Survey of Component-Based Software Engineering within IoT Development

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***Abstract*—The Internet of Things (IoT) is a growing area in everyday life. New applications under the umbrella term IoT are being developed continuously. A typical IoT system consists of quite a large set of interchangeable components. In prototype development the Raspberry Pi and Arduino have become core components of wireless sensor network solutions. This research looks at how component-based software engineering (CBSE) and off-the-shelf components can be taken advantage of when defining IoT systems. We will attempt to identify the common properties of IoT systems and compare how well these properties relate to the CBSE component characteristics: composability, deployability, comprehensive documentation, independence, and standardization. The research methodology used in this study is a literature survey. The main results of the study show that CBSE is not widely used. There has been very little research on the software side of applications, as most studies have focused on describing the hardware side of implementations. The conclusion can be made that, in order for studies to be reproducible, the software side should be described in more detail.**

Keywords*—IoT, CBSE, internet of things, component-based software engineering

I. INTRODUCTION

The Internet of Things (IoT) is a growing area in everyday life. New applications that fall under the umbrella term of IoT are constantly being developed. The IoT paradigm is the integration of several technologies and communications solutions [1]. In the IoT world, ready-made or off-the-shelf components are often used to build prototypes.

This study examines how component-based software engineering (CBSE) and ready-made software components can be utilized in defining IoT systems. The following research question can be asked: "Is CBSE generally considered in IoT development? If so, how?"

To answer this research question the literature survey research method has been used, identifying the common properties of IoT systems. Further, these properties are compared with the features of CBSE components, i.e., composability, deployability, comprehensive documentation, independence, and standardization [2].

The hypothesis of the study is that because IoT systems consist of several software and hardware components, it should be worthwhile using CBSE defined characteristics. Further, the findings of the survey are used to evaluate the applicability and prevalence of the CBSE method in IoT system development.

This study is part of the research related to IoT carried out by the Software Engineering and Intelligent Systems (SEIntS) group at Tampere University, Pori, Finland.

The structure of this paper is as follows: In Section II, we review the related research about CBSE. In Section III, we present the research method. Section IV introduces the findings of the survey. In discussion Section V we expand on the findings of the survey and the study is summarized in Section VI.

II. BACKGROUND

Component-based solutions and research topics were the topic of a previous paper on the SW / HW framework [3]. A sensor network consists of several layers, from data gathering devices to data users. The SW / HW framework is placed in the data gathering layer. The three types of data gathering constructions presented introduce software components, hardware components, and their interconnections. In addition, the research generalizes the required software and hardware components for IoT data collection prototypes into a single SW / HW framework.

The rise of object oriented programming languages has led to the component based ideology in software [2].

CBSE defines five basic properties for software components:

- **A composable** component has publicly defined interfaces and all external interactions go through these. It also provides information, such as its methods and attributes for external use.
- **A deployable** component is self-contained and it can operate as a stand-alone entity on a component platform that provides an implementation of the component model. For example, a cloud database has several inner components which may or may not be used.
- **A documented** component offers the documentation which lets the users decide whether the components meet their needs.
- **An independent** component can be used as a stand-alone without using other specific components. If the component needs external services, these should be specified in the documentation.
- **a standardized** component has defined component interfaces, component metadata, documentation, composition, and deployment, which are in accordance with the agreed model.

In the field of software engineering, CBSE is a widely recognized approach to the design and implementation of software.

III. Literature survey

The research method is based on a systematic mapping study. According to [4], a systematic mapping study is designed to give an overview of the research area by classifying and counting contributions in relation to the categories of the classification. The main difference between the systematic literature review method [5] and a systematic mapping study is the need to provide an update of how to select studies during the research when conducting a systematic mapping study. For the selection of the studies, we decided to perform an online search. We used the search engine and database of articles in IEEEXplore Digital Library in this study. The selection process is described below:

1) We selected two combinations of search terms: the combination of "IoT", "component based", and "Arduino" or the combination of "IoT", "component based", and "Raspberry Pi". The search including Arduino gave 52 results and the search with Raspberry Pi gave 86.
2) We excluded studies published before 2020. Most of these are technical studies and were partly discussed before in [6] and [7].(52/86 -> 26/34 results).
3) The studies were reviewed and if there was no mention of the software that was developed or tested, the study was excluded from the research.
4) The remaining studies were read, and based on the content of each study, it was decided whether or not to include it in the mapping study.

