was the power profiling.

Results of the analyses showed that managing the resources efficiently was the factor that effected CP's effectiveness the most. However, there is a clear gap in this research field: there has been limited work assisting developers in choosing the most suitable: software architecture, application interface and behavior of the application in terms of resource consumption. Therefore, from the current work we aware that preliminary analysis and estimation of applications' resource consumption are still lacking in term of software architecture, interface, and behavior.

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APPENDIX A
List of Included Studies in the SLR:

Study ID	Ref.	Study ID	Ref.
S1	[9]	S21	[39]
S2	[10]	S22	[45]
S3	[11]	S23	[41]
S4	[12]	S24	[54]
S5	[13]	S25	[32]
S6	[14]	S26	[51]
S7	[15]	S27	[36]
S8	[16]	S28	[52]
S9	[2]	S29	[55]
S10	[20]	S30	[38]
S11	[29]	S31	[33]
S12	[18]	S32	[35]
S13	[19]	S33	[40]
S14	[17]	S34	[43]
S15	[37]	S35	[34]
S16	[47]	S36	[30]
S17	[49]	S37	[46]
S18	[50]	S38	[44]
S19	[42]	S39	[53]
S20	[48]	S40	[31]