Next Steps for Augmented Reality On-the-Move: Challenges and Opportunities

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Figure 1: Augmented Reality on-the-move explored in various contexts: AR on a farmers market [73], AR for sightseeing [50], AR concepts for biking [26, 35, 53], and AR exercising at home [3, 4]

Abstract

Recent advancements in augmented reality (AR) technologies have brought us closer to the vision of everyday ubiquitous computing and pervasive AR use. State-of-the-art AR glasses now enable mobile, on-the-move experiences that extend beyond laboratory settings. This promise has already been explored across diverse mobile contexts, including transportation, entertainment, shopping, and tourism. This workshop focuses on AR on-the-move, examining how AR can support interaction in dynamic settings where environmental and social contexts shift rapidly and users are in locomotion. We will discuss both the unique challenges and the rich opportunities such scenarios present for meaningful augmentation and new forms of interaction. By uniting established scholars and emerging researchers from across HCI, this workshop seeks to map out critical directions for future inquiry. Through hands-on activities and reflection, participants will collectively identify key opportunities, challenges, and next steps for advancing research on AR on-the-move.

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CCS Concepts

• **Human-centered computing** → **Mixed / augmented reality**.

Keywords

Augmented Reality, Mobile Interaction, On-the-Move

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1 Motivation

Augmented reality (AR) [1] technologies have become increasingly accessible in recent years. Following an initial wave of phone-based AR applications (such as Pokémon Go [54]), contemporary head-mounted displays (HMDs) are now reaching a broader audience. Devices such as Microsoft HoloLens 2, Magic Leap 2, XReal glasses, Meta Quest 3, Apple Vision Pro illustrate the potential of AR to transform personal computing, as they can be deployed in everyday settings to support people with tasks while on-the-move [46]. Prior work has demonstrated that AR devices can provide constant access to information, enabling pervasive experiences that adapt to the dynamic requirements of users' context and supporting continuous usage across dynamic real-world scenarios [22]. Such context-awareness [23, 43] is feasible through the integration of artificial intelligence (AI) and machine learning (ML) methods, including generative AI and large language models (LLM's) [10]. This integration allows users to query LLM's verbally in real-time and to leverage image recognition for immediate, situated interaction. AI-integrated glasses, such as the Oakley and Ray-Ban Meta Glasses, are characteristic examples, which are designed for seamless integration into daily routines [56, 57].

Researchers have long considered AR to support everyday activities such as transportation (e.g., automated vehicles [40, 51], navigation [37] and safety [5, 52]), exercise (e.g., sports [15, 71], walking meetings [12]), retail (e.g., shopping [74]), gaming, text input [34], and sightseeing (e.g. Points of Interest (POIs) [50]). Thereby, many studies have focused on *where* and *how* digital information should be displayed to maximize usability, for example through optimized text placement and readability [33, 44]. More recently, this work has expanded to scenarios where users are in motion, reflecting the growing importance of AR applications that support navigation, exercise, and on-the-go activities. Interacting with virtual content while walking and using AR technologies, such as HMDs, introduces challenges that differ from stationary use, prompting investigations into suitable interaction techniques and display strategies for mobile contexts [13, 32, 65].

Yet, only a handful of studies have explored AR HMDs outdoors and in-the-wild while users are engaged in everyday tasks [12, 61]. The majority of empirical work has been conducted indoors or in controlled lab environments [61, 67], largely due to the technical limitations of earlier devices. With the increasing maturity of AR technology, however, including improvements in display quality, tracking, and wearability, it has become more and more feasible to study AR in real-world, outdoor contexts [12, 50, 73, 74].

At the same time, mobile AR introduces challenges that remain unresolved. The form factor of AR glasses continues to shrink due to ongoing miniaturization of components (e.g., XReal glasses [93], and Meta Orion [55]), but their ergonomics and social acceptability are not yet fully optimized. Locomotion further complicates design, as users move through dynamic environments, information must be presented in ways that are quickly attainable without obstructing vision. Therefore, novel approaches are needed to ensure safe and effective augmentation, such as visualizing only a runner's limbs for a virtual training companion rather than rendering a full avatar. More broadly, there is a risk of overwhelming users with both the constant motion of the physical environment and the additional digital overlays—echoing concerns raised in speculative depictions such as *Hyper-Reality* [17]. Designing AR for these settings requires balancing clarity, speed, and mental effort while minimizing distraction.

