An Overview and Analysis of Publications on Locomotion Taxonomies

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Abstract

In immersive virtual environments, locomotion allows users to change their viewpoint in the virtual world and is one of the most common tasks. Locomotion taxonomies can describe relationships between the locomotion techniques and thus represent a common understanding, form the backbone of many studies and publications, and can increase the comparability of studies. Therefore, it is relevant for VR researchers, developers, and designers to get an overview of previous research on taxonomies including benefits, drawbacks, and possible research gaps. Current literature reviews focus on locomotion techniques instead of locomotion taxonomies. Thus, a time-consuming search, evaluation and comparison of many publications is required to get such an overview. We present the design of a currently performed systematic literature review examining taxonomies of locomotion techniques. In addition, we present initial results including an overview of publications introducing locomotion taxonomies, their relationships, and impact. We aim to provide a reference to potential taxonomies to support the choice of a locomotion taxonomy and insights into the research field evolution to aid the design of novel locomotion taxonomies.

Index Terms: Human-centered computing—Human computer interaction (HCI)—HCI theory, concepts and models; Human-centered computing—Human computer interaction (HCI)—Interaction paradigms—Virtual reality;

1 Introduction

Currently, *virtual reality* (VR) is facing an increasing popularity and broader availability due to consumer-grade VR devices that place users in a *virtual environment* (VE).

To allow an exploration of the VE and the fulfilment of tasks in VR, users often have to change their viewpoint. This locomotion can, however, lead to simulator sickness [14, 42] and disorientation [10]. Thus, the *locomotion technique* (LT) used to allow users the change of their viewpoint specifies the performance of tasks in VR and is crucial for the acceptance of the overall VR application. For this reason, numerous novel LTs have been introduced with the rising popularity of VR [7], leading to a greater pool of LTs. This requires researchers, developers, and designers to get an overview of existing LTs to know all possible choices among LTs, identify gaps, or design a novel LT. Recently, multiple overviews of LTs for VR have been constructed. Boletsis [7], Zayer et al. [3], and Cherni et al. [13] provide surveys and the Locomotion Vault project [28] provides an interactive online database of LTs.

While these overviews can be an agglomeration of LTs, a structure that clusters similar LTs provides a high-level view and can help to quickly identify or discard whole groups of LTs. In addition to providing an overview, Boletsis [7] introduces a novel taxonomy and the Locomotion Vault project [28] allows to cluster LTs based on expert and database similarity. Since the taxonomy determines the similarities of LTs, it affects the choice and design of LTs. Choosing a taxonomy, however, is not straightforward since the number of locomotion taxonomies rises and there exist no surveys, analyses, or guidelines for locomotion taxonomies. In order to be able to make a decision, an overview of possible locomotion taxonomies is required as well as decision criteria. Possible criteria are the scope to ensure that the taxonomy addresses the relevant LTs or the impact to establish comparability with many other studies. An illustration of the research field evolution can provide insight into emerging developments and trends [23].

Therefore, we conducted a *systematic literature review* (SLR) based on the guidelines by Kitchenham [26] to provide an overview and analysis of locomotion taxonomies. Our results include an analysis of publications on locomotion taxonomies over time to provide an overview of possible taxonomies, their impact and scope. We aim to support developers and researchers in identifying possible locomotion taxonomies.

2 Method

We followed the procedure for performing an SLR as proposed by Kitchenham [26]. First, we performed a preliminary search to identify existing reviews or the need for a review if no such reviews exist. Second, we performed an SLR based on the review protocol that is described below.

Research Questions To identify research questions, we conducted a preliminary search, examined the surveys on LTs, and performed group discussions. In the introduction, we described the need for an overview of taxonomies for LTs including their scope and impact as well as the general evolution of the research field. Thus, we formulated the following research questions:

R1: What are existing taxonomies or categorisations for LTs?
R2: How did the research field of taxonomies evolve?
R3: What are common elements of these taxonomies?
R4: What impact do these taxonomies have?

