# Evaluating Open Science Practices in Indoor Positioning and Indoor Navigation Research

A Survey of the IPIN's Reference Papers of 2022 and 2023 Editions

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***Abstract*—The importance of reproducibility and transparency in scientific research has always been a cornerstone of the scientific Ethos. Recently, after identifying the challenges in terms of reproducibility in various research fields, the necessity of wide adoption of Open Science practices has become prominent. The field of Indoor Positioning and Indoor Navigation is no exception to these realizations. The current work provides a comprehensive review of Open Science practices followed in recent publications in the field, analyzing all reference papers from the 2022 and 2023 editions of the International Conference on Indoor Positioning and Indoor Navigation (IPIN).Particularly, the level of use of open data, open code, and open materials, is studied. Moreover, for all works relying on Open Research Data (ORD), our analysis went a step deeper characterizing multiple relevant features describing the data used, such as the technologies, the measurement types, and the environments associated with the open data. Our findings reveal that 22.4% of papers use open research data, 10.5% utilize open code, and 21.1% incorporate other open materials. However, only 7.9% of papers provide both open data and code. This study underscores the need for wider adoption of those practices, to enhance the transparency, reproducibility, replicability, and reliability of research outcomes of the field of indoor positioning. The files containing the complete characterization of the reviewed publications and of the Open Science practices followed are publicly available in [1].**

***Keywords*—Localization, Positioning, Reproducibility, Open Data, Open Code, Open Materials**

## I. Introduction

The landscape of indoor positioning and indoor navigation research has gained relevance and popularity over the last decade. At the same time, increasing emphasis has been given to reproducibility and transparency in scientific research, relying on Open Science practices. This paper aims to contribute to this evolving landscape by providing a comprehensive review of recent publications from the International Conference on Indoor Positioning and Indoor Navigation (IPIN) conference, focusing specifically on the adoption of open data, open code, and transparent/reproducible evaluation practices.

Open Science practices and Research Reproducibility are closely related and intertwined. In the renowned 'A manifesto for reproducible science' [2], the authors suggest that '*Transparency is a scientific ideal, and adding 'open' should therefore be redundant. Science often lacks openness: [...] most data, materials and code supporting research outcomes are not made accessible, for example, in a public repository*'.

The motivation for this work stems from a growing recognition of the importance of reproducibility in scientific research. The European Commission's scoping report on the Reproducibility of Results in the EU highlights an increasing awareness of reproducibility issues across multiple disciplines [3]. Scoping studies from various disciplines [4–7] provide a realistic picture of the status of reproducibility in their respective fields by rigorously examining relevant literature and offering fact-based conclusions. In the relevant work 'Towards Reproducible Indoor Positioning Research'[8], the authors commented on this practice, suggesting that "*an objective understanding of the status of a field can assist the decision-making towards positive change. Therefore, a relevant survey on the current level of reproducibility of indoor positioning research would be an excellent steppingstone, and a future baseline to evaluate the progress of the indoor positioning community in this aspect*."

The current work aims to contribute in this direction, by creating a snapshot of the current level of adoption of relevant Open Science practices in this field. To achieve this objective, in this work, we systematically analyze reference papers from recent editions of the IPIN conference. Our analysis follows a structured approach:

- Characterization of Open Research Data (ORD): We will identify the use of new or existing ORD within each paper. ORD encompasses raw or processed measurements that can be utilized as inputs to positioning systems, models, or algorithms to generate position estimates.
- Characterization of Open Code: We will assess the use of open source code, defined as programming code that can be reused, extended, or adapted by future researchers.
- Characterization of Open Materials: Beyond open data and code, we will also identify the provision of new or the reuse of existing open materials, which include tools

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and resources that facilitate the overall indoor localization workflow. Examples of open materials include program executable files, mobile applications, and other assisting tools not categorized under open data or open code.
- Analysis of Papers Using ORD: For papers that utilize ORD, we will delve deeper into their methodologies, examining various aspects such as technologies employed, types of measurements, deployment environment types and characteristics, and data utilization techniques.

By systematically characterizing these elements, we aim to provide a comprehensive overview of the current practices in the IPIN community regarding openness and reproducibility.

## II. Methodology

For this work, all reference papers presented at the IPIN conference over the past two editions (2022, 2023), were analyzed. A total of 152 papers were examined [1], and their features across several categories were characterized.