In this workshop, we aim to **establish a multidisciplinary platform that brings together researchers, practitioners, and designers to examine how AR can be meaningfully integrated into dynamic, real-world contexts such as everyday life, sports, and transportation.** We specifically focus on settings in which users are on-the-move, where both body and environment are in flux, and where interaction demands differ from stationary scenarios.

While prior workshops have investigated directions such as adaptive and context-aware AR powered by AI, generative content creation, always-on assistants, and accessible AI-driven design [76], as well as purposeful and situated uses of AR [14], our focus diverges by foregrounding the unique challenges and opportunities that arise when AR is deployed in motion-rich environments. By focusing on on-the-move contexts, this workshop addresses the need to design AR systems that remain reliable and supportive in motion-rich contexts such as navigation, exercise, and other mobile activities.

2 Background

To further understand the context of this workshop we highlight several works dealing with interaction on-the-move, followed by AR augmentation placement strategies. Then we reflect on several research opportunities regarding AR on-the-move.

2.1 Interaction with AR On-the-Move

Designing interactions for people on-the-move introduces distinct user requirements compared to stationary contexts and has long been a key concern in HCI research [48]. Early work has largely examined AR interactions while people are in motion under controlled conditions. For instance, Li et al. [41] used a treadmill to study how different motion types—standing, walking, running, and jumping—affect AR interaction performance, while Shin et al. compared eye-, head-, and ray-based pointing in standing versus walking conditions [68]. Others investigated walking-based interactions indoors, exploring techniques such as lateral path shifts for target selection [59], or gait variations as input gestures [82]. Hertel et al. [27] provide a broader lens on these developments by introducing a taxonomy of AR input techniques, highlighting the

[1]For this workshop, AR is used as a general term that includes both AR and MR applications. We are interested in cases where MR is defined as "strong" AR or a synonym for AR [72]

importance of multimodality in mobile AR, where single-channel inputs frequently encounter limitations.

In mobile contexts, each modality brings benefits but also drawbacks. Eye-gaze supports rapid target acquisition [8] but suffers from "Midas Touch" [31] and ocular fatigue [42]. Hand- and arm-based pointing feels intuitive [9] but quickly induces fatigue ("Gorilla Arm" [28, 62]) and can compromise safety during mobility. Controllers offer precision but conflict with the goal of always-available, device-free input. Head orientation presents a compelling compromise [69], being hands-free and hardware-independent, and effective for coarse navigation [16, 91], though it lacks the fine control of manual gestures [24] and the speed of gaze [1, 8].

2.2 Displaying AR Content On-the-Move

Existing research refers to virtual content placement in AR in terms of a coordinate system with three possibilities: (1) body-anchored, (2) world-anchored and (3) screen-anchored [19, 39]. Numerous studies have investigated how AR virtual content should be visualized when people are in motion and have compared coordinate possibilities for different tasks and contexts. Characteristically, Matviienko et al. compared all three coordinate possibilities on both smartphone AR and an HMD in an outdoor sightseeing context [50]. Rasch et al. explored the influence of different on-body AR content placements on walking and virtual task performance [65]. Some works have conducted evaluations in-the-wild [45], and others even outdoors [12, 13, 74].

2.3 Research Opportunities

Interference with Environment. Research highlighted the trade-offs when accessing information while using AR on-the-move. First, a user's perception of the surroundings may decrease [95], which means that, for example, when driving a car, there is an increased collision risk when too much visual attention is focused on the AR information [29]. Such negative consequences can lead to a higher risk of injury for vulnerable road users, if their attention is diverted by AR [11, 70]. Visualizations need to be carefully designed and adapt to the user's current situation. Research has explored adaptive visualizations that adapt information density (see Figure 2) and content placement [21, 79, 80]. This indicates that designing for AR on-the-move can be challenging as it requires careful understanding of safety considerations and attentional demand [7].

