IEEE Access
Multidisciplinary | Rapid Review | Open Access Journal

Received 17 January 2025, accepted 25 February 2025, date of publication 5 March 2025, date of current version 13 March 2025.

Digital Object Identifier 10.1109/ACCESS.2025.3548134

SURVEY

Human Following and Guidance by Autonomous Mobile Robots: A Comprehensive Review

ANDREA EIRALE, (Member, IEEE), MAURO MARTINI, (Member, IEEE), AND MARCELLO CHIABERGE, (Member, IEEE)
Department of Electronics and Telecommunications (DET), Politecnico di Torino, 10129 Turin, Italy
Corresponding author: Andrea Eirale (andrea.eirale@polito.it)

ABSTRACT Collaborative and companion robots are at the forefront of technological innovation, transforming human-robot interaction to address a wide range of tasks and activities. This review provides a comprehensive examination of the current state of research on human following and guidance with autonomous mobile robots. Covering the evolution of research from the inception to the latest advancements in this area, we categorize existing literature based on various attributes including fields of application, technologies employed, and social acceptability. We critically analyze and compare state-of-the-art approaches in perception, tracking, planning, control, and human-robot interaction, highlighting their effectiveness and feasibility. We further classify studies based on application domains where person following and guiding tasks are particularly impactful, such as healthcare, personal assistance, logistics, and tour guiding. We identify persistent challenges and outline open problems, offering recommendations for future research directions. Our review aims to serve as a foundational reference for researchers and practitioners, fostering continued innovation and development in the deployment of autonomous robots for human following and guidance.

INDEX TERMS Autonomous robots, collaborative robotics, human–robot interaction, person following, robot guidance, survey.

I. INTRODUCTION

Autonomous service robots are emerging as the frontier technology to enhance human well-being. Despite advancements in robotic design and manufacturing revolutionized the field, intelligence remains the cornerstone for integrating autonomous robots into our daily lives. According to Artificial Intelligence experts, physical or embodied AI is a critical challenge for the next wave of innovation [1], [2]. As a result, robotics research is set to play a central role in global efforts to provide mobile and service robots with advanced capabilities that can meaningfully contribute to society.

Service robots are primarily designed to assist humans in social environments or demanding tasks. In healthcare, robots revolutionized patient care by assisting medical staff with the transportation of medical supplies [3] or by guiding patients in the medical environment [4]. These robots reduce physical strain and allow healthcare professionals to focus more on patient care. In logistics, robots streamline warehouse operations by following workers to carry heavy loads, optimizing workflow, and reducing the risk of workplace injuries [5]. Retail environments are also witnessing the integration of service robots, where they enhance customer assistance by guiding shoppers through stores, providing product information, and even carrying purchases [6], [7]. Moreover, in the realm of personal assistance, robotic platforms offer invaluable support to individuals with mobility challenges [8], following owners through their homes [9], and even assisting with daily tasks [10], [11].

An essential capability of intelligent assistive robots in these applications is to follow or accompany humans to specific destinations effectively. When following, the humans lead the task, and the robot pursues them. Typically, the robot trails behind the human, retracing their path.

The associate editor coordinating the review of this manuscript and approving it for publication was Francesco Mercaldo.

Alternatively, the robot may accompany the person side-by-side, which often results in more natural and effective Human-Robot Interaction (HRI) but introduces additional challenges. Although following and guiding constitute two different tasks, they share several similarities [12]. In both cases, the robot must maintain proximity to the human to keep track of them while ensuring a socially acceptable distance by adapting its velocity to the user's walking pace. Both following and guiding tasks necessitate sophisticated sensor arrays and advanced algorithms for environmental perception, human detection, and navigation. Robots must be able to distinguish between animate and inanimate objects, recognize human intentions, and make split-second decisions to avoid obstacles and ensure a smooth interaction. Contextually, approaching the extensive literature on autonomous navigation, perception, control, and human-robot interaction can be dramatically hard and time-consuming for a novice researcher. Therefore, we believe that a focused survey highlighting the latest advancements and emerging trends in human-following and guidance by autonomous robots is an essential and valuable resource for the service robotics community.

