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Development of Arduino applications for IoT applications in software engineering education: a systematic literature review

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ABSTRACT

The continuous development of software applications is a necessary step in producing high-quality products that will consistently meet end-user expectations and stakeholder needs. Development of Arduino applications, embedded in a product's hardware, can and should be considered at the software engineering phase itself, even though current practice dictates it be handled by product engineers. The method used in this investigation was based on a systematic literature review (SLR). Therefore, this paper depicts a gap that currently exists within the body of literature surrounding the development of Arduino applications for 'internet of things' (IoT) applications in software engineering education in commercial and research fields. The result of this study are two findings investigates: i) relevant Arduino application development used in software engineering and ii) method for applying software engineering for Arduino applications. The limitations and constraints of each technique in respect to Arduino apps were also examined in order to provide a better understanding of each body of study's weaknesses and strengths. We realise that these studies are still insufficient and need to be evaluated and improved further.

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1. INTRODUCTION

The development and implementation of hardware for rapid internet of things (IoT) applications are mostly handled by engineering fields and practices. In electronic engineering, IoT has had the chance to produce smart product development and innovation in areas such as robotics, aerial and telecommunications, and computing. However, failure to develop product engineering to consider a product's software development life cycle (SDLC) in its software engineering phase may lead to failure in producing good quality products. Thus, the product quality received by stakeholders will not be up to standard, and will lead error-prone equipment [1]. Furthermore, most application-lead areas of IoT technology are insufficiently developed and difficult to approach due to limited resources [2]. Thus, a proper approach should be considered as it would be beneficial for industries and society at large, improving the overall quality of life.

Developing IoT technologies is currently a very intense process, and it is expected that all IoT devices should be able to be connected to one another [3]. Some solutions for this strenuous process were found using the Arduino platform, like an Arduino-based solution [4] with an economic smart meter that integrates sensors for the realization [5]. Arduino applications refer to integrated Arduino devices and applications. The success of Arduino applications reflects how they are designed and implemented during the software development phases. This can be taken to mean that, to develop high-quality information and communication technology (ICT) systems, the requirements to developing such quality must be considered [6] and elicit and validate as earlier in software engineering phase [7], [8]. Therefore, the software engineering phase is an essential process in the development of Arduino software applications, which could involve research into robotics and computing.

In today's world, Arduino applications have been integrated to developed IoT applications that allow them to perform at a capacity that utilizes all the information that has been connected through the internet. For instance, the applications of Arduino as a part of IoT have been utilized by people in the fields of medicine (dental), home economics, agriculture [9] and business [10]. Although it is considered a part of our daily life, the functionality of Arduino applications needs to be thoroughly designed and developed [11], as they involve various devices and applications. Furthermore, Arduino applications are contemporary technology that allows them to make information modifications with the use of internet access. The Arduino is a fantastic instructional tool for students who are not pre-planned in the microcontroller because it is well-equipped with libraries, allowing students to easily access different components [12]. To address such issues, many approaches, methods, models, frameworks, and tools have been developed to ease a product engineer or software engineer's burden in managing the Arduino application before the product is delivered to clients and stakeholders. However, according to existing studies, there is a necessity for enhancements on the tools that help product engineers and software engineers develop Arduino applications. Therefore, there have been several works on the challenges of working with Arduino in software engineering that include it in the development process.

This paper presents a review of existing works and tools for developing Arduino applications using software engineering in education learning. The following is how the paper is structured: section 2 describes the method used to conduct this research. Section 3 presents the overall findings, which include a description of selected tools required by Arduino applications on the market, as well as comparison analyses and discusses this study, and section 4 concludes with a conclusion.

2. METHOD

A qualitative research methodology was used in this study. We performed the systematic literature review (SLR) using the original settings recommended by [13]. The SLR is divided into three phases: i) planning the SLR: to identify the factors and challenges from research questions (RQs), formulation and validation of the review protocol, next, ii) conducting review: relevant studies identification and studies of primary, and data extraction (DE) and quality assessments (QA), QA checklist and DE strategy, and finally iii) reporting the review: to present the QA result. Each stage is represented in depth in the next subsection.