Social Impact. There are also challenges in tailoring information within public spaces. While personalization can enhance the AR experience, [63] found that it may lead to users becoming distanced from one another due to information gaps. This can create a sense of privilege among users who have access to certain content, while marginalizing those who cannot afford the same level of access. Additionally, prior work has highlighted social acceptability concerns of publicly using AR HMDs, often drawing unwanted attention to users [92]. Stefanidi et al. also showcased the importance of including and considering non-users when designing outdoor AR interactions [74].

Moving Beyond Laboratory Conditions. There are also difficulties when transferring findings from lab-settings to real-world, as Huckauf et al. [30] found that switching attention between AR graphics and the lab scene resulted in additional 10% attention load, and hypothesized that the real-world cost in switching would be much larger. However, outdoor field studies can also be challenging as it requires both ethical and practical considerations, especially when moving at higher pace such as a bike [49]. Uncontrolled outdoor environments further lead to perceptual issues, an area that has been extensively researched for more than 20 years [6, 20, 36]. HMD technology has matured into compact mobile devices tackling issues such as display brightness, tracking stability and input modalities, making it easier for researchers to explore AR user experience in uncontrolled, public environments [77].

Augmenting Human Capabilities. Decades of AR research has explored how to extend human capabilities for personal and professional settings. Seminal work such as the Touring Machine combined a compute unit, HMD and GPS tracking allowing users to annotate the world, retrieve context-based information, and rely on spatially registered navigation aids in a city environment [18]. Since then, researchers have studied outdoor AR experiences for entertainment [81], content creation [38], capturing city infrastructure [64], or construction site monitoring [96]. AR has also been used to expand human perceptual capabilities by enabling x-ray vision for underground visualization [66], or supporting exocentric exploration of large areas [60, 78]. In contrast to previous work, the maturity of AR technology enables a paradigm shift in mobile AR research using HMDs, as it no longer depends on bespoke hardware to work outdoors and in public. This allows fundamental research to move out of the lab and explore user experiences within the real-world context and identify the impact of augmenting human capabilities [12, 13, 73, 74].

3 Goals & Topics of Interest

This workshop aims to bring together researchers, practitioners, and designers to discuss AR on-the-move in real-world scenarios. Participants will exchange lessons, practices, and experiences from field deployments, alongside insights from state-of-the-art research. The program includes hands-on demonstrations to foster direct engagement, while also addressing key challenges and opportunities for AR in everyday on-the-move contexts. Building on these discussions, the goal of this workshop is to lay the groundwork for a special issue that outlines future directions for AR on-the-move.

The topics of interest include theories, technologies, and applications related to the use of AR technologies on-the-move. Relevant topics include, but are not limited to:

- Context-aware AR
- AR in social contexts
- AR interaction techniques for mobile settings
- Deploying AR in everyday scenarios (e.g., biking, navigation, exercise)
- AR applications in indoor/outdoor sports
- Low fidelity prototyping of AR on-the-move experiences
- Accessibility and inclusivity in mobile AR use

4 Pre-workshop plans

We aim for 20-30 participants to participate in the workshop. To achieve this, we will announce the call for participation (CPF) (see

Figure 2: AR augments human perception with additional context-based information. Unchecked augmentation can quickly lead to clutter distracting users on-the-move causing safety issues. Adaptive visualization, as shown here, adjust information density and presentation style to balance the information in the user's view [80]. How can adaptive visualizations help users with AR on-the-move?

subsection below) on the workshop's website and share it extensively with potential interested individuals and communities. Participation is welcome from (academic) researchers, and industry professionals. The CFP will additionally be distributed through HCI-related mailing lists (e.g. CHI Announcements) and on social media platforms such as LinkedIn, BlueSky, Instagram, etc. Those interested will be required to submit a position paper (2-4 pages, ACM single-column format). To ensure an inclusive and accessible workshop we will reach out to participants to understand and cater for special needs.