This article builds on and extends previous surveys in the field [13], [14]. The most recent survey, conducted by Islam et al. in 2019 [14], categorized studies based on operational medium–ground, underwater, or aerial–and further classified them by factors such as sensor type, interaction mode, number of robots and humans involved, and autonomy level. However, we believe many of these categorization factors are often more closely tied to the specific application domains of the robotic platform. This observation led us to adopt a different approach in our survey. We organized the categorization around core methods and enabling technologies that are fundamental across all domains and critical for effectively implementing person following and guiding robots. Moreover, we expanded the scope of our survey by integrating robot guiding tasks alongside person following, reflecting a more comprehensive understanding of human-centered navigation. In the second section of the paper, we also re-organized studies based on their most relevant application fields, discussing the unique challenges and advancements within each of them.

Therefore, this paper provides a detailed exploration of person following and guiding robots, examining their broad applications and potential to reshape human-robot interaction, ultimately influencing the way we live and work. In particular, the contributions of this paper are manifold:

- We systematically review the scientific literature on human following and guidance by mobile, autonomous robots, spanning from early research to the latest advancements. Our review offers an in-depth comparison and discussion of state-of-the-art approaches across key areas essential to the functioning of person following robots. These include perception (how robots sense and interpret their environment), tracking (how robots continuously monitor and follow the target individual), planning (how robots determine optimal paths), control (how robots execute physical movement), and interaction (how robots communicate and engage with humans). Our comparison focuses on evaluating the effectiveness and feasibility of different approaches, providing insights into their practical applications and potential limitations.
- We categorize these works according to their application domains, highlighting the primary usage and specific functions of person following and guiding robots in various fields such as healthcare, personal assistance, logistics, and tour guiding. This categorization helps clarify each field's specific challenges and requirements, allowing for a more tailored understanding of the technologies employed.
- We present and analyze the primary evaluation methods used in literature to assess the performance of these systems. Each technology area–perception, tracking, planning, control, and interaction–has its own set of performance metrics and experimental setups. Then, we critically evaluate the solutions proposed in literature, focusing on their feasibility, practicality, outcomes, and costs.
- Finally, we identify and highlight the open challenges that persist in the field of person following and guiding robots. These challenges include improving the system's adaptability to different contexts, such as when the robot needs to follow a group of people, take the lead in guiding an individual, and maintain high speeds during pursuit. Based on our review and analysis, we provide a set of recommendations for future research directions. These suggestions aim to guide researchers in overcoming current limitations, addressing technical gaps, and pushing the boundaries of what person following robots can achieve.

A. REVIEW METHOD

We conducted a systematic review of the literature on human following and guiding robots to provide a comprehensive synthesis of the state-of-the-art in this field. This survey is intended to assist researchers in analyzing and organizing previous work on these topics while also identifying key trends, challenges, and advancements in robot deployment for following and guiding tasks. We selected only studies that specifically addressed human following and guiding applications tackling meaningful technical aspects such as perception, tracking, navigation, and interaction.

Our search was conducted using various search engines, such as Google Scholar, Scopus, IEEE, Science Direct, Sage Journals, and Springer. We used the following keywords: "Robot person following", "Robot human following", "Robot guide", "Robot guidance", and "Robot guiding". We limited the scope to peer-reviewed conference papers, journal articles, and book chapters, all published in English. No restrictions were placed on the starting publication date, as we aimed to cover the entire breadth of available literature on these topics. The initial search was carried out on 28 May

