Categorization of Technologies used for Fingerprint-Based Indoor Localization

Mário Andrade Vieira de Melo Neto and Gibeon Soares de Aquino Júnior

Department of Informatics and Applied Mathematics
Federal University of Rio Grande do Norte
Campus Universitário, Lagoa Nova, 59078-900
Natal, RN, Brazil
Email: mariovmelo@gmail.com, gibeon@dimap.ufrn.br

***Abstract*—Indoor localization systems have become very popular in recent years. These systems provide a new automation layer for the localization of people or objects in indoor environments, which makes them crucial for many applications. The indoor localization techniques can be classified in the following classes: proximity, fingerprint, triangulation and vision analysis, being the fingerprint class the most used. This paper presents the results of a literature systematic mapping on fingerprint-based indoor localization, aiming to identify the technologies used for this purpose. The selected search strategy returned 1003 papers, which underwent a series of inclusion and exclusion criteria that resulted with 539 articles being accepted. This work identified that the main technology used for indoor localization is the WIFI, followed by ZigBee. As a contribution, this study is intended to provide an overview of the indoor location area and the technologies used in others studies.**

Keywords–indoor localization;fingerprint; technologies;

I. INTRODUCTION

Indoor localization systems have become very popular in recent years. These systems provide a new automation layer for the localization of people or objects in indoor environments, which makes them crucial for many applications. According to [1] after more than one decade in this area, the indoor localization problem remains unsolved. There does not seem to exist a technology or a combination of technologies that can solve this problem in an acceptable manner and at a low cost.

For outdoor location, the most popular technology is the Global Positioning System (GPS) [2], which works based on satellites, making it quite accurate in external locations but inappropriate for indoor spaces. This limitation is caused by the inability of the satellite's signals to propagate in areas that are full of obstacles, causing failures or the impossibility to calculate the target's position. Aiming to achieve the same success as the GPS, indoor localization systems have been increasingly gaining space, providing new strategies for the detection of people and objects. There are many real world situations in which these systems can be used, such as: detection and control of products stored in a warehouse, location of medical personnel or equipments in a hospital, location of firemen in a building on fire, location of police dogs trained to find explosives in a building and finding tagged maintenance tools and equipment scattered all over a plant [3].

Currently, large companies [4][5] are investing in research and development of solutions for indoor localization. Nevertheless, there is still no localization solution proven effective on indoor environments at the same scale that GPS is for outdoors. One of the reasons for this is the high complexity of indoor environments, which are always associated with a number of challenges such as the influence of obstacles (walls, equipment and people), overlap of signals emitted by various types of equipments present in the locations, variety of buildings types and dimensions that are considered small when compared to outdoors.

According to [6], the indoor localization techniques are classified using the following classes: triangulation, proximity, fingerprint and vision analysis. The fingerprint technique was chosen for this study because according to [7][8], is the most widely used approach for indoor localization [9][10]. The fingerprint-based indoor localization is defined as the determination of a position through the process of mapping the environment's aspects, such as the strength of the received signal, the magnetic field present at a location or any other characteristic that can identify a position. With the result of this mapping and the position where it was done, it is possible to make an inference to get approximate location of people or objects without the need of any specialized equipment.

This paper aims to perform a literature review on the fingerprint-based indoor localization subject in order to assist researchers providing an overview of the indoor location area and the technologies used in others studies. Therefore, a systematic mapping was performed using the guidelines defined by [11][12]. The purpose of this review was to identify the most used technologies, the types of researches that are being conducted and the resultant contributions to the area. It is important to obtain an overview so that researchers can identify the most promising technologies present in the area or propose the use of new technologies in this context.

The rest of the paper is organized as follows: Section II describes the protocol used to perform the mapping. Therefore it presents research questions, search terms used, classification scheme and paper selection process. Section III presents the main results, their implications and threats to validity. Section IV concludes the study and indicates future trends on the subject.

II. RESEARCH METHODOLOGY

In this paper, we present a systematic mapping review based on guide written by [11]. Figure 1 shows an overview of the systematic mapping process used in this study.

