



Survey Paper

Tracking for mobile devices: A systematic mapping study

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ABSTRACT

Tracking is an important task that is used for several applications, such as navigation assistance and augmented reality. The improvement and popularization of mobile devices in recent years allowed these applications to be executed on such devices. Thus, several tracking techniques proposed lately take into consideration the benefits and limitations of handheld devices. Therefore, the goal of this work is to perform a systematic mapping in order to provide trends and classification regarding the recent publications in the area of tracking for mobile devices. This study collected 2276 papers from three scientific databases using an open-source crawler, from which 360 were selected to be classified according to four properties: tracking type, degree of freedom, tracking platform and research type. The analysis of these data resulted in a map of the research field, which was presented under three perspectives: the distribution and trends over time of each classification property and the relationship between them. Besides the visual map, the full list of classified papers is available through an open-source web-based catalog. The results showed that the number of publications is increasing every year, which shows a growing interest in this field. Moreover, most works use the device's sensors for tracking in location-based applications and almost all of them calculate a 2D or 2D + θ pose. There are also several papers about vision-based techniques to compute the device's pose and in the majority of them a full 6D pose is computed. Beyond that, there is a clear preference for systems that calculate the pose locally on the device and only a few use a remote server to assist in this task. Moreover, more than 92% of all papers propose a new technique or use existing ones to create a solution.

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1. Introduction

There are several applications that require tracking, which is the computation of an object placement relative to a real world element or location over a time period. For instance, some augmented reality software use the camera pose related to a marker to display a virtual content registered with the pattern [1]. Another example is a GPS navigation device that calculates its location relative to the road in order to show the driver directions to a destination [2]. However, this is a challenging task. Moreover, determining this placement can demand a lot of computational power and memory depending on the approach and the required information.

Mobile devices, such as phones and tablets, are becoming increasingly popular. Research shows that approximately a third of the world's population owns a handheld device [3,4]. Moreover, these devices are constantly improving regarding processing power and memory space available [5], which makes them powerful enough to perform complex tasks, such as tracking. This scenario favors the creation of numerous types of applications since such devices create several opportunities that are only possible when the user can be mobile.

During the past years, researchers have proposed different techniques to perform tracking on mobile devices. As the research area matures and the number of related papers increases, it becomes important to summarize the current state-of-the-art and provide an overview of the trends in this specialized field. In order to address this issue, this paper presents a systematic mapping of the literature in this area. The main goal of this mapping is to analyze, classify and map existing papers about tracking for mobile devices, providing a primary study and an inclusive overview of this topic.

Systematic mapping is a method to review, classify, and structure papers related to a specific research field [6]. It is frequently used in medical research and lately has been applied to software engineering. Unlike systematic reviews, the goal of this research method is not to perform a deep analysis of works in order to identify the best practices of a field, which usually includes a quality evaluation. The aim of a systematic mapping is to provide an overview of a wide range of papers. This broader analysis enables to observe more papers, which allows more general conclusions [6]. Nevertheless, both methods use a well-defined methodology, which reduces bias [7]. Moreover, systematic mapping papers have an educational value to provide

valuable information for students and young researchers, being a useful first step for Ph.D. candidates [8].

To the best of the authors' knowledge, there is currently no study that synthesizes or systematically analyzes, classifies and maps existing papers about tracking for mobile devices. However, some surveys were found about the field or one of its specific subareas. For instance, [9] evaluated wireless indoor localization techniques and [10] listed tracking algorithms for mobile phones that use only their sensors, as well as their applications. There are also surveys regarding mobile augmented reality, in which tracking is an important step. Examples are [11] that studied the overall acceptance and user experience of mobile augmented reality consumer applications, [12] that presented the technologies and methods to perform augmented reality on mobile devices and introduces some applications, and [13] that conducted a survey about augmented reality browsers and performed a quantitative and qualitative analysis regarding the usability aspects of these tools.