2.1. Planning

In this planning phase, two components were identified namely i) the RQ and ii) review protocol formulation and validation. The purpose of planning to allow defining the RQs is constructed in relation of the aim of this study. Then, review protocol formulation and validation to define the basic review procedures. This is makesure that the subject does not depend in evaluation process.

2.1.1. Research questions

For keeping the review focused, the RQs is specified. In software engineering, we initialise the terms and Arduino functions for its issues, and challenges factors. The population, intervention, comparison, outcomes, and context (PICOC) criteria from [13] are used to structure the study questions, as shown in Table 1 with its descriptions.

Table 1. Summary of PICOC

Criteria	Descriptions
Population	Arduino development, software engineering
Intervention	Challenging of Arduino application development
Comparison	Models, methods, and techniques that are currently in use
Outcomes	Arduino application prediction, success factors
Context	In research studies and industry, empirical data is used

In this stage of the SLR, the questions were designed purpose for DE to achieve these two objectives with construct two RQ, research objectives 1: to identify the relevant Arduino application development in software engineering education, RQ1. What are the Arduino application development in software engineering education? and research objective 2: to investigate the shortcomings and limitations of current approaches and techniques for using Arduino in software engineering education, RQ2. What are the various models, techniques, and approaches for incorporating Arduino into software engineering education? relation with its motivations.

2.1.2. Review protocol formulation and validation

A review protocol outlines the steps that will be taken to carry out a specific systematic review. This ensures that pre-defined required to reduce the biases by researchers. Therefore, there are four components are constructed in this review protocol. The all components including i) source selection, ii) study selection procedure, iii) QA checklist, and iv) DE strategy. All components are depicted in next subsection.

2.1.2.1. Source selection

The document search technique used to obtain data from IEEE Xplore, ScienceDirect, Springer, Scopus, ACM Digital Library, and Google Scholar utilising OR and AND searching for objectives 1 and 2. These types searching focuses on issues, problems, characters, and factors covered on objective 1 while another type searching including method, technique and approaches with combination type searching, Arduino development application in software engineering that covered on objective 2.

2.1.2.2. Study selection procedure

According to Table 2, first, the RQ were used to compute the major searches in these studies as RQ as explained above. Second, the title or remove the studies not related of our search criteria is examined. Third, Boolean operator such as AND OR or NOT were used to link the result from the search string in source selection. Fourth, the citation is retrieved and investigate abstract and keywords in remain studies for the relevant studies. Finally, inclusion/exclusion as stated in Table 3 were used to filter remaining studies.

Table 2. Selection process

No.	Descriptions
1	Derive major search from RQs
2	Reviewed the article title and deleted papers that did not meet our search criteria
3	In the search phrase, use the Boolean operator (AND, OR amd NOT) to link result terms
4	To find related research, retrieve the citation and read the abstract and keywords in the remaining papers
5	Table 3 lists the inclusion/exclusion criteria that were used to filter the remaining research

Table 3. Inclusion or exclusion critreria

Inclusion criteria	Exclusion criteria
Papers focusing on Arduino	Papers present not subject to peer review
Papers describes Arduino	Papers presenting results without provide evidence
SLR	Studies unrelated to the RQs
Paper describes Arduino in software engineering education	Uncertain studies
Paper describes Arduino in software engineering education method	

2.1.2.3. Quality assessment checklist

We employed the DE form from primary study. Many primary studies did not answer all the DE form's questions. We retrieved the important information from the original research using the DE form. The QA was then applied to each primary study, based on the type of study, there are four QA were derived namely QA1) Are the inclusion and exclusion criteria for the review defined and appropriate? QA2) Is it possible that the literature search uncovered all relevant studies? QA3) Did the reviewers evaluate the quality or validity of the research, and QA4) Were the important facts or research adequately depicted?