Following the process, the first step was to define the research questions, which are presented as follow: Which technologies are used in fingerprint-based indoor localization?

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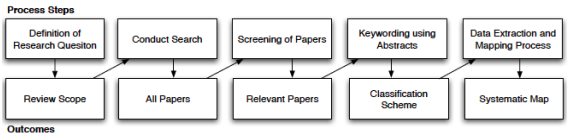

Figure 1. Systematic Mapping Process defined by [11]

(RQ1); How are the papers distributed over time?*(RQ2)*; In the papers found, which types of researches were used? *(RQ3)*; What are the main type of contribution described in each work? *(RQ4)*.

A. Search Strategy

The research started by identifying the key terms used in the proposed subject. For this, several searches were conducted on the research databases in order to identify possible synonyms and keywords that could return the highest number of relevant papers. As a result of these pilot searches, the following terms were chosen:

("indoor location" OR "indoor localization" OR "indoor positioning") AND (fingerprint)

Our search strategy used the most well-known academic work databases in the science computer area, which are: IEEEXplore, ACM digital library, Springerlink.

In order to obtain all the relevant works, we used the meta-search engine Scopus [13], since it covers all the sources that are relevant to our study. It was performed a solo search resulting with 1003 papers for evaluation.

B. Inclusion and Exclusion Criteria

Every recovered paper was manually evaluated using a set of criteria in order to identify whether it would be included or not in the mapping. For this purpose, we evaluated title, abstract, keywords and, when necessary, introduction and conclusion.

The inclusion criteria used to indicate whether a paper would be part of the mapping or not are: propose or evaluate an indoor localization technology and the paper was already reported, only the latest will be considered.

For a paper to be excluded from the mapping, it needed to fit into at least one criterion as follows: papers not written in English and papers that do not have full versions available.

C. Selection Process

This stage of the protocol was divided into two phases. First, we applied the inclusion and exclusion criteria, which resulted in papers that were relevant for the mapping process. Table I shows this result. The second phase was responsible for analyzing and classifying the papers based on the definition of the categories identified during the development of the classification system described in Section II-D.

In the process of selection and classification of works, no inclusion criteria using quality levels were applied. This way, we tried to avoid the discard of studies relevant to the research because we could compromise the overview of the area, which we wish to obtain.

TABLE I. SELECTION PAPERS STAGE

Stage	Description	n
1	Identified relevant papers	1003
2	Excluded inaccessible papers	1003
3	Excluded based on language	996
4	Excluded duplicated papers	954
5	Excluded based on title	946
6	Excluded based on abstract	829
7	Relevant papers	539

D. Classification Scheme

The papers were classified based on three different facets. Each facet consists of a set of categories in which papers can be mapped. The facets are: technology, main contribution and research type.

Technology Facet: Determines the technologies used in the research. This classification was obtained through the keywording process [14]. Figure 5 presents this result.

*Contribution Facet:*This classification determines the main type of contribution achieved by the researcher. In other words, the improvements proposed for the subject. These contributions have been obtained using the keywording process and are presented in Table II.

Research Type Facet: This classification was suggested by Wieringa et al. [15] and defines six categories, which are briefly described in Table III.

E. Data Extraction

During this phase, all necessary data for our mapping study of the 1003 papers obtained in stage 1 of the selection process was extracted based on a predefined extraction form. This form allowed the extraction of all data with all of the details needed for the research questions analysis. Since our focus was to obtain a list of technologies used for indoor localization, the data extraction was performed individually for each paper.

III. MAIN FINDINGS

In this section, we summarize and structure the results according to the research questions defined in Section II. For each set of results, we will make a brief interpretation and name some of the reviewed papers.