The survey was started by selecting the search terms of components that are commonly used for testing different kinds of prototypes. The search terms "Raspberry Pi" or "Arduino" were not commonly used before 2015, and by limiting our search to studies published after 2020, we excluded most of the simple and basic technical studies from the results. The third step was to go through the studies to determine whether CBSE characteristics could be found.

After the keyword selection process, the papers were read through quickly and attention was paid to software side solutions. The first goal was to find self-developed software components in the studies. In addition, it was examined whether the paper used a previously presented or defined application, algorithm, or software library components. For example: If the paper had commonly mentioned cloud usage, it was considered whether the cloud was specified, described, and the use case presented.

If Arduino or Raspberry Pi was mentioned, then the paper was included in the study. The paper was examined to see how the developed application was described: whether the source code, or diagrams (use case, sequence, class, or architecture) were shown. The articles were assessed based on CBSE criteria. If no clear application component was found, then the study would be removed from the list.

IV. Results of survey

The first set of results includes 60 studies which met the search criteria. The result set included four duplicates because of the separate searches for "Raspberry Pi" and "Arduino", and these were removed.

Regarding the research question, it became apparent at the very beginning of the study that CBSE had not been utilized when prototyping IoT applications. Therefore, we started to search for CBSE characteristics in the selected studies; the results are summarized in Table I.

Table I shows the five CBSE characteristics in columns and the surveyed studies in rows. One row represents one surveyed study that presents a developed system which can be considered to contain one or more CBSE characteristics. If a selected study did not contain any CBSE related characteristics, it was omitted from the table.

Initially 60 studies were included in our survey. Of those 26 included CBSE characteristics and were included in the last phase of the survey, and 34 studies were left out.

The overall usage of CBSE characteristics was low. However, a few interesting points could be found in the studies. One study [11] introduced an anti-theft system, which uses an earlier developed algorithm [35]. The study shows a good example of how to combine different components for new implementations for different purposes. Another study [10] presented a collision avoidance parking system, which uses motionEyeOS[1] as part of the application. MotionEyeOS represents a typical CBSE component because it has a publicly defined and documented system which can be implemented for various purposes. Furthermore, the study [10] mentioned several ready-to-use software components, e.g., Android app, Xampp, Apache, and MySQL, but their usage was not described.

The study [32] published in the article "Psychoacoustic Annoyance Implementation With Wireless Acoustic Sensor Networks for Monitoring in Smart Cities" was an exception in the selected set of articles; it also provided source codes in the github.com online version control service.

The article "Medicine Box Reminder for Patients with Chronic Disease with IoT-Based Database Monitoring" provided a relatively comprehensive view of its components and interfaces, as well as employing quite a wide selection of free-to-use software components [26]. For example, the article discussed the created REST API and the technologies used in the creation of the API. The details in the article helped us to identify the CBSE characteristics.

Similarly, in the article "Access Control and Management System over Real Estate Objects as a Part of IoT Network Community" [29], a detailed description of the

[1]https://github.com/ccrisan/motioneyeos/wiki

	composable	deployable	documented	independent	standardized
[8]			X	X	X
[9]			X	X	X
[10]			X	X	X
[11]	X	X	X	X	X
[12]	X	X	X	X	X
[13]	X	X		X	X
[14]		X	X	X	X
[15]	X	X	X	X	
[16]	X				
[17]		X	X		X
[18]	X				
[19]	X				
[20]	X				
[21]	X				
[22]	X	X		X	
[23]			X	X	X
[24]			X	X	X
[25]					X
[26]	X	X			X
[27]		X			
[28]		X			
[29]	X	X		X	X
[30]					
[31]	X	X		X	
[32]	X	X	X	X	X
[33]	X	X		X	
[34]	X	X		X	X

TABLE I: selected studies with CBSE characteristics.

developed system was the key factor in facilitating the discovery of CBSE characteristics in the developed system. The REST architecture model is used in this system too, and even the JSON format used in the transactions is mentioned.

