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Review

Papers Mentioning Things Board: A Systematic Mapping Study

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Abstract: In a previous article, we conducted a Systematic Mapping Study (SMS) devoted to identifying the open-source IoT platform that nowadays offers the most features as well as adequate documentation and which, therefore, is a useful middleware in the development of IoT applications. In light of the final findings of such a study, ThingsBoard was selected. The present paper reports on the findings of a subsequent mapping study. We queried the Scopus database looking for articles that mention ThingsBoard either in the Title, in the Abstract, or among the authors' Keywords. 55 items were retrieved and carefully read. At the end of this stage, we were able to answer the following research questions: Are there available studies mentioning ThingsBoard? In which ambits? What is the role of ThingsBoard in the studies where it is mentioned? What are the gaps in current research and the implications for future research? The study goals are general, so the final findings might be of interest to IoT professionals, as well as to scholars. In detail, the SMS provides insights into the breadth of usage and the domains where ThingsBoard has been applied successfully, indicating its suitability and potential for a wide range of IoT-related projects. Moreover, a few gaps to be filled with further research have emerged.

Keywords: Systematic Mapping Study, Internet of Things, IoT Platform, ThingsBoard, Application Domains

Introduction

Global IoT technology market reached about USD 406 billion in 2022 (https://www.vantagemarketresearch.com/industry-report/iot-technology-market-1449, accessed on 25 June, 2023). Unfortunately, it has been remarked that developing IoT applications is intrinsically difficult due to the many critical issues that this activity poses for instance, (Dias *et al*., 2022). IoT platforms play a central role in the development, deployment, and management of IoT applications in almost all real-life domains. Di Felice (2023) reports on a Systematic Mapping Study (SMS), which searched the literature about open-source projects with the intent of building a view of today's ready for use IoT platforms. In light of the final finding of such a study, Things Board emerged to be the most suitable middleware among the existing open-source IoT platforms.

Starting from the conclusion of such a previous SMS, we carried out a second mapping study, which is reported in the present paper. This time, the aim of the research was to select published studies focusing on ThingsBoard, in order to summarize the existing body of knowledge about such a platform in a thorough and unbiased manner.

Paper's Contribution

The carried out study allowed answering the following research questions: Are there available studies mentioning ThingsBoard? In which ambits? What is the role of the Things Board in the studies where it is mentioned? What are the gaps in current research and the implications for future research? The study goals are general, so the findings that we derived might be of interest to scholars as well as to IoT professionals.

The remaining part of this study is structured as follows. The next section gives a summary of the previous SMS; while Section Materials and Methods recalls the phases that compose SMSs, hence describes our SMS. The Results section reports on the final findings from the study, Treat to Validity sets the boundary of the present study, while the Conclusion ends the paper.

This section summarizes the SMS reported in (Di Felice, 2023), in order to clarify the criteria that led to the selection of the ThingsBoard platform. The aim of that study was to search the state of the art open-source projects in order to get an overall picture of IoT platforms ready to be used in the development, deployment, and management of IoT applications. The necessity of carrying out an SMS is motivated hereafter.

The choice of the software platform that matches the requirements of the application to be developed is complex because the capabilities and features of IoT platforms are variable. In addition, today there is a huge number of available candidates and this hampers the selection process. Research by IoT Analytics mentions 613 companies that offer an IoT platform. Ismail *et al*. (2018), it is reported that about 300 IoT platforms were mentioned in the literature. More recently, a similar message was repeated by Mijuskovic *et al*. (2020).

The SMS reported in Di Felice (2023) (carried out on June 2023) was carried out as a hand-operated search of articles stored in the Scopus database that compares IoT platforms. Ten papers (issued in journals, conferences, surveys, and book chapters) were selected, downloaded, and carefully read. A summary of each of these studies is given in Di Felice (2023). For the purposes of the present one, it is sufficient to recall just one of them, namely (Held *et al*., 2022).