A. Results of Literature Mapping

In order to answer RQ2, Figure 2 presents the number of included papers separated by year, with the higher value occurring in 2013 with 141 papers. We noticed a small decrease in the amount of included papers in 2014. This can be explained because the mapping execution took place in January/2015, so many papers were still not available in the research databases. It is noticed that in the last three years, the featured subject has received more attention in the 2012-2014 period, obtaining an increase of 40% in the number of papers when compared to the 2004-2011 period. We notice that there is a tendency that the number of papers in 2014 overcomes the number of papers in 2013 due to the growth rate of the inclusion curve.

Figure 3 presents the distribution of the classified papers in the research type facet defined in Section II-D. The obtained results answer RQ3 and demonstrate that most papers - about 90% of the total report solution proposals. This number

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TABLE II. CONTRIBUTION TYPE FACET

Category	Description
Solution	Represents a software or computational solution. Also apply to this definition: tool, system or application.
Method	Indicates how things should be done, i.e., using Bluetooth to perform the indoor localization. Algorithms, techniques and approaches are part of this classification.
Scheme	Describes a plan or protocol to treat specific problems. Defines a set of procedures and rules for the research or proposed solution.
Metric	Metrics and measures for indoor localization.
Model	Represents a mathematical model description for indoor localization.

TABLE III. RESEARCH TYPE FACET

Category	Description
Validation Research	Techniques investigated are novel and have not yet been implemented in practice. Techniques used are for example experiments.
Evaluation Research	Techniques are implemented in practice and an evaluation of the technique is conducted. This also includes to identify problems in industry.
Solution Proposal	A solution for a problem is proposed, the solution can be either novel or significant extension of an existing technique. The potential benefits and the applicability of the solution is shown by an example or a good line of argumentation.
Philosophical Papers	These papers sketch a new way of looking at existing things by structuring the field in form of a taxonomy or conceptual framework.
Opinion Papers	These papers express the personal opinion of somebody whether a certain technique is good or bad, or how things should been done.
Experience Papers	What and how something has been done in practice. It has to be the personal experience of the author.

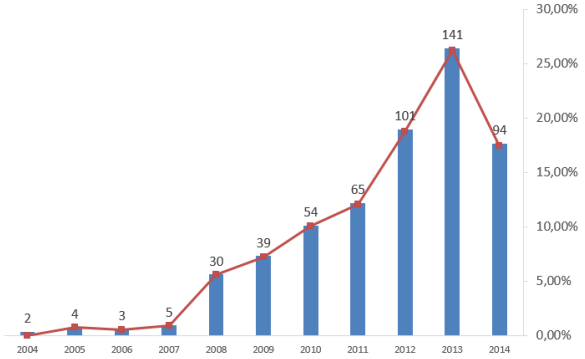

Figure 2. Included Papers per Year

indicates that although many studies are focused on solutions, there are still gaps to be filled related to solutions to perform indoor location with better accuracy and reliability. A study that exemplifies a solution proposal is presented in [16], where it is proposed a system for indoor location using WIFI signals and Smartphone sensors to estimate the location of a human being in a corporate environment, achieving an accuracy of about 2.3 m.

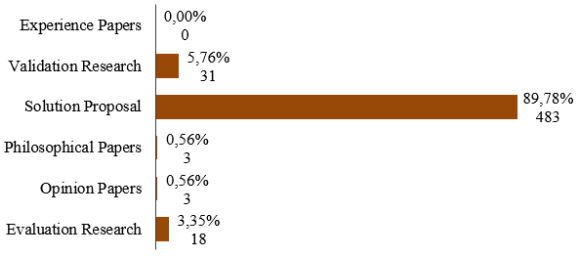

Figure 3. Distribution of research types

The numbers of validation and evaluation researches represent together approximately 10% of the total of researches done. This demonstrates the low amount of researches for the validation of solution proposals in laboratories or in the industry. Another point that has drawn attention refers to the fact that the philosophical papers are represented by only two papers. The papers found in this category aim to propose taxonomies and conceptual frameworks. Thus, a low number of papers shows that there are conceptual and definitional gaps to be exploited, which indicates the need to obtain theoretical foundations, discussions and categorizations.

