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DATA NOTE

REVISED Available Wireless Sensor Network and Internet of Things testbed facilities: dataset

[version 2; peer review: 2 approved, 1 approved with reservations, 1 not approved]

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Abstract

The availability of data is an important aspect of any research as it determines the likelihood of the study's commencement, completion, and success. The Internet of Things and Wireless Sensor Networks technologies have been attracting a huge amount of researchers for more than two decades, without having a consolidated or unified source that identifies and describes available Internet of Things and Wireless Sensor Network testbed facilities. In this paper, a dataset including 41 distinct testbed facilities is described. These testbed facilities are classified according to their key features such as Device Under Test (DUT) type, mobility, access level, facility count, connection/interaction interfaces, and other criteria. The systematic review process resulting in the gathered data set consisted of three filtering phases applied to relevant articles published between the years 2011 and 2021 as obtained from the Web of Science and SCOPUS databases.

Plain language summary

In this Data Note, we present data collected for the purpose of carrying out a systematic review of the available Wireless Sensor Network and Internet of Things testbed facilities. The data was collected through multiple stages and in each stage, the pre-defined criteria were applied. We provide a dataset describing the hardware and software aspects of Wireless Sensor Networks and Internet of Things testbed facilities available in the market and scientific community. The data were gathered through an extensive systematic review process of scientific articles published between the years 2011 and 2020. The review aims to obtain good-quality data for people who are actively researching the Internet of Things or Wireless sensor Network testbed facilities or anyone who is interested in that field.

Keywords

Testbed facility; Data set; Wireless Sensor Networks; WSN; Internet of Things; IoT

Open Peer Review

Approval Status ? ✓ ✓ ✗

	1	2	3	4
version 2 (revision) 28 Nov 2023		✓ view	✓ view	✗ view
version 1 24 Nov 2022	? view	? view		

1. **Prasanth A**, Venkateswara College of Engineering, Sriperumbudur, India
2. **Ihsan Ali**, University of Malaya, Kuala Lumpur, Malaysia
3. **Ousmane Thiare**, Gaston Berger University, Saint-Loui, Senegal
4. **Mohamed-Lamine Messai**, University of Lyon 2, Lyon, France

Any reports and responses or comments on the article can be found at the end of the article.



This article is included in the Horizon 2020 gateway.



This article is included in the Wireless Communications collection.

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Author roles: Judvaitis J: Conceptualization, Data Curation, Formal Analysis, Methodology, Project Administration, Supervision, Validation, Writing – Original Draft Preparation, Writing – Review & Editing; **Abolins V**: Methodology, Supervision, Validation, Visualization, Writing – Original Draft Preparation, Writing – Review & Editing; **Elkenawy A**: Data Curation, Investigation, Validation, Writing – Original Draft Preparation, Writing – Review & Editing; **Ozols K**: Funding Acquisition, Investigation, Project Administration, Supervision, Validation, Writing – Original Draft Preparation, Writing – Review & Editing

Competing interests: No competing interests were disclosed.

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The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

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First published: 24 Nov 2022, **2**:127 https://doi.org/10.12688/openreseurope.15176.1

REVISED **Amendments from Version 1**

We have improved the grammar in the paper and we have improved the description of Figure 1 in the main text stating more clearly what is depicted there. We have added a research objective description in the introduction section of the article.

Any further responses from the reviewers can be found at the end of the article

Introduction

Nowadays, the Internet of Things (IoT) term is often used due to its significant role in enabling smart interactions between machines, sensors, and the environment[1]. The IoT approach aims to orchestrate a set of "things" or technologies such as sensors, actuators, radio frequency identification (RFID) tags, near field communications (NFC), and machine-to-machine (M2M) communications, by means of network protocols, in order to achieve the required goal by the developed IoT system[1,2]. IoT applications and use cases can vary from manufacturing and agriculture to healthcare and transportation, with a wide spectrum in between[1]. One specific example of an IoT application could be an indoor localization system using an IoT testbed as described by Elkenawy *et al.*[3].