The following seven open-source IoT platforms were compared (Held *et al*., 2022), from an initial collection of 135 papers published before June 2021: Eclipse Kapua, FIWARE, Mainflux, Node-RED, OpenRemote, SiteWhere, and ThingsBoard. These candidates were rated with respect to the following 14 independent aspects: (1) Connectivity; (2) Security; (3) Deployment; (4) Scalability and stability performance; (5) Scaling technologies; (6) Cloud hosting support; (7) Data and action processing; (8) Data visualization; (9) Data analytics; (10) Resilience mechanisms; (11) Abstraction and model terminology; (12) User management Authorization; (13) Persistent communication and message handling; (14) License model. The quantitative formal method adopted by the authors assigned to each feature a score in the range (0.3). ThingsBoard got the highest score (i.e., 30.5) among the seven candidates. It is worth noting that ThingsBoard gained the top score (i.e., 3) for 11 features out of 14, while the Data analytics feature obtained the worst score (i.e., 1). To overcome this limit ThingsBoard, in January 2023 it was released Trendz Analytics. This tool allows us to extract insights, optimize operations, and drive informed decision-making.

In light of the previous analysis, the conclusion of the SMS carried out in Di Felice (2023) was that ThingsBoard is today the answer to the research question at the basis of that study.

Materials and Methods

SMSs are a category of literature reviews (Kitchenham and Charters, 2007). They are appropriate to give an overview of a research field in order to establish if research evidence exists on a specific topic and to provide, at the same time, an evaluation of the extent of the evidence. As suggested in Kitchenham and Charters (2007), the SMS was articulated in the following phases: Planning, Conducting, and Reporting the review results. The latter phase is self-evident, while the second one implements the first phase. So, in the following, we focus on the Conducting phase. It comprises three activities: (a) A definition of the study need; (b) A definition of the research questions; and (c) A definition of the mapping protocol (Fig. 1).

Study Need

Today, IoT platforms differentiate with respect to functions and services that they make available for the development, deployment, and management of IoT systems. With respect to the ThingsBoard platform, Section Background listed 14 distinct features. The objective of this SMS was to set up a map of the ambits where ThingsBoard has been used so far in order to answer the following research questions.

Research Questions (RQs)

- (RQ1) Are there available studies mentioning ThingsBoard?
- (RQ2) In which ambits?
- (RQ3) What is the role of ThingsBoard in the studies where it is mentioned?
- (RQ4) What are the gaps in current research and the implications for future research?

Mapping Protocol

This step was articulated in the six activities described in Fig. 1:

- Search string. The search string was “ThingsBoard”. It derives naturally from RQ1
- Inclusion criteria. Papers disseminated in journals, conferences, surveys, and book chapters that mention ThingsBoard
- Exclusion criteria. The collection of articles returned by Scopus has to be narrowed by ignoring: (a) Duplicates; (b) Conference reviews; and (c) Documents not written in English

Table 1: Metadata about the items retried by Scopus

Document type	Number of Publications %	Distribution over the year's	Number of publications %	Distribution over the year's	Number of publications %
Book chapter	3 (05.4)	2023	12 (21.8)	2020	7 (12.8)
Article	16 (29.1)	2022	8 (14.5)	2019	4 (07.3)
Conference paper	36 (65.5)	2021	19 (34.5)	2018	5 (09.1)

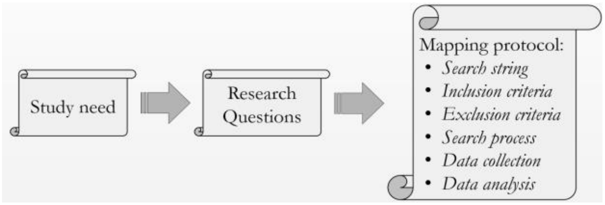

Fig. 1: Steps of the research methodology

- Search process. It was realized as a hand-operated search of Scopus articles that mention ThingsBoard either in the Title, in the Abstract, or among the authors' Keywords. The search was carried out on January 5, 2024. 55 items were retrieved
- Data collection. A PDF file collecting authors' names, titles, abstracts, keywords, and DOI, of each item returned by Scopus, was downloaded Then, the exclusion criteria were applied to the returned set. Since the search involved only items in the Scopus database, duplicate publications were not possible. Moreover, Scopus allows to set of filters to restrict the output of the search. The selection of the English language is an explicit option (i.e., Language = "English"). Analogously, it is possible to specify the Document type of interest. Therefore, the cardinality of the returned set of candidates remained unaffected. Lastly, when two or more researchers assess each paper, agreement between them has to be measured using, for instance, the Cohen Kappa statistic. This step was not applicable to this study
- Data analysis. The aim of this step of the mapping protocol (Fig. 1) was to synthesize the 55 items, to derive an answer for the research questions. As usual for SMSs, at this stage, the investigation was limited to the reading of the mentioned PDF file. Table 1 shows the distribution over the years of: (a) The selected publication types (i.e.: Article, Conference Paper, and Book Chapter) and (b) The total number of publications. The next section summarizes the findings