In order to answer RQ4, we present in Figure 4, the amount of papers for each main contribution defined. This classification was obtained using the key wording process described in Section 2.3. The numbers for solutions and methods contributions represent more than 97% of the total, which demonstrates that the researcher's focus are on the pursuit of "how" to make the indoor localization of objects or persons. Of this total, the methods represent more than 63% of all papers. This significant value can be explained due to sub-categories grouping, such as algorithms, techniques and approaches in a higher-level category.

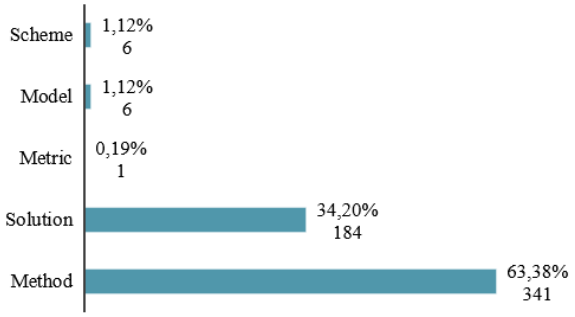

Figure 4. Distribution of contribution types

The solutions represent 34% of all of the papers, which demonstrates that the researchers' search for a computational solution capable of performing satisfactorily the localization of people or objects in indoor environments. Another important

fact is that the only article to propose a new metric for the subject is [17], which proposes a metric that quantifies the localization effectiveness provided by an access point (AP).

B. Categorization of Technologies

Once we have mapped all of the technologies used in the subject, we organize the set of technologies for fingerprint-based indoor location in six major categories which is shown in Figure 5. After the distribution of the technologies in the categories based based on the transmission medium employed for spreading the information, we realized that the Radio Frequency category has a higher amount of researches, which is mostly due to WiFi and ZigBee attendance. The large majority of the researches focus on Radio Frequency and Sensor-based technologies, which demonstrates the path that the researchers have been following for indoor location infrastructure and devices.

Figure 5 presents the data needed to answer the RQ1, including the technologies used in the evaluated papers and their quantities. It is noticed that the number of technologies used exceeds the number of papers evaluated because, in some cases, more than one technology has been used in the research. Among all, the technology that was mostly used was the WIFI, which surpassed more than 6 times the second place. According to [18], in 2012 about 1.5 billion devices were activated using with WIFI. In addition to this, another fact should be taken into consideration: the cost. Since the needed infrastructure exists practically everywhere, it would not be necessary to modify or insert any equipment, therefore reducing costs.

Another technology that deserves to be mentioned due the number of researches presence is the ZigBee. Despite being very similar to WIFI and Bluetooth, it proposes better power management and low data transmission [19]. Despite these features, there are some factors that prevent ZigBee to be used in large scale, such as high cost to deploy and short range. According to [20], the Bluetooth technology will be present in almost 4 billion devices being 1 billion of this total on smartphones in 2016. So, it was expected a much larger number for this technology. Since we expected that, it would be at least among the top five. This technology has some advantages for indoor positioning as presents [21], however [7] presents one characteristic may have direct influence in the presented numbers of using Bluetooth in localization is that, in each location finding, it runs the device discovery procedure; due to this, it significantly increases the localization latency (10 – 30 s) and power consumption as well. For this reason, the Bluetooth technology has a major issue to overcome when it comes to realtime positioning applications.

Despite being a Radio Frequency-based technology, the GPS category was separated into a main category because it is an established technology and can provide by itself the outdoor location. Some studies use it combined with other technologies for better indoor positioning precision. However, [22] is the only case in which the GPS is used by itself without the use of any auxiliary technology to perform indoor location.

The Sensor's category has gained a lot of attention in recent years in the area and the technologies responsible for it are undoubtedly accelerometers and gyroscopes. This large increase is directly linked to the Smartphone popularization process. According to [23], 1.75 billion people have Smartphones with advanced capabilities. These smartphones with advanced capabilities typically have multiple sensors, such as accelerometers and gyroscopes, which are the most used in researches in the Sensors category, indicating that there is still a large gap for this theme when compared to the number of papers in the Radio Frequency category.