Search Strategy Based on the overview obtained from the preliminary search and the derived research questions, the following keywords were extracted: *taxonomy*, *locomotion*, and *virtual reality*. For each keyword, similar terms (e.g. synonyms, abbreviations, or alternative spellings) were added to the query keywords. In the last step, these query keywords were combined by AND's and OR's to generate the following search strings:

(taxonomy OR classification scheme OR survey) AND
(locomotion OR travel) AND
(virtual reality OR immersive virtual environments)

The searches were performed in multiple search databases, namely Google Scholar [19], IEEE Xplore [22], ACM Digital Library [1], Semantic Scholar [2], dblp [34], CiteSeerX [33], and Scopus [15]. In accordance to Badampudi et al. [6], the first ten search results were retrieved for each search string. In a second step, we performed backward snowballing as proposed by Jalali and Wohlin [24]. By examining the referenced literature in the retrieved publications, secondary sources were added. Since the SLR focuses on the whole history and evolution of taxonomies, there was no restriction to the publication year.

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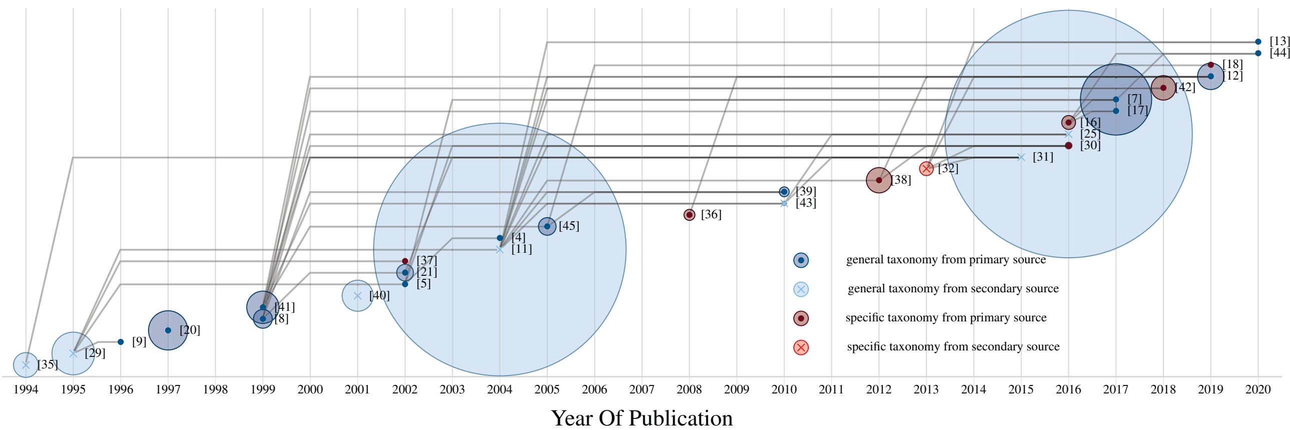

Figure 1: Scope and impact of the identified taxonomies. The radius of the circles is proportional to the overall citations per year (C_Y). Lines visualise citations between the publications (C_T).

Selection Criteria Patents were excluded directly using Google Scholar's search mask since our preliminary search did not yield any patents on taxonomies for LTs. By excluding patents directly, there is a higher number of possibly relevant publications among the first ten search results. All publications had to be written in English to be understandable. We also expect the impact of taxonomies published in another language to be incomparable to taxonomies in in English due to the language barrier. Publications reintroducing already presented taxonomies were excluded since we already retrieve the taxonomies from the original papers. In the next step, duplicates were omitted. Among the remaining publications, two researchers screened each publication. The publications had to contain an explicit categorisation or taxonomy of LTs in general or an explicit categorisation or taxonomy of a subcategory of LTs.