To safeguard the robustness of our analysis we opted for the following methodological approach. All authors participated with two hats: those of an "analyst" and a "reviewer". Each paper was randomly assigned to an analyst/reviewer pair, among the co-authors. The analyst performed an in-depth examination to identify all relevant information about the paper and all relevant fields (existence of ORD, Open Code and Materials, etc.), entering this information into an accessible spreadsheet, noting any missing information, and providing necessary comments.

Once the analyst's work was completed, the reviewer then reviewed the analyst's characterization, suggesting potential changes, seeking clarifications, or completing missing information. This often involved the reviewer conducting a similar search to cross-check the analyst's findings. After completing the review, the analyst integrated the reviewer's feedback, either accepting suggestions or discussing differences of opinion to reach a common understanding. Ambiguous issues were discussed among all co-authors until an agreement was reached. All co-authors participated in this process, alternating between the roles of analyst and reviewer to ensure coherence and uniformity in interpreting dataset features. Differences in views were discussed in group meetings to avoid future discrepancies. This method improved the precision of characterization and helped clarify ambiguous cases, enhancing decision-making coherence.

We categorize the features considered when analyzing each paper into five categories. The first category, General Information, includes basic details about each paper, such as the title, authors, year of publication, and DOI. The second category, Open Research Data, involves identifying the type of data that is used by each paper (real data, simulation-based, etc.), as well as the use of new or existing ORD within each paper. In the third category, Open Code, we investigate the availability and main characteristics of any code associated with the papers. This includes determining whether new code was introduced, the type of code available (e.g., code implementing the proposed method, experiments or dataset loading), library versions used, URLs, and programming languages. The fourth category describes the potential use of open materials such as applications, executable files, or mobile apps related explicitly to localization. Lastly, the fifth category was filled only for those cases where an ORD Dataset was used, diving into its multiple characteristics. For those papers, we analyze the technologies, signal types, and measurements involved. We also examine the environmental context, such as the number of floors and buildings associated with the dataset, the area size, and whether outdoor environments were included. Moreover, we characterize the file types used and whether the papers employed and shared subsets for training, validation, and testing purposes.

## III. Results

This section presents the results obtained after analyzing all the reference papers published within two editions of the conference. Fig. 1 shows the types of data that all analyzed papers deal with. Most papers (69.74%) use real data to produce the results. These data may originate from real-world measurements by the paper authors or from public ORD. Simulation data are used in 17.11% of papers, mostly in situations where real-world experiments are challenging to perform with state-of-the-art technologies whose hardware is not easily available. Additionally, 12.50% of the papers explore a combination of simulated and real data, typically employing simulation for training and prevalidation of the proposed models, and real data for evaluation. A residual percentage of papers (0.66%) do not use any data type, representing papers such as surveys.

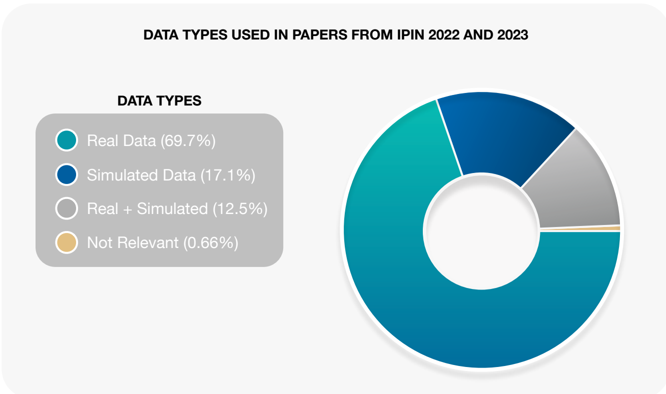


Fig. 1: Data types used in papers from IPIN 2022 and 2023.

The upper plot of Fig. 2 depicts the percentage of papers that use some kind of open resources (data, code, or material). Over 60% of papers do not use any open resources. The middle row indicates that, overall, 22.4% of papers use (new or old) ORD, 10.5% use (new or old) open code, and 21.1% use other (new or old) open material. The bottom plot of Fig. 2 illustrates the papers proposing new open resources, with 7.2% of papers sharing new ORD, 6.5% sharing new open code, and only 2% sharing new open material.