By analyzing the list of technologies obtained, we realized that several studies focus on more than one technology at a time. Figure 6 presents the rate of hybrid approaches found in the evaluated papers compared to the number of included papers per year. For a better analysis, a ratio line linking the two measures is presented. We noticed that between 2004 and 2007, no research was performed using combined technologies. Since 2008, researchers began to discreetly use hybrid approaches, which are responsible for about 9% of all of the papers written in the period; the use of hybrid approaches remained stable until 2012, having a 1% decrease in 2009. From 2012, we noticed a gradual growth with a constant rate of 2% a year. Despite the low number of researches with this characteristic, there is a tendency that, in the upcoming years, this number will grow and new solutions and methods using combined technologies will be proposed. We believe that one of the reasons that led the researchers to use this type of approach is the fact that indoor environments can be very complex and that no single technology is able to satisfactorily adapt itself to these environments complexities in order to perform an accurate localization.

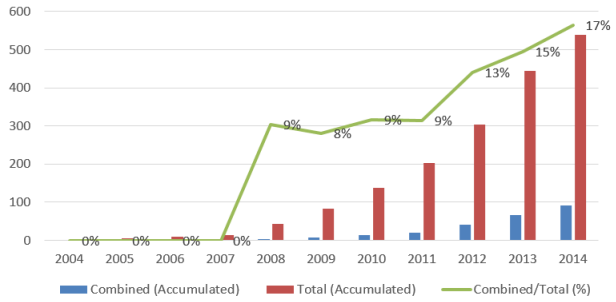

Figure 6. Combined technology use evolution

Analyzing the set of technologies category from the perspective of hybrid approaches, like it was set forth in the previous subsection, we present in Figure 7 the numbers of papers that use single and combined technologies over the technologies categorization. We realize that, in most studies, the radio frequency category uses only one technology. The fact that this number is so expressive when compared to the others can be explained by the presence of WIFI, since in most of the analyzed papers, it was identified that when a research involves this technology, it tends to use single technology as opposed to combined technologies. We believe that the researchers consider WIFI to be the standard technology for indoor localization like GPS is for external localization. The sensors category, in its turn, is totally the opposite of Radio Frequency since most of their studies that is, 86% of them - uses more than one technology. This trend of combining various technologies using sensors has grown over the years and one of the reasons for this growth may be the popularization of internet of things and ubiquitous

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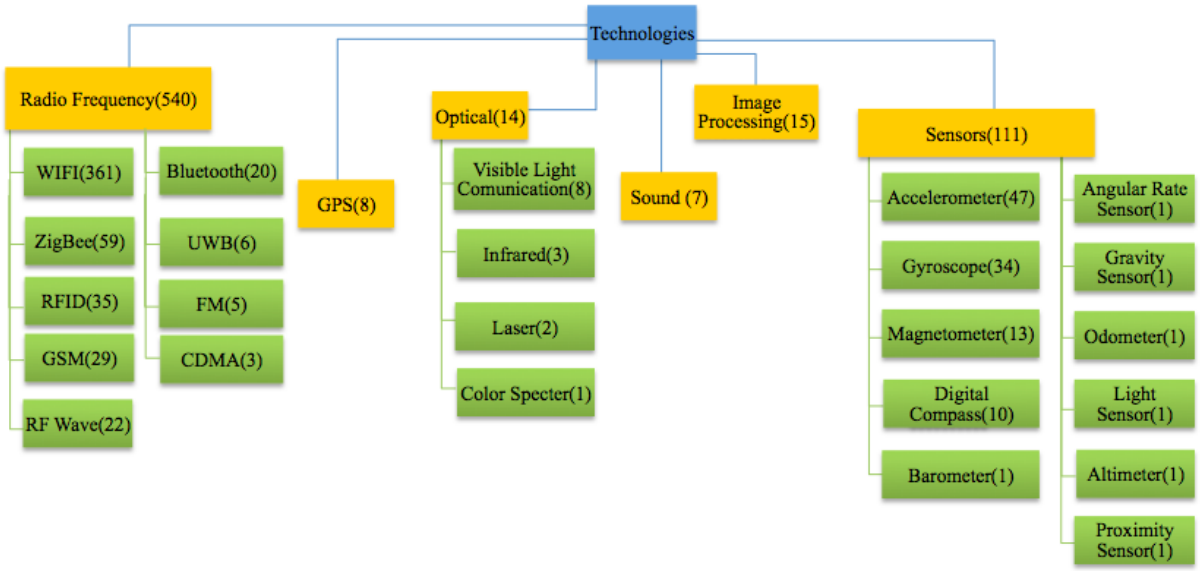