Results

Table 2 shows the number of occurrences of the "ThingsBoard" keyword, respectively, in the Title, in the Abstract, or as a Keyword in the set of the 55-item output of the Scopus search. 83.64% of the returned items mention ThingsBoard either in the Title or in the Abstract, which denotes that in the vast majority of these papers, such an IoT platform plays a central role.

Table 3 shows the ambits where the ThingsBoard IoT platform has been used so far and the number of occurrences of each of them. As can be seen, ThingsBoard has had two complementary categories of usage: (a) To implement IoT solutions in specific application domains (83.6%); and (b) To support either basic or general-purpose research studies. About the application domains, the most recurring ones are Environmental monitoring (8), Smart healthcare (7), Smart cities (6), Basic research (5), Smart agriculture (5) Smart factory (5).

Hassan *et al*. (2020) propose a taxonomy of IoT applications aggregated around the following six top-level principal fields: Healthcare, environment, smart cities, industry, infrastructures, and commerce. Table 4 shows the correspondence between those six fields and those in Table 3. As we see, the ambits listed in Table 3 cover the first five fields. The commerce field that at the moment remains out does not pose special challenges. Studies that have already appeared have underlined the beneficial effects that the IoT can play in connection with central topics of the digital market such as Inventory management, Supply chain management, and Personalization based on consumer preferences (Manogaran *et al*., 2021). ThingsBoard has features suitable for providing support in each of these application areas (Held *et al*., 2022). So, we can say that it is just a matter of time before papers proposing its adoption to those fields will appear.

Khanna and Kaur (2020), seven IoT application domains are mentioned and deeply examined. Table 5 shows the correspondence between those domains and those in Table 3. As we see, the ambits listed in Table 3 cover the seven domains.

In the five papers classified as Basic research, ThingsBoard is used either for comparison with other IoT platforms (Ismail *et al*., 2018; Held *et al*., 2022; Ottolini *et al*., 2022), to implement the theory presented in the study (Carratù *et al*., 2021), or to introduce a blockchain authentication scheme tailored for ThingsBoard (Jang *et al*., 2021). In the four papers classified as General purpose, ThingsBoard is used either to build an environment that provides automation with a security layer of Blockchain technology (Pal *et al*., 2023), to set up an IoT architecture suitable to implement generic IoT applications (Kiran *et al*., 2020), as the cloud IoT platform in the design and implementation of an open-source IoT-based SCADA system (Aghenta and Iqbal, 2019), or as cloud IoT platform for implementing a generic IoT monitoring system (Scott and Eleyan, 2019).

Table 2: Occurrences of the "ThingsBoard" keyword

	In the Title	In the Abstract	As Keyword
Occurrences	13 (out of 55) 23.64%	33 (out of 55) 60.00%	9 (out of 55) 16.36%
Item ID	Bestari and Wibowo (2023); Sabuncu and Thornton (2022); Ilyas *et al*. (2021); Casillo *et al*. (2021); Okhovat and Bauer (2021); Jang *et al*. (2021); Henschke *et al*. (2020); Sunehra and Siddireddygari (2020); Aghenta and Iqbal (2019); Scott and Eleyan (2019); Kadarina and Priambodo (2018); De Paolis *et al*. (2018); Cadavid *et al*. (2018)	Ismail *et al*. (2018); Held *et al*. (2022); Hamza *et al*. (2023); Nguyen *et al*. (2023); Dwiyaniti *et al*. (2023); Le *et al*. (2023); Motade *et al*. (2023); Alavi *et al*. (2020b); Krueganta *et al*. (2023); Pal *et al*. (2023); Carratù *et al*. (2021); Narasimharao *et al*. (2022) Trevathan and Schmidtke (2022); Low *et al*. (2022); Velasco-Hemandez *et al*. (2022); Chhorn *et al*. (2022); Ottolini *et al*. (2022); Tashakkori *et al*. (2021); Barakat *et al*. (2021); Eridani *et al*. (2021); Saha *et al*. (2021); Almheiri *et al*. (2021); Cardenas_Rivero *et al*. (2021); Lee and Saputri (2021); Malik *et al*. (2021); Winkler (2021); Georgiadis *et al*. (2021); Lawal *et al*. (2022); Moussa *et al*. (2021); Sălăgean and Zinca (2020); Kiran *et al*. (2020); Boonjun and Kammuang-Lue (2020); Mohammed *et al*. (2019)	Abdulbaqi and Hashim (2023); Huhs *et al*. (2023); Maksimović and Ćosović (2022); Alavi *et al*. (2020a; 2019; 2018); Kumar *et al*. (2021; 2020); Khoa *et al*. (2021)