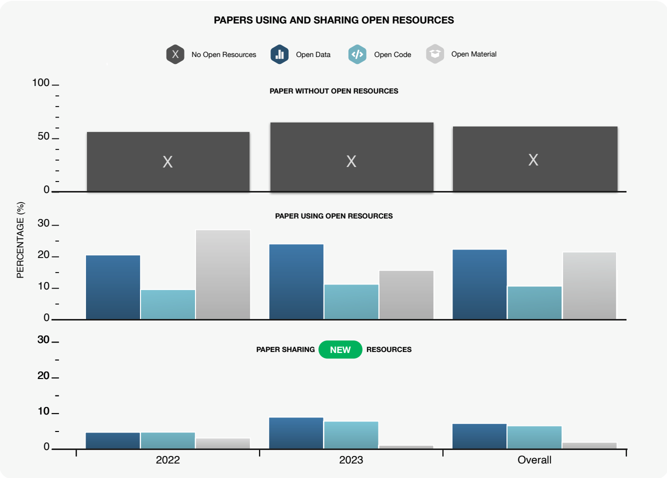


Fig. 2: Papers without any open resources (no open data nor code neither material) (Top); papers using (new or old) open data, code and material (Middle); and, papers sharing new open data, code and material (Bottom).

Focusing on the papers using open research data, either reused or new, Fig. 3 shows the percentage of each technology found, representing the ORD presence and usage across the various technologies. As we can observe, a variety of technologies used for Indoor Positioning were identified. Ultra-Wide Band (UWB) technology, stands out with a relatively low presence of 6.25%. This percentage is indicative of its still emergent status. The Global Navigation Satellite Systems (GNSS) shows moderate usage (12.50%), due to the low applicability in indoor environments. Bluetooth Low Energy (BLE) and cameras share a similar percentage of 15.62%, suggesting their prevalence in contemporary technological ecosystems. "Other technologies" collectively also hold a 15.62% adoption rate. The use of Inertial Measurement Units (IMUs) is particularly prevalent, with an adoption rate of 31.25%. However, it is WiFi that leads with the highest adoption rate of 50%, clearly demonstrating the widespread use of this communications technology for positioning purposes.

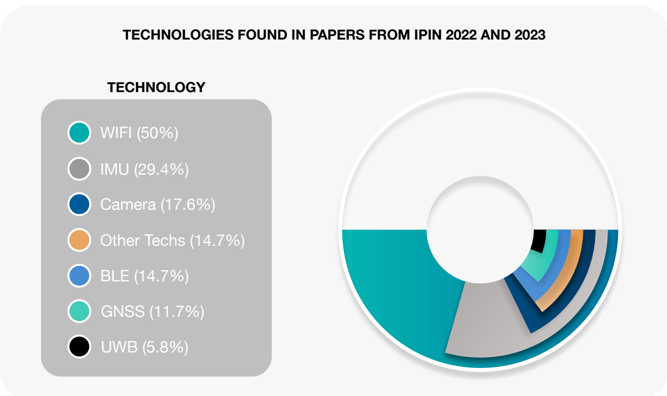


Fig. 3: Technologies found in papers using ORD from IPIN 2022 and 2023

Figure 4 details the types of measurements by technology. In radio technologies, like Wi-Fi or BLE, the Received Signal Strength Indicator (RSSI) is predominant as it is easy to measure. Some datasets also include more sophisticated measurements like the Time of Flight (TOF) or Channel State Information (CSI), but they are fewer because they require dedicated hardware and software to collect. Two BLE datasets also include channel information. UWB-based datasets allow obtaining CSI, TOF, and the Channel Impulse Response (CIR) measurements. Most datasets that include inertial data, provide accelerometer, gyroscope, and magnetometer data, some only provide accelerometer and gyroscope, while there is one dataset proving only data from the magnetometer. GNSS location estimates are found more often than raw measurements since, in many devices, such as smartphones, they are more easily obtained. Camera-based datasets include images and point clouds (from sensors like LiDAR). Several other technologies were also present in open datasets, such as Zigbee, 5G, visual Simultaneous localization and mapping (SLAM) (using a Google Tango), Attitude and Heading Reference System (AHRS) (giving orientation), fiber optic gyroscope with odometer and altimeter.

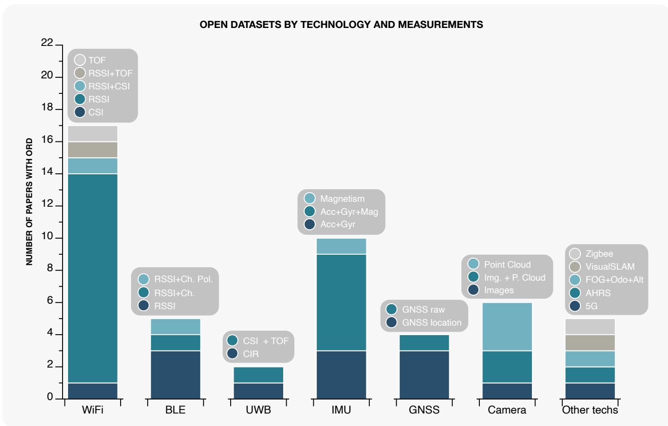


Fig. 4: Technologies and types of measurements of used ORD.