To build a complete IoT system as a Wireless Sensor Network (WSN) infrastructure, an efficient prototyping procedure must be carried out as a first step. Testbed facilities are a great tool for prototyping purposes compared to other simulation or emulation tools, as they represent the real-world conditions more precisely, which in turn speeds up the development process and could make the process of developing WSNs, making debugging and testing less time consuming[4,5]. A plain definition for the WSN testbed facility would be a realistic/physical environment consisting of a large number of permanently deployed sensor nodes (25+ nodes according to Ruskuls *et al.*[6]) with a software backend that provides a basic set of functionalities such as node reprogramming and remote interaction. On top of that, a lot of testbed facilities provide additional features such as data logging, experiment scheduling[7], energy metering[8], *etc.*

A good dataset demonstrating testbed facilities, in terms of facilities' capabilities versus market needs, would provide guidelines with regard to design choices for testbed facilities and provide useful information during the creation and execution of scientific experiments, in addition to fueling innovative solutions and remarkable competition[9] within the market. To the best of our knowledge, a comprehensive and up-to-date dataset for testbed facilities is a scarce resource that is not yet available to the research community. An illustrative example of this is that querying "IoT testbed" in Google Dataset Search would result in:

- Data generated during a testbed experiment;
- Specifications of a testbed facility;
- Description of a cluster of testbed facilities (e.g. cybersecurity testbeds category).

A broader survey has been done by Judvaitis *et al.*[10] by extracting information about 3059 sensor network deployments according to different categories, which is one of the few existing attempts for synthesizing a complete dataset for actual sensor network deployments. This data set was gathered with the aim of providing a definite overview of existing Wireless Sensor Networks and Internet of Things testbed facilities available for scientific and industrial use and identifying possible gaps to be filled by future testbed facility developments.

The research question addressed by this article is how many and what testbed facilities are available and how do they compare against one another.

Methods

This dataset was gathered following the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA)[11] checklist. The initial search was done in two databases *Scopus* and *Web of Science* (WoS) using the following queries:

Scopus: TITLE (testbed) AND TITLE-ABS-KEY (wsn OR iot OR "sensor network*" OR "internet of thing*") AND SUBJAREA (comp) AND PUBYEAR < 2021 AND PUBYEAR > 2010

WoS: TI = ("testbed") AND (AB = (wsn OR iot OR "sensor network*" OR "internet of thing*") or AK= (wsn OR iot OR "sensor network*" OR "internet of thing*")) and SU="Computer Science" and py =(2011–2020)

The raw results returned 346 articles from Scopus and 176 articles from WoS. After 163 duplicates were removed, 359 unique articles were left for further analysis. In the phases described below each article was mainly processed by one reviewer independently. For each reviewer in each phase articles were assigned randomly. This minimized the risk of biases while assigning the articles to a particular reviewer. The confusing and difficult-to-evaluate articles were discussed in weekly meetings or re-evaluated by another reviewer.

First phase

In this phase, only the abstracts of all 359 were analyzed. The aim was to filter articles that did not contain a description of the testbed facility. With a testbed facility, we understand the following: the facility provides remote access to the embedded hardware which can be used freely without any restrictions regarding the usability or functionality, and it should meet the following minimal requirements:

- Designed to run a variety of different experiments, where the devices under test are completely controlled by the user;
- Users do not need physical access to the hardware-reprogramming or any other interaction with software can be performed remotely;
- Provide a user interface specifically designed for testbed facility purposes.

Access to the testbed facility can be restricted and is not necessary for a testbed facility to qualify, so it does not necessarily need to be public. Articles containing descriptions of improvements to testbed facilities were also to be included, even if they did not contain a description of the testbed facility itself. The guidelines for researchers who did the screening were the following:

(a) Open the article you are going to evaluate.

(b) Read the abstract.

(c) Make a decision about the article, does it contain a testbed facility description, and, if so, mark it as included for further analysis.

(d) Mark the article as screened.

(e) Go to the next article.

We used Mendeley (https://www.mendeley.com/) to quickly share the progress between the team members and automatically obtain the abstracts for the articles. 9 team members (3 of which are the authors) screened the abstracts. As a result of the first phase, 170 articles were dropped, as they did not contain a testbed facility description. A total of 189 articles were left for further analysis.

Second phase

The aim of this phase was to filter out non-testbed facility articles and group the articles by distinct testbed facilities, assuming that there can be multiple articles per testbed facility. In this phase, the full article was screened, and, using the same criteria as in the previous phase, the article was marked as "containing testbed facility" or not. We used a Microsoft Excel worksheet to track the progress and split the work between researchers. 4 team members (3 of which are the authors) screened full texts of articles. After the second phase, 125 articles were marked as not containing a testbed facility description.

Third phase

In this phase, to minimize the risk of missed articles in the second phase, all 189 articles (the same articles as in the previous phase) were processed and predefined values (with their descriptions) were extracted: device under test (DUT), Sensors (the type), location (generic description of the place where the DUTs are located), mobility (can the DUTs physically move while the experiment is ongoing), architecture (the internal design of the testbed facility), workstations (workstation is a DUT-to-server relay, typically a Linux-capable device that forwards the data and commands between server and DUTs), DUT location accuracy (what is the precision to which the user knows the DUT location), cost of implementation (if provided), deployment options (is the testbed suited and intended to deploy outside of the laboratory), facility count (assuming there might be more than one facility), functionality (the features this testbed facility provides to users), access level (what is the level of user control), user interface (the type of used UI), assistive tools (any tools designed to facilitate or improve the user experience), DUT connection and interaction interfaces (physical connections available), and whether the testbed facility is available as Open Source.