Table 3: Ambits where the ThingsBoard IoT platform has been used with profit

Environmental monitoring	8	Abdulbaqi and Hashim (2023); Nguyen *et al*. (2023); Le *et al*. (2023); Krueganta *et al*. (2023); Bestari and Wibowo (2023) Trevathan and Schmidtke (2022); Ilyas *et al*. (2021); Winkler (2021)	Smart farm	4	Hamza *et al*. (2023); Chhorn *et al*. (2020); Tashakkori *et al*. (2021); Cadavid *et al*. (2018)
Smart healthcare	7	Narasimharao *et al*. (2022); Barakat *et al*. (2021); Saha *et al*. (2021); Kiran *et al*. (2020); Sunehra and Siddireddygari (2020); Kadarina and Priambodo (2018); De Paolis *et al*. (2018);	Microgrid	3	Alavi *et al*. (2020a; 2019; 2018)
Smart city	6	Huhs *et al*. (2023); Maksimović and Ćosović (2022); Okhovat and Bauer (2021); Lee and Saputri (2021); Lawal *et al*. (2022); Moussa *et al*. (2021)	Smart teaching	3	Sabuncu and Thornton (2022); Casillo *et al*. (2021); Moussa *et al*. (2021)
Basic research	5	Ismail *et al*. (2018); Held *et al*. (2022); Carratù *et al*. (2021); Ottolini *et al*. (2022); Jang *et al*. (2021)	Smart grid	2	Alavi *et al*. (2020b); Khoa *et al*. (2021)
Smart agriculture	5	Eridani *et al*. (2021); Kumar *et al*. (2021; 2020); Malik *et al*. (2021); Georgiadis *et al*. (2021)	Autonomous vehicle	1	Almheiri *et al*. (2021)

Table 3: Continue

Smart factory	5	Dwiyaniti *et al*. (2023); Motade *et al*. (2023); Velasco-Hemandez *et al*. (2022); Cardenas_Rivero *et al*. (2021); Boonjun and Kammuang-Lue (2020)	Water distribution	1	Low *et al*. (2022)
General purpose	4	Pal *et al*. (2023); Sălăgean and Zinca (2020); Aghenta and Iqbal (2019); Scott and Eleyan (2019)	WSNs	1	Henschke *et al*. (2020)

Table 4: Taxonomy in Hassan *et al*. (2020) vs this study

Hassan *et al*. (2020)	This study
Healthcare	Smart healthcare
Environment	Environmental monitoring, Water distribution
Smart cities	Smart cities, Autonomous vehicles, Smart
Teaching	
Industry	Smart grid, Microgrid, Smart factory, Smart farm
Infrastructures	WSNs
Commerce	

Table 5: Taxonomy in Khanna and Kaur (2020) vs this study

Khanna and Kaur (2020)	This study
Mobility	Autonomous vehicle
Smart grid	Smart grid
Smart buildings	Smart city
Public Safety and	Environment
Environmental monitoring	Monitoring
Healthcare and independent LIVING	Smart healthcare
Industrial processing	Microgrid, WSNs
Agriculture and breeding	Smart agriculture, smart farm, water distribution

Discussion

The considerations collected above answer RQ1, RQ2, and RQ3. For the convenience of the reader, the answers are collected in Table 6. The IoT practitioners can benefit from the presented results, because knowing the state of the art in the usage of ThingsBoard in real-life projects may be a source of inspiration for them and, then, speed up their future work. For these subjects, it is also relevant to know that rich documentation about ThingsBoard is provided on the platform website (https://thingsboard.io/docs/). The documentation includes detailed step-by-step deployment and installation guides, as well as a rich set of tutorials and examples covering all the basic platform features.