2.1.2.4. Data extraction strategy

The investigation will next be carried out using relevant articles and primary studies. Table 4 depicts the DE and QA procedures used to elicit data from primary research. Finally, data from eighteen papers was collected and used to create answers to the two RQs. The Kitchenham principles were heavily included into the creation of this SLR report. In the following section, each phase is represented in detail.

2.2. Conducting review

The second phase of this SLR is constructed where the first phase is completed and agreed. Here, the identification of relevant studies primary studies is conducted according to the RQ. Then, the DE and QA are implemented based on collected from the primary research. Both components are explained in detail in these subsections.

Table 4. DE strategy

Search focus	Data item	Description
General	Bibliography	Derive the author, year, title, source
	Article type	Consider type of article such as journal/conference, paper/technical report
	Aims of study	Construct aim or goals of primary study
	Design of study	Study design use a surveys and controlled experiments
RQ1	Comparison	Comparisons to define Arduino application development for software engineering education
	Examples	Examples of Application Arduino development
RQ2	Approach/method	Describe the Arduino development methodology used in software engineering education
	Existing/new	Explain whether the method is novel or whether it is already in use

2.2.1. Relevant studies identification and studies of primary

We then examined the article titles to eliminate any studies that were not obviously relevant to the research issue. The abstract, key words, and conclusion were then utilised to exclude unrelated works. There were 58 studies left after using these two strategies. We examined the 58 articles and chose 25 publications as primary studies for this SLR based on the inclusion/exclusion criteria. In addition, we utilised the same selection techniques to find more primary studies related to the research focus in the reference lists of the 25 main studies that were chosen.

2.2.2. Data extraction and quality assessments

Using the DE form, we collected information from primary research. Many main studies failed to answer all the questions on the DE form. The DE form was used to retrieve the critical information from the primary study. According to the kind of study, after that, the QA questions were applied to each primary study. We gave yes or no answers to the QA questions. We picked a binary scale since we did not want to give the research a quality score.

2.3. Review of reporting

25 primary papers as the data were choosed to produce answers to the two RQs as explained in above. We strictly followed Kitchenham and Charters [13] directions when writing the SLR report. We begin our evidence synthesis for our SLR with a study of the literature. We also addressed the RQs using the selected primary publications. Table 5 displays studies number conducted for QAs utilising SLR's level layer. The study removed 30 studies and three of them were duplicates. Following a quality review of 25 investigations, eight papers were identified for evidence synthesis, whereas seventeen studies were excluded.

Table 5. QA result

Criteria	Paper study
Before QA	58, duplicates=3, exclusion=30
After QA	25, accepted: 8, rejected: 17

3. RESULTS AND DISCUSSION

This section describes the research findings and provides extensive comments. The result describes about key findings of our research that we have conducted the SLR in this study that focusing on two RQs. Meanwhile, discussion to interpret the implication of our findings from the results. The result of this study and the discussions are represented and intepreted in next subsection.

3.1. Result

We compared the eight available papers on Arduino development in IoT applications. We demonstrate the comparison based on methodology, strategy, technique, and arduino applications aims in software engineering in relations of the two RQs. Under the limits of the study questions indicated above, we explored and depicted the work of result of this two RQs. All of result of RQs is explained in additional depth.

3.1.2. RQ1: what are the Arduino application development in software engineering education?

Table 6 compares the criteria addressed when developing an Arduino application. The most recent research by [14] produced a unified modeling language (UML) model that can be used for software engineering but is confined to phases of software development. Further, Heo [15] then discussed the FRUTO kit, an Arduino-compatible modular kit. To boost the number of users who meet the design criteria, the FRUTO kit is developing a Scratch-like block programming tool. Another work by Novák *et al.* [16] provides an arduino platform for educational teaching materual but they have difficulty of problem concept in teaching. Next, Kim and Lee [17] proposed Arduino-based education program that can be used in after school that related to the teaching learning method while researcher in [18] proposed a model-based approach. Therefore, we believe that the Arduino application is still shallow and limited in software engineering specifically in education setting, such as in eliciting requirements phases of SDLC.