All articles were processed again by the whole team to minimize the risk of error in the previous phase. We used JSONForms (https://jsonforms.io/) to make the extraction process smoother and obtain machine-readable data in JSON format. After the third phase, 134 articles (125 from the previous phase + an extra 9 articles) were excluded and 55 articles were included in the dataset. There were multiple testbeds with more than one article describing them. In total, 41 unique testbed facilities were described in 55 articles. An overview of all the systematic review phases described above is summarized in a flow diagram in Figure 1, depicting the whole process.

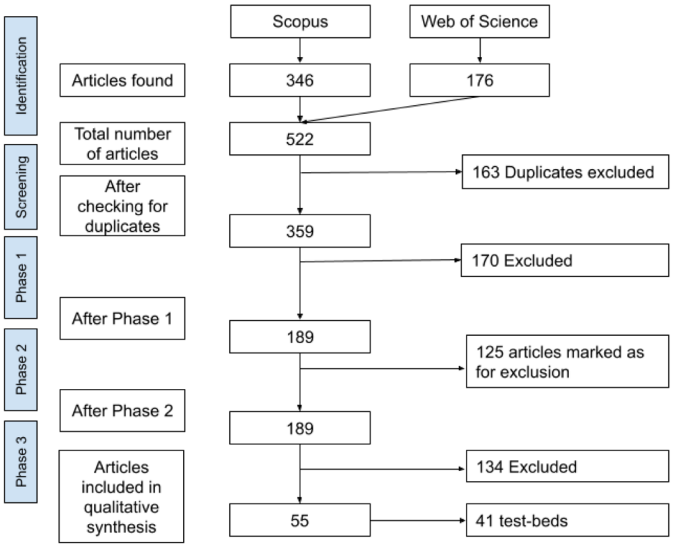

Figure 1. Flow diagram overview of the systematic review methodology and results at each phase.

Data processing

As the data describing testbed facilities contains data entries that are not machine-readable, the nature of the resulting data set does not allow processing using programming tools such as Python/Jupyter Notebooks, it can only be viewed as a textual compilation of different specifics about the evaluated testbed facilities. As a remedy to this situation, we compiled a subset of all the extracted data unifying and simplifying the extracted values to be more easy to use. The unifying process and actions taken were discussed with the team members to gain a unified vision of the process. Still, the process itself was done by the leading researcher to minimize the interpretation difference risks. After this process, the team members reviewed the unified dataset. The newly obtained machine-readable data set is in unified JSON format and thus can be read and analyzed by any modern programming language script or data analytics application, the data set includes some initial analytic scripts written in Python. The machine-readable data set contains less information overall, as similar values were merged for increased readability. In the published dataset we have included both versions, together with the tools used to obtain the datasets.

Ethical approval and consent

Ethical approval and consent were not required.

Data availability

Underlying data

Zenodo: *Available Wireless Sensor Network and Internet of Things testbed facilities: dataset,* https://doi.org/10.5281/zenodo.7157221[12].

This project contains the following underlying data:

- **raw_dataset** contains the files for each article containing a testbed facility description with the extracted information in json format;
- **json** contains json files for each testbed facility processed with the aim of improving the machine readability of the dataset;
- **output.json** contains a json array with the names of extracted features and the list of testbed facility IDs corresponding to the json file names with such features;
- **feature_extraction.ipynb** contains the script used for the initial analysis of the JSON files about testbed facilities.

Extended data

Zenodo: *Available Wireless Sensor Network and Internet of Things testbed facilities: dataset,* https://doi.org/10.5281/zenodo.7157221[12].

This project contains the following extended data:

- **Supplementing_info/raw_exports/**contains the raw list of articles exported from SCOPUS and WoS databases;
- **Supplementing_info/processed/1-combined.xlsx** contains the combined list of articles;
- **Supplementing_info/processed/2-deduplicated.xlsx** contains the deduplicated list of articles;
- **Supplementing_info/jsonforms/**contains the web-based tool used for testbed facility feature extraction in the Third phase;

For further details on the structure and contents of each folder please view the README.md file.

The dataset is licensed under CC-BY 4.0 International (CC-BY 4.0) Public Domain Dedication license.