Regarding the area size of the environment where datasets were obtained, Fig. 5 shows the distribution by area size classes. In situations where a paper uses more than one ORD, the dataset with the largest environment was considered. Most datasets comprise an area between 100 and 1000 $m^2$, and are mainly associated with Wi-Fi and BLE.The second most used class of coverage area is $> 100.000$ $m^2$. This is mainly due to papers using UJIIndoorLoc [9] and the crowd-sourced dataset [10]. UJIIndoorLoc is particularly known within the IPIN community, and it covers multiple multi-floor buildings. All datasets covering large areas include Wi-Fi data. Some of them also include BLE, IMU, GNSS, and camera data. Datasets from smaller environments, with areas $\leq$ 100 $m^2$ typically include Wi-Fi data with RSSI and CSI, BLE data with RSSI and channel information, IMU and Zigbee data. A significant portion of studied papers considered ORD whose area cannot be determined based on the available metadata.

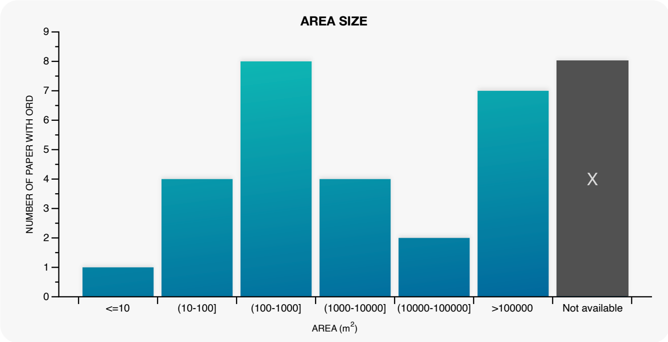


Fig. 5: Open research data based on the area size.

Figure 6 shows the distribution of open datasets based on the type of environment. Almost half of the analyzed datasets were collected in office-like environments, such as universities, offices and laboratories. Approximately 30% of papers using ORD explored diverse environment settings for evaluation and testing, since they comprise data from multiple types of environments which include combinations of environments such as residential, office, industrial, and other. "Other" particular types of environments account for 12% of datasets, e.g., simulated or urban scenarios. Shopping centers as well as residential/home environments account for almost 3% of the datasets each.

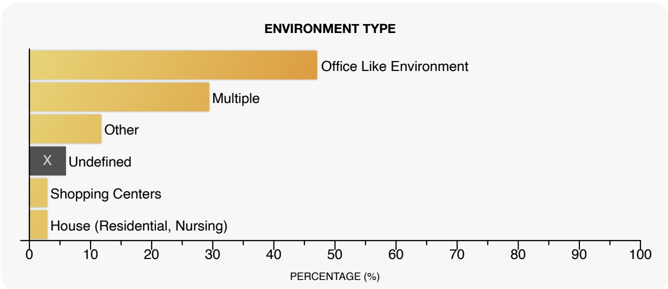


Fig. 6: Open research data by environment types.

Lastly, Fig. 7 depicts the level of usage and sharing of specific data subsets (such as training, validation, or test sets), used for predetermined roles in the evaluation process typically, but not exclusively, in Machine Learning (ML). Particularly, the upper plot depicts the answers to the question of whether such subsets were used in the papers involving ORD. The authors mentioning a training and test set is a typical example of such a case. The bottom plot describes whether such subsets were used, if they are openly available and whether the split used preexisted or if it is newly provided by the authors.

## IV. Discussion

The analysis of the open science practices followed over the two last editions of the IPIN conference brought invaluable lessons learned, identified shortcomings with open resources, and allowed us to identify good practices followed by conference participants.