Table 6. Arduino application development in software engineering

Year	Author(s)	Application	Name
2021	Geller and Meneses [14]	-	UML
2020	Heo [15]	Arduino-compatible modular kit	FRUTO
2018	Novák *et al.* [16]	-	Arduino platform
2017	Kim and Lee [17]	Arduino-based education program	Arduino-based education
2015	Pramudianto [18]	-	A model-based approach

3.1.2. RQ2: what are the available approaches or models or methods used applying arduino in software engineering?

To develop an application, software engineering must be considered as early as possible to determine whether development will involve only software application or require an integration of software and hardware. A software application of good quality begins with analysis of requirements gathered from clients and stakeholders. Design and development, implementation, testing, and maintenance are processes application developers must be considered before the end of product can be delivered to the client and users. However, current work and tools studied by researchers, as illustrated in Table 7, have ignored and lack much of this, and taken a very limited approach in the consideration of software engineering for the development of Arduino and IoT applications. Thus, it is necessary to have a tool to guide software engineers and product engineers to better understand and learn about the software engineering phase for Arduino applications as embedded systems in IoT applications. Based on the above analyses, a clear limitation into the query the impact Arduino applications have on IoT devices in software engineering design methodologies exists. However, this may be since the methods and tools for developing Arduino applications and applying them during software engineering are very limited. Further, each phase of the five phases in SDLC comprises sequentially to be completed to develop software solutions. The analyses of results are explained in next subsection, discussion.

Table 7. Software engineering education for approaches/models/methods/tools comparison

			Specialization		Method/model/approach/framework/tool					Platform		
Year	Author(s)	Focus detail	Software Engineering	Engineering	Model	Method	Approach	Framework	Tool	System Application	Web based	Mobile App
2016	Hertzog and Swart [19]	Design-based module		✓				✓				
2015	Candelas *et al.* [20]	Arduino-based practice		✓	✓					✓		
2019	Santosa and Waluyanti [21]	Problem based learning		✓	✓							
2016	Zambonelli [11]	Keys software engineering Concepts and abstractions	✓			✓						
2018	Chacón *et al.* [22]	IDE							✓	✓		
2018	Fezari and Dahoud Al [23]	Arduino-based projects		✓						✓		
2018	Wood and Ganago [24]	Arduino-based embedded system		✓						✓		
2021	Geller and Meneses [14]	UML	✓	✓	✓							
	Total		**2**	**6**	**3**	1	0	1	1	**4**	0	0

3.2. Discussion

We did a study of the eight studies based on the SLR results, comparing them based on the models, methods, approaches, and frameworks of IoT applications. We observed that majority of the studies investigated comparable premises, such as problem-based learning, Arduino-based practise, and UML models. The UML was discovered to be useful for both software engineering and engineering. Based on our analysis, we discovered that IoT applications that supported the Arduino application used a variety of approaches and processes. We also discovered that IoT applications were developed depending on the uniqueness and purpose of their distinct tools. In terms of engineering representation, product engineering was the most turned to in arduino applications for educational purposes. It was also found that the model was frequently used for developing product engineering. In term of platforms, we found that system applications were widely used in the above study. Integration between mobile applications and their web-based counterparts were very limited.

Several studies have addressed such as researchers in [14], this study developed a UML model for an IoT system. The proposed UML was applied to a case study for the monitoring and prediction of power consumption. They also embedded an artificial intelligent in it geared towards power consumption forecast that was able to make decisions and predictions. An activity diagram of class was also presented to show the different levels of the IoT system used in the study's IoT system. Zambonelli [11] proposed and framed a starter to key concepts and abstract designs and developments of IoT for engineering IoT systems and applications. These keys software engineering concepts and abstractions involved stakeholders and users, functionalities, avatars and coalitions, and design and implementation. The results of the proposed methodology provided a foundation for developing guidelines for a new IoT-oriented software engineering discipline. Hertzog and Swart [19] developed two design-based modules for undergraduate students. Based on the findings, some of the features were found to be successful and had received positive feedback. The feedback included the following comments: i) most students understood the theory, ii) it was a valuable learning experience, iii) it helped develop the students' creative thinking regarding programming, and iv) students were able to grasp fundamental design principles.