Acknowledgements

In addition to the authors of this article, the following individuals provided their work to the acquisition and processing of this data: Janis Arents, Vladislavs Medvedevs, Artis Mednis, Andris Ivars Mackus, Krisjanis Nesenbergs, and Rihards Balass. All six collaborators participated in the weekly meetings and discussed articles that in all three phases were selected as difficult or confusing. All acknowledged contributors have agreed to be named in this manuscript.

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http://www.doi.org/10.5281/zenodo.7157221

Open Peer Review

Current Peer Review Status: ? ✓ ✓ ✗

Version 2

Reviewer Report 26 February 2024

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✗ **Mohamed-Lamine Messai**
University of Lyon 2, Lyon, France

In this submission, published scientific papers on sensor and IoT networks testbeds are used to construct a dataset. However, the aim of constructing such a dataset is not clear. Additionally, the use of IoT context depends on the application requirements. Does studying the availability of testbed facilities necessitate a dataset?

A clear definition of an IoT system is needed; is an IoT system a WSN connected to the Internet? In my opinion, and for more clarification for the readers, the reference section should include the 41 references to testbeds.

The design of sensor and IoT networks is application-sensitive, a point the paper does not consider. For example, in some kinds of applications, mobility is used, but not all testbeds offer this possibility.

The authors present three minimal requirements needed to use a testbed, but in my opinion, other requirements need to be added.
For the 170 articles that were dropped, have the authors checked that the descriptions are not available on testbed websites, GitHub, etc.?

Why use the same criterion "containing testbed facility" for both phases 1 and 2? These two phases could be merged.

The transition from Phase 3 to Phase 4 requires more details.

The authors do not indicate why their dataset is useful. Why is the URL of the testbeds' websites not a feature in the dataset (FIT IoT-Lab, etc.)?

Finally, the paper lacks a conclusion.

Is the rationale for creating the dataset(s) clearly described?

Partly

Are the protocols appropriate and is the work technically sound?
Partly

Are sufficient details of methods and materials provided to allow replication by others?
Partly

Are the datasets clearly presented in a useable and accessible format?
Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Wireless sensor and IoT Networks, ML & Cybersecurity, datasets

I confirm that I have read this submission and believe that I have an appropriate level of expertise to state that I do not consider it to be of an acceptable scientific standard, for reasons outlined above.

Reviewer Report 17 January 2024

https://doi.org/10.21956/openreseurope.18263.r36699

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Ousmane Thiare
Gaston Berger University, Saint-Loui, Senegal

This article makes a great contribution to the Internet of Things and wireless sensor networks, particularly in the availability of testbeds with a data set.

The question of the availability of complete data on which researchers can work has always been a crucial issue in research related to IoT and wireless sensor networks. It's worth noting in this paper, however, how a rigorous selection has been made to really focus on available resources from reliable and different sources. This is an assurance and also brings precision and reliability for the benefit of the research community in this field.
The paper does address the collection and classification of data, but doesn't really say how this data should be exploited for future research.

Personally, this article will enable the research community to use testbeds for the transition from simulations to real deployments. This will prevent researchers from using more simulation tools rather than real deployments.

Is the rationale for creating the dataset(s) clearly described?

Yes

Are the protocols appropriate and is the work technically sound?
Yes

Are sufficient details of methods and materials provided to allow replication by others?
Partly

Are the datasets clearly presented in a useable and accessible format?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Internet of things, Wireless sensor networks, distributed systems

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Reviewer Report 05 January 2024

https://doi.org/10.21956/openreseurope.18263.r36476

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Ihsan Ali
University of Malaya, Kuala Lumpur, Wilayah Persekutuan, Malaysia

Most of my comments are addressed by the authors. The paper may be accepted for indexing.

Is the rationale for creating the dataset(s) clearly described?
Yes

Are the protocols appropriate and is the work technically sound?
Yes

Are sufficient details of methods and materials provided to allow replication by others?
Yes

Are the datasets clearly presented in a useable and accessible format?
Yes

Competing Interests: No competing interests were disclosed.

I confirm that I have read this submission and believe that I have an appropriate level of

expertise to confirm that it is of an acceptable scientific standard.