4.1 Call for Participation

Advancements in augmented reality (AR) technologies have brought us closer to the vision of ubiquitous computing and pervasive AR in everyday life. State-of-the-art AR glasses now enable mobile, on-the-move experiences that extend beyond laboratory settings.

This workshop focuses on *AR on-the-move*, examining how AR can support interaction in dynamic settings where environmental and social contexts shift rapidly and users are in locomotion. We will discuss the unique challenges and rich opportunities such scenarios present for meaningful augmentation and new forms of interaction.

Prospective participants are asked to submit via the workshop's website a short position paper (2–4 pages, ACM single-column format) that addresses the following topics:

- The participant's background and experience using AR in mobile or real-world settings.
- A description of a system that they developed, participated, or experienced.
- A reflection piece that identifies one or two key challenges and opportunities for AR in on-the-move contexts. Ground the discussion in specific ideas, methods, or case studies to illustrate and elaborate these points.

They are also invited and encouraged to present a live or video showcase of the described AR system. Submissions must be received by the deadline stated on the website. All submissions will be reviewed by the organizing committee, and participants will be selected based on relevance, diversity of perspectives, and potential for contributing to fruitful discussions.

Upon acceptance, participants will be invited to prepare a brief presentation or demonstration to share during the workshop. At least one author of each accepted submission must attend and all participants must be registered for the workshop. Moreover, all accepted position papers will be made available on the workshop website ahead of the event to facilitate cross-reading and engagement among participants.

Join us to discuss the future for AR on-the-move: https://hci.plus/sites/ar-on-the-move.

5 Workshop Structure & Activities

The workshop will take place over one afternoon, structured in two 90-minute sessions that combine presentations and interactive activities. We will begin with a short introduction to present an overview of the planned workshop activities. This is followed by a keynote from an invited expert, and by participants' paper or demo presentations to promote interactive discussion. In the second session, participants will work in small groups to examine selected challenges and opportunities in depth. The workshop will conclude with a plenary reflection to consolidate insights and capture concrete next steps for advancing AR in real-world contexts.

The proposed timeline for the workshop is shown in table 1. We will adapt the timeline depending on the number of participants to allow for a well-balanced and energetic workshop.

5.1 Activity 1: Introduction & Keynote

The workshop will open with a brief introduction by the organizers, outlining the schedule, activities, and overall goals for the day. Then a keynote from an invited HCI expert will follow, intended to situate the workshop theme within current research, highlight key challenges, and inspire participants for subsequent activities. The speaker's bio and presentation abstract will be published on the workshop website ahead of the event.

5.2 Activity 2: Paper Presentations - Interactive Demonstrations

In the second activity of the workshop, participants are asked to briefly present themselves (e.g., their work, research interests) and their position papers or demonstrations. Each short presentation will be followed by a focused Q&A to encourage exchange among participants. The presentation format will depend on the number of participants (e.g., PechaKucha).

5.3 Activity 3: Group Discussions

At the start of the second session, the organizers will initiate a discussion on the challenges and opportunities that emerged from both the keynote and the accepted position papers. Participants will then be divided into subgroups (3-5 people) focusing on specific topics, discussing them in detail and defining next steps. Sticky notes and sketch papers will be provided to each group to visualize and document their ideas.

5.4 Activity 4: Outcomes & Reflections

The final activity will center on group presentations and a plenary discussion moderated by the co-organizers. Each group will briefly share their main insights and propose next steps for AR in real-world settings. Building on these presentations, the organizers will facilitate a larger-group reflection to connect outcomes across groups, identify common directions and tensions, and discuss opportunities for future collaboration.

Table 1: Tentative Workshop Timeline

Time	Activity
10 minutes	Opening
20 minutes	Keynote
60 minutes	Participants' demos and presentations + Q&A Main Break
40 minutes	Subgroups to discuss challenges opportunities in detail and define next steps
30 minutes	Group presentations on next steps for AR in real-world settings
20 Minutes	Follow-up plans + closing

6 Post-workshop Plans & Outcomes

To extend the impact of the workshop, we will foster ongoing collaboration among participants and organizers beyond the event. The workshop results will be communicated to a larger audience through the workshop website. Participant's position papers will be published on open-access platforms such as CEUR-WS or arXiv. and will be shared on the organization website. A selection of academic venues will be considered based on the outputs of the workshop sessions (e.g. an ACM Interactions report, a CHI paper based on the discussions).