Now, let's turn to answer RQ4. RQ4 complements RQ2, in fact, it aims to identify the ambits that, so far, have been least investigated. The answer to RQ4 is, therefore, more oriented to the academia.

Main Findings

- Storage. IoT systems frequently deal with big and continuous data, which leads to the issue of how to keep track of real-time data and, consequently, how to provide fast retrieval of the data of interest for analysis and visualization purposes. In ThingsBoard, telemetry data can be stored in an SQL database which can be, then, easily queried. The database (called thingsboard) comprises 66 tables that collect metadata about the key concepts of a generic IoT application in addition to the involved telemetries. Motade *et al*. (2023) describe such an approach adopted to implement Smart Data Tracking for Package Transportation
- Computing paradigm. So far, the Cloud is the prevalent deployment solution adopted for IoT applications, because it offers computing resources on-demand and boundless storage. However, it has been pointed out that connecting IoT devices to the Cloud poses severe issues (Paolone *et al*., 2022). To fill the gap between IoT devices and the Cloud, the Fog-Edge computing paradigms have been introduced (Ali *et al*., 2022)

The reading of the 55 studies confirmed that ThingsBoard can be used both in Cloud architecture and in Fog/Edge architecture. The best choice is determined by the constraints posed by the application to be developed. For instance, in (Hamza *et al*., 2023) ThingsBoard runs on a cloud server, while in (Le *et al*., 2023) it runs on a fog server, consisting of a Raspberry Pi 4 computer:

- Scalability. IoT applications have to be able to handle a large number of devices maintaining the same level of performance. On the ThingsBoard homepage, it is written that: "Single instance of ThingsBoard server can constantly handle 20,000+ devices and 30,000+ MQTT publish messages per second, which in summary gives us around 2 million published messages per minute". The last sentence brings us good news about the scalability of such an IoT platform, but the question is: Do there exist scientific studies that confirm this claim? Hereafter, we mention two of them

Table 6: The answer to the first three research questions

RQ	The answer
RQ1	Yes
RQ2	Table 3
RQ3	(a) To implement IoT solutions in specific application domains (b) To support either basic or general purpose research studies

Da Cruz *et al*. (2018) carried out a performance evaluation study on 11 open-source platform alternatives. SiteWhere (https://github.com/sitewhere) obtained the better score. One year later, (Ismail *et al*., 2018) compared the performance of ThingsBoard against SiteWhere. The study evaluated two protocols: MQTT and HTTP REST. The performances of the two platforms were measured (using Prometheus) for different payloads of requests coming from virtual devices connected to them. The results of the comparison can be summarized as follows: In REST, the performance of ThingsBoard overcomes SiteWhere, while in MQTT, SiteWhere has superior performance, but the error rate is higher. In addition, when the size of the message increases, ThingsBoard performs better than SiteWhere:

- Data visualization. From the carried out SMS, it has emerged that significant attention has been paid to the real-time monitoring of sensed data since it represents a basic requirement of most IoT applications. The domain of Remote Healthcare Monitoring, for example, strongly relies on such a feature of the ThingsBoard IoT platform (Barakat *et al*., 2021)

Almost all the retrieved studies emphasize that ThingsBoard offers the ability to create interactive visualizations, known as dashboards. Dashboards allow monitoring and managing the sensed data and the IoT devices efficiently. Moreover, a rich widget library to choose from allows end users to adapt dashboards to their specific needs by populating them with widgets.