Version 1

Reviewer Report 15 September 2023

https://doi.org/10.21956/openreseurope.16415.r33751

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Ihsan Ali
[1] University of Malaya, Kuala Lumpur, Wilayah Persekutuan, Malaysia
[2] University of Malaya, Kuala Lumpur, Wilayah Persekutuan, Malaysia

The article presents a valuable contribution to the field of Internet of Things (IoT) and Wireless Sensor Networks (WSN) research by addressing the crucial issue of testbed facility availability. Here is a critical review of the article:
On the positive aspects of the article, the study underscores the importance of testbed facilities in IoT and WSN research. Availability of comprehensive data on these facilities is essential for researchers to plan and conduct experiments effectively. Moreover, the systematic approach to collecting and classifying testbed facilities based on key features such as DUT type, mobility, access level, and connection interfaces is commendable. This classification provides a clear and organized overview of the available resources. Furthermore, the article transparently outlines the systematic review process used to gather the dataset. The use of well-established databases like Web of Science and SCOPUS adds credibility to the data collection process. Finally, the willingness to share the collected dataset is a positive aspect of the article. Making this data available to the research community can significantly benefit scholars and practitioners in the IoT and WSN domains.

My critical analysis and few reservations are as follows.

While the article broadly addresses the availability of testbed facilities, it could benefit from a more explicit focus on specific research questions or objectives related to these facilities. Defining the research goals and context more clearly would enhance the article's relevance.
More experimentation is needed on the collection of data. Synthetic data always raises several concerns. The article briefly mentions the dataset but lacks an actual presentation of the dataset, making it difficult for readers to access and utilize this valuable resource. Providing a link or access to the dataset itself would greatly enhance the article's usefulness.
On the contrary, the article does not discuss any limitations or potential biases in the dataset or the systematic review process. Acknowledging these limitations would provide a more balanced perspective for researchers using this data.
The article mainly focuses on data collection and classification, it could expand on potential future research directions or applications of the gathered dataset. This would help guide researchers

interested in using the data for various purposes.

Finally, the article lacks a concise conclusion section summarizing the key findings, contributions, and the broader implications of the dataset for the IoT and WSN research community. A well-structured conclusion would enhance the article's overall impact.

In summary, the article addresses a significant gap in IoT and WSN research by compiling a dataset of testbed facilities. Its systematic approach and transparency in data collection are commendable. However, to maximize its value, the article should clarify its research objectives, present the dataset itself, acknowledge limitations, suggest future research directions, and provide a robust conclusion. These improvements would make the article an even more valuable resource for the academic community.

Is the rationale for creating the dataset(s) clearly described?
Yes

Are the protocols appropriate and is the work technically sound?
Partly

Are sufficient details of methods and materials provided to allow replication by others?
Partly

Are the datasets clearly presented in a useable and accessible format?
Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: WSNs, IoT, Sensor Cloud, Cloud Computing

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 24 Nov 2023

Valters Abolins

Dear Ihsan Ali, thank you for the provided review, comments and suggestions, here is our answers to them: We have added a research objective description in the introduction section of the article. The dataset itself is available and is mentioned in the article in the section "Data availability" as bibliography reference [12]. It is published in the well recognized Zenodo platform and can be found here: https://doi.org/10.5281/zenodo.7157221 We are not aware of any limitations or biases in the dataset or the systematic review process, if we know them, we would have addressed them. With the only exception being the queries executed on the SCOPUS and Web of Science databases and the limits they impose on the found results, but they are published in the article. As for the potential future research directions, by the time of writing it was

only a plan, but as of now, the complete systematic review about the published dataset is completed and published by us. The article by written by us "Testbed Facilities for IoT and Wireless Sensor Networks: A Systematic Review" can be found here: https://doi.org/10.3390/jsan12030048 Just for the clarification, this dataset publication is only about the gathering and compiling of the dataset and the systematic review I mentioned deals with the analysis of the gathered data and trends.

Competing Interests: No competing interests were disclosed.

Reviewer Report 28 July 2023

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Prasanth A
[1] Venkateswara College of Engineering, Sriperumbudur, Tamil Nadu, India
[2] Venkateswara College of Engineering, Sriperumbudur, Tamil Nadu, India

This article contains new and significant information adequate to justify the publication. However, the reviewer has some suggestions, as listed below:

1. Some sentences have grammatical errors. So, the authors need to check the grammatical errors throughout the paper.

2. Figure 1 should be properly explained in the main text.

Is the rationale for creating the dataset(s) clearly described?
Yes

Are the protocols appropriate and is the work technically sound?
Yes

Are sufficient details of methods and materials provided to allow replication by others?
Partly

Are the datasets clearly presented in a useable and accessible format?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Internet of Things and Wireless sensor network

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 24 Nov 2023

Valters Abolins

Dear Prasanth A, thank you for the provided review and suggestions, here is our answers to them: 1. We have re-read and corrected the grammar in the paper as you suggested, leading to quite a large amount of edits improving the overall grammar and fluency of the paper. 2. We have improved the description about the Figure 1 in the main text stating more clearly what is depicted there.

Competing Interests: No competing interests were disclosed.