Through the workshop activities, and building on the expertise of facilitators and participants, the anticipated workshops outcomes are: 1) an overview of key challenges and opportunities for AR in real-world settings, 2) the articulation of next steps for AR in real-world settings, 3) a collaboration towards a joint (journal) contribution

7 Organizers

The organizing team includes scholars with a variety of backgrounds with extensive experience in hosting workshops at major HCI venues.

Helen Stefanidi is a PhD student and research fellow at the HCI division of the University of Salzburg, Austria. Her research focuses on exploring the meaningful integration of AR technologies in everyday on-the-move activities, particularly in real-world outdoor contexts [73–75].

Vincent van Rheden is an interaction designer and research fellow at the HCI division of the University of Salzburg, Austria. Furthermore, his work explores how to support athletes "on-the-move" [86, 87, 89]. General interests are in embodied interaction and SportsHCI [83, 84]. He has also explored some AR contexts [47] and has co-organized various movement interaction related workshops at major HCI venues [58, 85, 88, 90].

Jan-Hendrik Sünderkamp is a PhD student and research fellow at the Digital Realities Lab of the Salzburg University of Applied Sciences, Austria. His research focuses on the use of augmented reality in outdoor contexts [74] and on interaction design for augmented reality while walking.

Linjia He is a PhD student at the Exertion Games Lab, Monash University, Australia. Her research interests lie in augmented reality and its applications in user experience. Her PhD project investigates how AR can be applied to cycling, with a particular focus on interface design and interaction [25, 26].

Michelle Adiwangsa is a PhD candidate at the School of Computing at the Australian National University. Her research explores how everyday tangible objects can be augmented to support various use cases, including exercise, rehabilitation, and gaming [2–4, 94].

Alina Itzlinger is postdoctoral fellow at the HCI division of the University of Salzburg. Her research explores various ways of how people (dis)engage with technology, involving diverse (un)user groups, interaction contexts, and methodological approaches; being particularly interested in exploring the social situatedness of AR on-the-move, such as, AR user and non-user interactions. She co-organized a series of workshops at CHI, CSCW, or GROUP.

Andrii Matviienko is an Assistant Professor at KTH Royal Institute of Technology in Stockholm, Sweden. His research focuses on Extended Reality (XR) and interaction with and within immersive spaces. He leads an Immersive technologies lab at KTH Royal Institute of Technology, where they explore ways of improving users' XR experiences via novel input techniques, haptic feedback, locomotion, taste, simulations, exertion games, and interaction on-the-go.

Julie Williamson is professor of Immersive Interaction at the University of Glasgow. Her research focuses on interaction in immersive environments, including co-located virtual reality, head-mounted displays for social and public settings.

Ian Oakley is Ian Oakley is a full professor at KAIST's School of Electrical Engineering in South Korea, where he heads the Wearable and Interactive Technology Lab. His research focuses on designing, developing, and evaluating input and interaction techniques for diverse wearable device form factors, including earbuds, wrist-wearables, smart glasses, and HMDs, with a specific focus on addressing mobility issues [68, 69].

Markus Tatzgern is professor at the Salzburg University of Applied Sciences, Austria, where he leads the Digital Realities Lab. His research focuses on adaptive visualization and multimodal interaction techniques for Extended Reality, aiming to seamlessly bridge digital and physical worlds with applications in training, learning, human–robot interaction, and everyday augmentation.

Alexander Meschtscherjakov is a full professor at the HCI division of the University of Salzburg. His research focus on new forms of user interface design, user experience with mobility systems, and persuasion to foster new forms of behaviour. He co-organized conferences such as AutomotiveUI'11 or Persuasive'15 and was co-organizer of more than 25 workshops (e.g., CHI'15-'21).

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