Figure 5. Technologies Categorization

computing [24]. For the GPS category, only one research paper using a single technology was found. The remaining works combine several technologies but in all of them, one of the technologies used is the WIFI. For image processing and Sound and Optical categories, the numbers of papers that use combined technologies is higher than the number of papers with single technology. These findings demonstrate that only the radio frequency category does not have the higher number of papers with hybrid approaches.

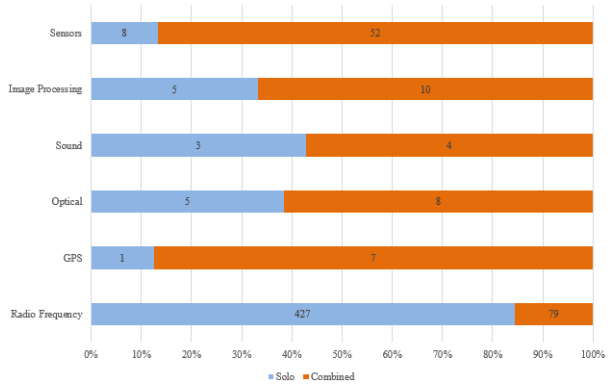

Figure 7. Combined tecnology over the technologies categorization

IV. CONCLUSION

In this paper, we report the results of a systematic mapping study on the subject of fingerprint-based indoor localization. The collection and interpretation of data related to this context produced a number of important discoveries, which allow us to understand the evolution of this area in recent years and also point trends and open issues. In addition to the results obtained from the data analysis, we created a categorization for the technologies used in the context of fingerprint-based indoor localization.

Initially, this mapping showed that the most used type of research is the proposed solution, which demonstrates the pursuit for an indoor localization solution. Another finding is the confirmation of the WIFI technology as the most used in researches performed on the focus area, which confirms our expectations since in fact it is the most disseminated and present technology in most locations. ZigBee also drew attention due to its large presence even though it's not as accessible as Bluetooth. On the other hand, Bluetooth appeared in a negative manner, since it was expected to be one of the most used technologies.

Based on the summarization of the results, we noticed an increase, starting from the years 2011-2012, in the number of researches using Sensors, especially accelerometers, gyroscopes and digital compasses normally present in most Smartphones. This leads us to the conclusion that Smartphones popularization caused a new bias to start to emerge in the area, which is the use of Sensors present in Smartphones to obtain new fingerprints for indoor localization.

Another finding presented by this mapping was the increase on the number of papers that use a set of technologies in their research. The most promising category on this matter is the Sensors, which represents 86 % of the reviewed papers. On the other hand, the Radio Frequency category obtained only 15%, which is mostly due to the WIFI technology, which is normally used in an isolated way.

Based on the achieved results, we notice the increasing use of Sensors in the proposed solutions, which might lead to a key role in future solutions. The new generations of Smartphones have been showing the market an integration with new and different Sensors. Since the localization in indoor environments is more complex than in the outdoors, there is a tendency for the new solutions to agglutinate different technologies and approaches. For this reason, we believe that hybrid solutions are the future of indoor localization, creating new opportunities for scientific and technological researches.

As a contribution, this study is intend to assist researchers

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providing an overview of the indoor location area and the technologies used in others studies. This insight may help on current and new researches on the area. In our future work, we intend to perform a systematic mapping on the others indoor localization classes.

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