In this work, tracking for mobile devices means that an off-the-shelf cell phone or tablet extracts information from the environment and then processes it locally or remotely in order to compute the device's pose related to the world, which will be used by an application or a service on the device itself. Thus, this study collects and analyzes works published in scientific databases, categorizes them according to four classification criteria and provides a visual summary of this result, as well as discussions about it. As part of the methodology, a list of research questions is proposed, which guides the search strategy, the definition of inclusion and exclusion criteria for relevant studies and the classification schema of all the selected studies. Moreover, the final classification is presented as a catalog of papers on a web application in order to make the data from this work public. Additionally, this website allows collaborators to contribute with new studies.

The remainder of this work is organized as follows: Section 2 describes the methodology used in this study, including the research questions and the classification schema. Section 3 reports the results regarding paper selection. The systematic mapping is presented in Section 4. Section 5 discusses the main findings of this paper and its implication for future studies. Finally, the conclusion is stated in Section 6.

2. Methods

The systematic mapping was conducted based on the process proposed by [6] and illustrated in Fig. 1. The process steps performed in this study are described in the following subsections.

2.1. Research questions

The goal of this systematic mapping study is to provide an overview of the current research on the topic of tracking for

mobile devices. The overall objective was defined in the following four research questions:

- RQ1: How has the frequency of research on tracking for mobile devices changed recently?
- RQ2: What are the most frequent approaches of tracking for mobile devices?
- RQ3: In which platforms has tracking for mobile devices been executed?
- RQ4: In which forums has research on tracking for mobile devices been published?

The first question aims to use the number of publications to investigate trends of the field in the past few years. The second and third questions explore the approaches and platforms researched in the field. The objective of the fourth question is to identify where tracking for mobile devices research can be found, which could be targets for the publication of future studies.

2.2. Scientific databases and search strategy

Three online academic search engines were used to find the relevant papers:

- ACM Digital Library;
- IEEE Xplore Digital Library;
- ScienceDirect.

In order to perform an automatic search on the selected libraries, the search string consisted of two parts. The former regards the tracking domain and the latter covers the device used. Thus, the search string was the following:

("tracking" OR "registration" OR "localization")
AND
("phone" OR "tablet" OR "handheld" OR "smartphone")

Tracking is the key term of the first segment and the other ones are its most used synonyms. Other terms were not used because a quick analysis showed that the majority of the papers found would not be selected for classification. An example is "positioning", which appears mostly in studies in which the device's pose is used only by an external agent and not on the device itself, such as the phone's position that is used by the carrier to determine in which GSM antenna it will connect to. Moreover, the analysis revealed that the relevant papers were already found using the chosen terms.

Regarding the second segment, the authors chose to search for each device instead of using the terms "mobile" or "mobile device". The reason is that these keywords returned too many papers and a quick analysis revealed that the vast majority of them use a broader concept of mobile device than the desired in this mapping. For instance, there are works that use mobile objects,

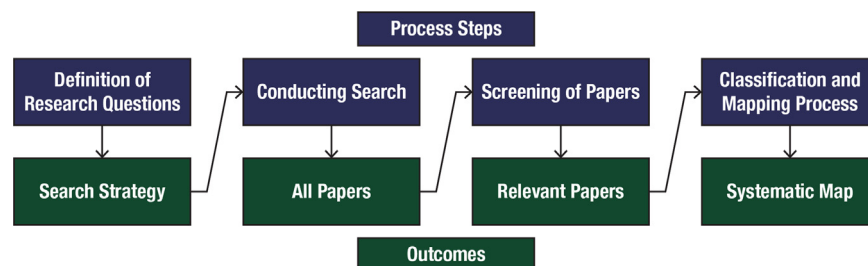


Fig. 1. Systematic mapping process. The research question guides the definition of the search strategy, which is used to collect the works. Some criteria are defined to select the relevant studies that are classified in order to provide the systematic mapping.

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