The study "Monitoring and Supervisory Control of Small Renewable Energy Generation Systems" [13] is an example of a study displaying all five characteristics. The developed system uses free-to-use components: Chirpstack, Node-Red, Influxdb, and Grafana. In addition, a flowchart of the application and the interconnections of the components were introduced. Although the source codes were not released, both sides of the application, hardware and software, were described with sufficient accuracy for reproducibility.

For example, a typical study without clarification of the software part is "IoT Based Design of Automatic Seat Belt System for Vehicles" [36]. The study accurately presents the background physics, mechanical implementation, and hardware, but the software components can only be inferred from the hardware environment used. This was quite common in the studies that displayed a developed system which did not have any CBSE characteristics.

V. Discussion

The aim of this study was to evaluate the current state of the art in the use of component based software development in the IoT world. The analysis was based on the collection of IoT prototype application studies. The amount of studies was so large that only the most recent studies were included in the survey. However, the conclusion is that this collection of studies has potential for more comprehensive analysis. This study also shows the lack of component based software development in IoT related prototype development.

There are several key points peculiar to IoT prototype system developments. Most of the studies present quite accurately the hardware side of the application: wiring schematics, sensors, and off-the-shelf components such as radio modules, single board computers, and finally their interconnections. However, the software side of the application was presented usually in less detail; ready-to-use components e.g., a database or cloud service were mentioned. The developed software might be mentioned, but only one study [32] in the selection group presented a public repository where the software could be obtained. Furthermore, if the developed prototype application included common technology e.g., MQTT, LoRa, node-Red, REST, the interconnections with these were commonly described with some kind of diagram.

Component based software and its interface connection to other systems are commonly presented with a diagram. The selected studies of our survey used several types of diagrams, e.g., a sequence or flowchart diagram to introduce the operation flow of the system. In addition, some studies presented a flowchart wider than the implemented system. This might lead to ambiguous blocks, so implementing these might be challenging. The actual workloads were not estimated in these studies.

Neither the source code nor the complete documentation for the developed systems described in the articles were available in most cases. This definitely made it impossible to assess whether any CBSE characteristics were present in the developed systems. Mostly, the surveyed articles

placed emphasis on other aspects of the systems than the software that was developed or used.

In the future one possible research direction for IoT prototype development and CBSE would be to further review published articles in the field to discover best practices for utilizing and reporting component-based software development. The findings could be used as the basis for a set of guidelines for CBSE-enabled IoT prototype development. In a further study, a second approach would be to establish an independent evaluation framework to enable the assessment of the benefits and drawbacks of using CBSE in the IoT context and developing guidelines and criteria for software specifications in IoT development projects.

VI. Conclusion

In this survey paper, we presented a comprehensive review on the use of component-based software engineering (CBSE) in IoT prototyping research. The survey focused on software components with the primary goal of determining how CBSE and off-the-shelf components can be exploited when defining IoT systems. In addition, we identified some common properties of developed IoT systems and compared how well these properties relate to the CBSE component characteristics: composability, deployability, comprehensive documentation, independence, and standardization. The main results of the study show that CBSE is not widely used. The survey also shows that the developed and self-made software components are omitted when presenting the structure of IoT applications. On the other hand, several studies demonstrated the use of freely available software components as part of an application. This study showed that software development should be considered and discussed in the design and presentation of IoT prototypes. Furthermore, in conclusion it can be said that in order for studies to be reproducible, the software side should be described in more detail.

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