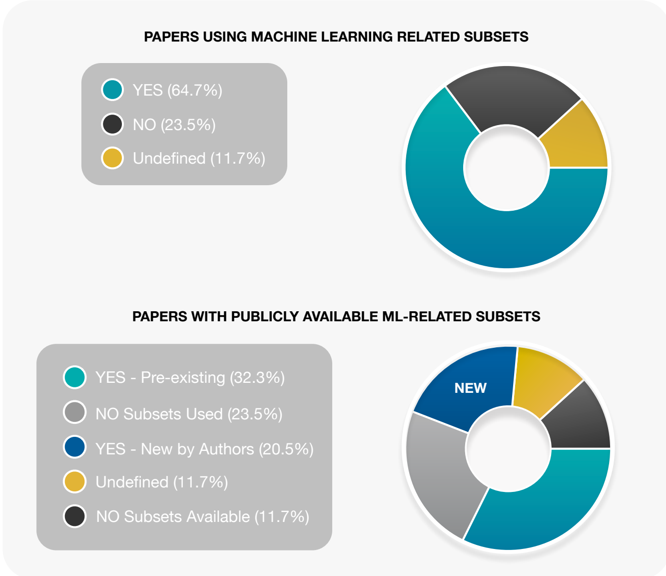


Fig. 7: (Top) Papers using subsets with specific roles (such as train, validation, test sets) that are common in the ML practice; (Bottom) Public availability of such subsets.

The first significant outcome is that 38 out of 152 (25%) full reference papers presented in the last two editions of the IPIN conference contain either open data or open code. This can be considered a milestone as the presence of such a volume of open resources seemed rather anecdotal in the conference's first edition. While the trend is quite positive, we are still far from reaching full transparency in research, through fully repeatable, reproducible, and replicable results in the vast majority of publications. Indicatively, despite the fact that almost all papers rely on real data, simulated data, or a combination of the two (Fig. 1), and they all reasonably rely on some code implementation, only 12 out of 152 (7.9%) full reference papers presented both open data and code.

It is noteworthy that researchers presented the data descriptor for an open dataset in the first edition of the IPIN conference [11], evidencing the consciousness of ORD within the community at that time. The total number of published reference papers in the last two editions is similar to what was published in 2010, with the main difference that a total of 5 new ORD have been shared or released within the conference. This evidences that the community is modestly becoming more conscious about the relevance of generating and sharing relevant data with the community.

A common key element for open resources is ORD. All the analyzed works with ORD relied either on reusing open data, providing new datasets to the community, or a combination of both. Those works passed a stringent peer-review process consolidating the quality of the works. However, a shortcoming comes with the fact that the paper review process. While papers are evaluated on their appropriateness for the conference topics, their relationship with respect to the state of the art, their possible impact, novelty, and results, there is no clear point for data quality assessment and openness, which are currently implicitly enclosed within the evaluation of the paper's soundness. In a new era, where the use and disclosure of open resources are common, the correct assessment of data and the evaluation of the environment's suitability become imperative. As identified by [12], a wrong use/partition of data might bring unreliable results and conclusions.

We have identified a noteworthy incoherence through the revised works. The way the datasets are cited differs, depending on the paper. While 11 papers provide direct citations to data repositories, 16 works do not. Usually, a citation to a research paper or a data descriptor paper is provided instead. In cases where a dataset is backed by a data descriptor, it is recommended to provide a citation for both, even if citing only the data descriptor guarantees credit to the author. The option of citing both brings all information about the data location (clear link to the repository) and also provides the sources for the full description of the dataset.

Besides "what is cited" for giving credit, there are different strategies for "how to cite". While an entry on the reference list is the common practice, authors still provide the reference to the repository as a plain hyperlink in a footnote. The latter approach hinders relevant information about the dataset title (if any), dataset authors, and release date. The former approach, a traditional citation, is often standardized as the major repositories, like Zenodo, provide tools to export citations to several formats and bibliography managers.

Furthermore, "where to cite" becomes a relevant feature as there is no standardized place for citing the datasets used. References to ORD have been found as footnotes anywhere on the manuscript, as citations within the evaluation setup, and, even, cited in a reproducibility section at the end of the manuscript. As the correct identification of the ORD is a key feature to enable reproducibility, we strongly recommend providing an unnumbered section "Data Usage and Reproducibility" (as we do in this manuscript) where to explicitly describe: 1) the existing data sources used (publicly available or not), 2) the new datasets presented in the work (publicly available or not), and 3) any additional materials supporting research reproducibility. In terms of data, it should be clear how many open and private/restricted dataset sources have been used within the manuscript.

While mentioning datasets or other open materials within a research paper, the authors usually employ a short version of the dataset name, which is sometimes provided by the dataset creators within the data descriptor or the data repository. However, some datasets are published with long titles and do not provide such short names. In these cases, the authors who come up with a short name for ease of reference to the dataset in their paper must ensure the selection of a representative short name that is not misleading. It is advised to the dataset donors to provide every dataset with a short name or acronym, to avoid any ambiguity and facilitate reference to their dataset.