- Programming. ThingsBoard offers a rich package of APIs that can be used to access and visualize the sensed data. Le *et al*. (2023), for example, use those APIs to implement both a Web and a real-time air quality monitoring mobile application. In addition, ThingsBoard offers REST API Clients to interact with the ThingsBoard from a Java application
- Analytics. IoT brings big data. The bigger the volume of the sensed data, the larger the need to turn them into insights. The ThingsBoard Trendz Analytics add-on assists the user of the platform in establishing the data analytics pipeline. This tool is not free, so it must be purchased. The alternative to buying it consists of developing one's own data analytics tool. This is what authors (Hamza *et al*., 2023) are doing

Gaps to be filled with further research:

- Privacy and Security. ThingsBoard allows customizing access rights and permissions of users according to the category of data at hand. However, none of the implementation studies that are part of the retrieved set put emphasis on the privacy and security of the sensed data. Sunehra and Siddireddygari (2020), for example, do not even mention these terms. Privacy and security are issues of primary importance in the Healthcare sector, where it is mandatory the protect the patient data from malicious disclosure. It has been pointed out that so far this issue is largely an open challenge (Bahbouh *et al*., 2023). It is worth noting that signals in this direction come from the basic research side (Jang *et al*., 2021; Pal *et al*., 2023). Particularly interesting is (Jang *et al*., 2021), example, since it introduces a blockchain authentication scheme specifically tailored for ThingsBoard
- Usability. We didn't find studies about the actual usability of ThingsBoard by IT users for none of the domains where it was used. So, an open issue to be taken into account in future studies concerns the introduction of suitable usability measures for such an IoT platform

Threats to Validity

This section addresses potential threats to the validity of the SMS, discussing construct, internal, external, and conclusion validity:

- Construct validity is concerned with the relationship between theory and findings. In the case of SMSs, such a category of threats could potentially originate at the data collection stage. The decision to investigate works on Scopus guarantees that the research has been peer-reviewed. Furthermore, having extracted works that cite ThingsBoard either in the Title, in the Abstract, or as an Author' keyword is equivalent to basing our conclusions on studies very focused on this IoT platform which, therefore, are fundamental for building a map adhering to the reality of the researches in which ThingsBoard played a significant role

Besides the 55 papers retrieved by Scopus, there are certainly other publications that mention the ThingsBoard keyword either in their body or in the title of some of the references. In both cases, these are studies that are not centered on ThingsBoard and which, in any case, are not returned by the Scopus search engine and, therefore, it is not certain whether they satisfy the requirement of having passed the standard peer review process. Rathi *et al*. (2021) is an example of a peer-reviewed work that mentions ThingsBoard in the Related work section, as well as in one of its references. Specifically, Kadarina and Priambodo (2018), which mention ThingsBoard in the title, cited:

- Internal validity is the extent to which the design and conduct of the study are likely to prevent systematic errors (Kitchenham and Charters, 2007). The rigorously defined mapping protocol (Fig. 1) assisted us in preventing this threat

- External validity refers to the relevance of the results and their generalizability. We cannot claim the generalizability of the findings, since the outcome of the SMS is a snapshot of previous research mentioning the ThingsBoard platform. About the relevance of the final findings, we can say that the more the retrieved studies were relevant, the more our findings were relevant. To address this threat, we queried the Scopus scientific repository which indexes journals that meet the requirement for peer-review quality adopted by several research agencies across the world
- Conclusion validity refers to threats that can impact the reliability of the conclusions. The analysis and interpretation of the results were conducted considering the 55 studies collected through the SMS. A potential threat might be caused by an incorrect interpretation of the results described in those papers. To mitigate this threat, all the articles were carefully reviewed

Conclusion

This study presented a mapping study focused on the ThingsBoard open-source IoT platform. The deep analysis of the selected 55 Scopus studies provided insights into the breadth of usage and the ambits where ThingsBoard has been applied successfully, indicating its suitability and potential for a wide range of IoT-related projects. The heterogeneity of the ambits confirms its effectiveness and versatility, as emerged at the end of the SMS reported in Di Felice (2023).

The SMS goals are general, so the final findings might be of interest to IoT professionals, as well as to scholars. For the latter, the open challenges concern security and usability. Two relevant topics that need further research.

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Author’s Contributions

Paolino Di Felice: Conceived ideas, collected papers from different sources, designed the outline of the manuscript and wrote the first draft of the paper.

Gaetanino Paolone: Reviewed the manuscript and provided critical feedback.

Both authors read all the 55 papers returned by Scopus.

Ethics

This article is original and contains unpublished material.

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