Candelas *et al.* [20] developed applications based on Arduino and other existing equipment. They implemented a focus on automatic control and robotics courses. According to their findings, the proposed experiments had the potential to attract students and help them understand, as well as empowering their knowledge for hardware and software development. Santosa and Waluyanti [21] developed an 'Arduino nano-based quadcopter learning media'. The objective of the approach was to motivate students to learn and understand the Arduino. The findings of their study found that understanding of the Arduino increased when using the problem-based learning model. Furthermore, they also found that acceptance of the students towards learning and creativity rose after the implementation of Arduino due to a hands-on application in class that adapted to real life scenarios.

Chacón *et al.* [22] studied the integration of integrated development environment (IDE) for developed Arduino applications. Here, they introduce the software and explained how to install the Arduino IDE, compiled and ready for developing applications using Arduino modules. The study also described the integration of IDE and Arduino applications that run the application and hardware. Fezari and Dahoud [23] developed an Arduino-based project to encourage learning that had an advantage for both students and teachers, aimed to achieve three goals, namely; i) for students to achieve clear goals for advanced learning; ii) for teachers to obtain a fresh outlook on what makes students learn; and iii) to bring out the joy of achievement. Based on these goals, they studied the effects of Arduino on engineering education instead of developed applications in software engineering. Wood and Ganago [24] developed the tool to allow students to grow an interest in technology applications from hobby to professional which encourages students to develop a project. Kouhia [25] developed Arduino-based embedded systems. The application developed a DIY monitoring system to allow users access to the data through the web. Users could interact with Project Greenhouse through the interface of the website. They related the work of IoT applications to web-based applications.

Based on the analyses, most of the development of Arduino for IoT applications are developed for product engineering, but almost none exist for software engineering or, more specifically, for the whole SDLC in education setting such as all of development of Arduino application may require process in software engineering. Thus, producing Arduino application can apply in software engineering instead of product engineering. Further, it is crucial software engineer to understand terms used in product engineering such as terms of Arduino application in hardware and software that used to develop IoT application, but all of these can be adapted in software engineering education as well as to produce a software solution. The development of Arduino application in software engineering specifically in educational setting should require a thorough study of SDLC that include eliciting requirements, problem-analysis, design and development, implementation, testing, and maintenance. Further, the process to develop IoT application at beginning of SDLC which is during gathering requirements from client-stakeholder so that it must fulfill and accomplish the client-stakeholder needs. Therefore, software engineering is limited in development of Arduino application.

4. CONCLUSION

Development of software applications is important in order to produce a good quality product to be received by the end user and fulfill stakeholder needs. Developing an Arduino application that embeds the hardware may also be considered during the software engineering phase. This should be done to guarantee that the requirements from stakeholders remain consistent, correct, and complement the application's design and development, testing, implementation, and maintenance. As a result, this study presented the SLR technique for Arduino IoT applications in Software engineering education in application and research purposes. We presented the findings and analyses of many research that demonstrated that the development of Arduino applications in the field of software engineering is limited. The strengths and disadvantages provide insight into the limitations of current tools. We conclude that present IoT application research in software engineering is immature and requires further investigation in order to provide a better software solution for future market and client stakeholders.

In the future, we intend to create an approach and an automated tool that can be utilised by both software developers and product engineers. This tool will aid software engineers and product engineers in the development of an Arduino application for use throughout the software engineering process. This tool will also be used by software engineering and product engineering students in educational settings purpose to allow them understanding terms used in software engineering.

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