Despite being less than 2 years old, we found that the resources of a few works are not available. Often, this happens because the used open dataset was not hosted in a repository ensuring long-term access, such as the *Alcala Tutorial* dataset used in Baskin *et al.* [13]. It may also happen that the authors cite a data descriptor that does not contain any hyperlink to data, making it impossible to reach the dataset. For instance, Luo *et al.* [14] cited SoLoc dataset [15], but we could not find that dataset. Finally, there are papers claiming to provide access to new ORDs, which are unavailable. For instance, Aranda *et al.* [16] mentions that the dataset and some code could be found at Zenodo or upon request to the corresponding author, but the Zenodo's link is not working at the time of writing this manuscript[1]. This usually happens because the dataset's release is postponed after the paper's acceptance, and this last step might be incidentally omitted. It would be advisable that a check is made in the camera-ready version of manuscripts, and any claim of data availability that is not be met at that time should be removed. The above three scenarios are not theoretical as they have been identified within the reference papers in the IPIN conference. Thus the relevance of providing some guidelines to mitigate their appearance.

We have identified two main categories for the type of data, namely "Real data" and "Simulated data". While the former corresponds to actual measurements in the real world, the latter means that data are synthetically generated with, for instance, a mathematical model that mimics the propagation loss. Simulated data are useful when the physics behind a positioning technology is mature enough to simulate real-world measurements and we have limited access to the sensing devices. This enables preliminary experiments without the need to deploy infrastructure or to perform extensive and demanding data collection campaigns in the real world. Overall, real data are richer and preferable for conclusive arguments as they bring forward the challenges one might encounter in a real implementation and deployment of positioning services.

## V. Conclusions and Future Work

In this work, we comprehensively analyzed recent works from the IPIN conference, focusing on the usage and sharing of open data, open code, and open material, which facilitate transparent and reproducible evaluation practices. We systematically characterized each paper based on its use of ORD, open source code, and additional open materials, extracting useful insights regarding the current state of these practices within the indoor positioning community. Furthermore, for all IPIN papers involving ORD, our analysis went deeper, characterizing technologies employed, types of measurements, environments studied, and utilization techniques.

By systematically characterizing the landscape of Open Data and Code in IPIN, we aim to provide a snapshot of a comprehensive overview of the current practices in the IPIN community regarding openness and reproducibility, at the current time. This analysis serves as a valuable resource for all relevant stakeholders, highlighting areas of strength and identifying opportunities for improvement within the field.

[1]Dataset authors have been informed about this issue and may fix this issue at the time of this manuscript's publication

Our motivation is to promote a culture of transparency and openness in indoor positioning research. By fostering such a culture, we anticipate the acceleration of the observed modest shift of our community toward more robust and reproducible scientific practices, ultimately enhancing the credibility and reliability of research outcomes.

Looking forward, there are interesting future research directions that we envisage to undertake. Parallel to the current work, we have focused on conducting a systematic review of all ORD available in the field of Indoor Positioning (IP) (referred to by the acronym ORDIP), which is currently under publication. That work is complemented by the provision of relevant guidelines for data sharing and utilization, facilitating interested researchers in collecting, sharing and reusing ORD in an efficient way. Another interesting future task is establishing public benchmarks that require complete methodological compliance, for enabling reliable and consistent comparisons of different methods. Furthermore, we are convinced that just as research papers undergo rigorous peer review, publishing positioning-related ORD data (such as fingerprint datasets) should also be subject to a similar review process to ensure their quality and reliability. Such steps will collectively enhance the transparency, reproducibility, and overall credibility of the research outputs in the IPIN community.

## Data Usage

A laborious, extensive systematic study of the reference papers of the last two editions of the IPIN conference has produced a detailed characterization of 152 papers, which is available in the supplementary material of this work [1].

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## CRediT author statement

All authors have contributed equally to this work throughout its long execution period and can all be considered the main authors of this manuscript.

Conceptualization: G.G.A., P.B, A.C., C.P., I.S., J.T.-S., Methodology: G.G.A., P.B, A.C., C.P., I.S., J.T.-S., Data curation: G.G.A., P.B, A.C., C.P., I.S., J.T.-S., Formal analysis: G.G.A., P.B, A.C., C.P., I.S., J.T.-S., Writing: G.G.A., P.B, A.C., C.P., I.S., J.T.-S., Visualization: G.G.A., C.P., I.S., Supervision: G.G.A., Project Administration: G.G.A., Funding acquisition: G.G.A.

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