Data Extraction Strategy The data required to answer the research questions above is extracted by hand from the retrieved publications and data provided by the Google Scholar search engine. We followed Isenberg et al. [23] by extracting metadata as the conference, year of the publication, and authors to obtain an overview of the research field and its development. Overall, the reference and full text as well as the following data was extracted:

- The proposed taxonomy (addressing R1 and R3)
- The title, authors, publication type (book or book chapter, journal paper, conference paper, or miscellaneous), conference, and year (addressing R2)
- The number of citations in January 2021 (addressing R4)

Taxonomies were classified as general if they aimed to address all LTs or specific if they focused on a specific set of LTs. The classification was done by two researchers—the author and a co-author—based on the scope described by the authors of the publications.

Quality Assessment Since there exists no common procedure to assess the quality of locomotion taxonomies, we did not enforce quality criteria yet.

3 Results

The search process delivered 587 publications (Google Scholar: 120, IEEE Xplore: 43, ACM Digital Library: 120, Semantic Scholar: 120, dblp: 3, CiteSeerX: 119, Scopus: 62). In a first step, 460 duplicates were omitted. The remaining 127 publications were used for backward snowballing and assessed with respect to the selection criteria. Among the 127 publications 21 fulfilled the selection criteria. Backward snowballing added 8 publications as secondary sources resulting in 29 included publications.

Each of the 29 publications proposed exactly one taxonomy. For these 29 publications, we conducted initial parts of a currently performed meta-analysis addressing how the research field evolved (R2) and what impact these taxonomies have (R4).

Fig. 1 visualises the temporal evolution of the research field by displaying the retrieved publications introducing a taxonomy, their impact, and relationship. The publications are depicted as circles. The circle radius is proportional to the number of citations per year (C_Y). General taxonomies are depicted in blue, while specific taxonomies are depicted in red. Taxonomies retrieved as secondary sources are visualised brighter and with a cross in the middle, while primary sources are visualised darker and with a point in the middle. Gray lines depict citations among the taxonomy publications (C_T).

Fig. 1 shows the publications on taxonomies found by our SLR. Overall, 29 taxonomies were proposed between 1994 and 2020, making 1.12 taxonomy publications on average per year. Recently, more taxonomies are introduced (11 taxonomies since 2015, i.e. 2.2 on average per year). More recent publications tend to be more specific compared to older publications. During 1994 and 2005 1 of 13 (7.7%) taxonomies was a specific taxonomy, while 7 of 16 (43.8%) taxonomies focused on a specific group of LTs during 2008 and 2020. Specific taxonomies focused on walking [16, 30, 32], redirection [36, 38], through-the-lens metaphors [37], teleportation [42], and elastic feedback [18].

The publications with the greatest impact were the books by Bowman et al. [11] (C_Y: 124.1) and Jerald [25] (C_Y: 121.6). When excluding these two books, the three publications with the greatest impact were the works by Boletsis [7] (C_Y: 35), Mine [29] (C_Y: 21), and Hand [20] (C_Y: 19.3). The publications cited most frequently by taxonomy publications were the works of Bowman et al. [11] (C_T: 9), Bowman et al. [8] (C_T: 5), and Templeman et al. [41] (C_T: 5).

4 Discussion & Future Work

We conducted an SLR and provide a list of publications introducing taxonomies for LTs. Our results address the evolution of the research field (R2) and the impact of the publications (R4). With respect to the research field evolution (R2) our data shows two recent trends: a rising number of taxonomies introduced per year and a shift to taxonomies that focus on specific groups of LTs. Regarding the impact of the publications (R4), we identified seven taxonomies with a high impact [7, 8, 11, 20, 25, 29, 41] that can be an interesting approach to establish comparability with many other works. Our overview can support the identification of promising taxonomies based on the impact, scope, or relationship to other taxonomies. In future research, we aim to perform a content-wise analysis of the listed taxonomies to answer all of the described research questions (R1-R4). Future independent SLRs on locomotion taxonomies could be used to estimating the number of missing papers [27].

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