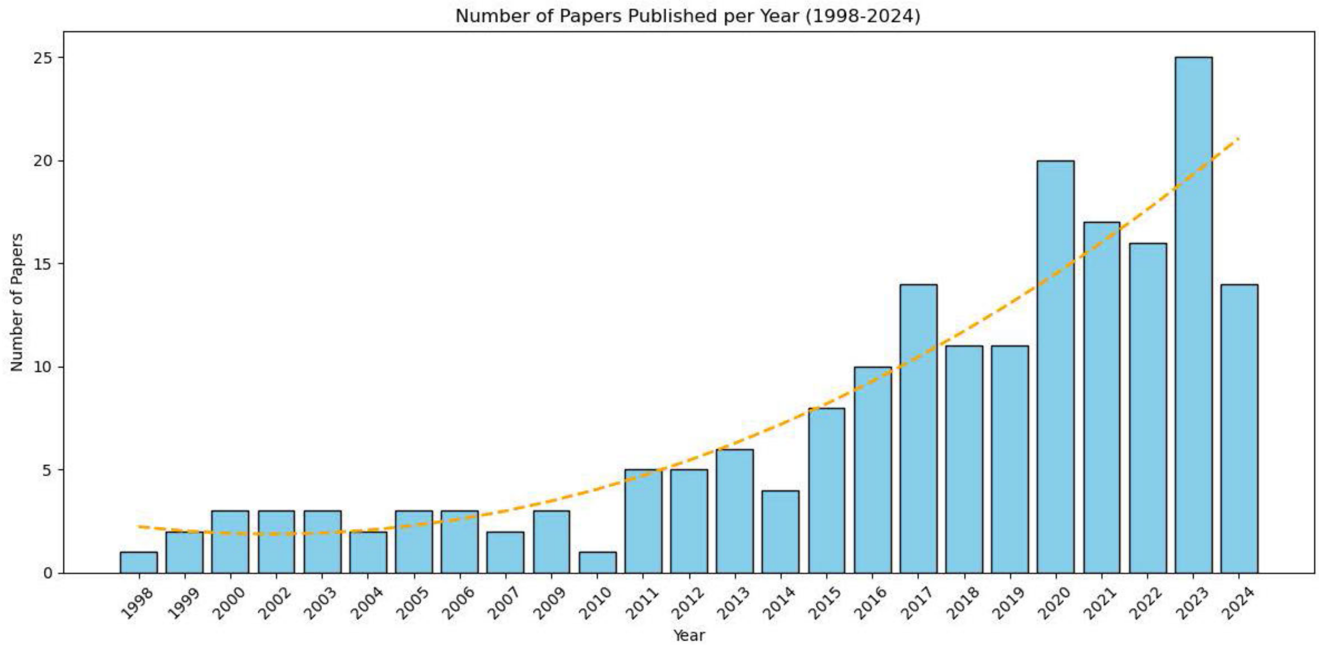

FIGURE 1. The yearly distribution of published papers in the field of human following and guidance with autonomous mobile robots.

2024, and a follow-up search was conducted on 08 January 2025.

In total, 482 works were retrieved and organized into a unique database, with metadata such as title, authors, publication date, venue, abstract, and citation count. After removing 16 duplicate entries, 466 unique works remained for review. We carefully evaluated each work, maintaining only those that explicitly focused on robots designed for person following and guiding tasks. Studies that primarily addressed perception, tracking, control, and/or human-machine interaction in a different context were excluded to preserve the relevance of the survey. Finally, a further screening was conducted based on the number of citations for each year. Older papers were only retained if their contribution remains relevant and holds significance in the context of more recent advancements in the field. After this rigorous selection process, 192 works were retained and form the core of the analysis presented in this paper. These studies represent the most relevant contributions to the field of human following and guidance by autonomous mobile robots and provide a foundation for future research. Figure 1 shows the annual distribution of these selected papers, demonstrating the increasing interest of research in the field. Moreover, the high rate of publication in the last two years reflects the real state of autonomous robot development: many unsolved challenges and practical tasks still have to be solved to fully launch the service robotics market.

II. METHODOLOGIES

Autonomous following and guiding tasks require a comprehensive suite of sensors and sophisticated algorithms to perform essential submodules: perception, detection and tracking, path planning, control, and human interaction. Perception enables the robot to understand its environment, detect obstacles, and consistently recognize and track the target person. The navigation system enables the robot to plan an efficient and safe path while maintaining social norms during movement. Planning and control modules work together to ensure the robot takes an optimal, obstacle-free route toward the goal while adjusting for real-time conditions and human behavior. Interaction is another vital component, allowing the robot to receive commands, communicate effectively, and provide socially appropriate responses.

In this section, we categorize and examine state-of-the-art approaches in these critical areas, central to the functionality of person following and guiding robots: perception, tracking, planning, control, and interaction. Figure 2 provides an overview of the methods discussed in this chapter.

A. PERCEPTION

The perception module plays a crucial role in autonomous systems. It is responsible for both detecting obstacles around the robot and identifying the target person to be tracked. The module must integrate various sensing techniques to create a cohesive and accurate environment representation, ensuring smooth navigation and interaction with humans. Typically, obstacle detection relies on Time-of-flight (TOF) sensors, which provide real-time distance measurements by calculating the time it takes for emitted signals to bounce back from surrounding objects. Among TOF sensors, Laser Range Finder (LRF) and LiDAR systems are the most commonly used in robotic applications [16], [19], [71], [73], [74], [75], [76], [77], [78]. These sensors offer high precision

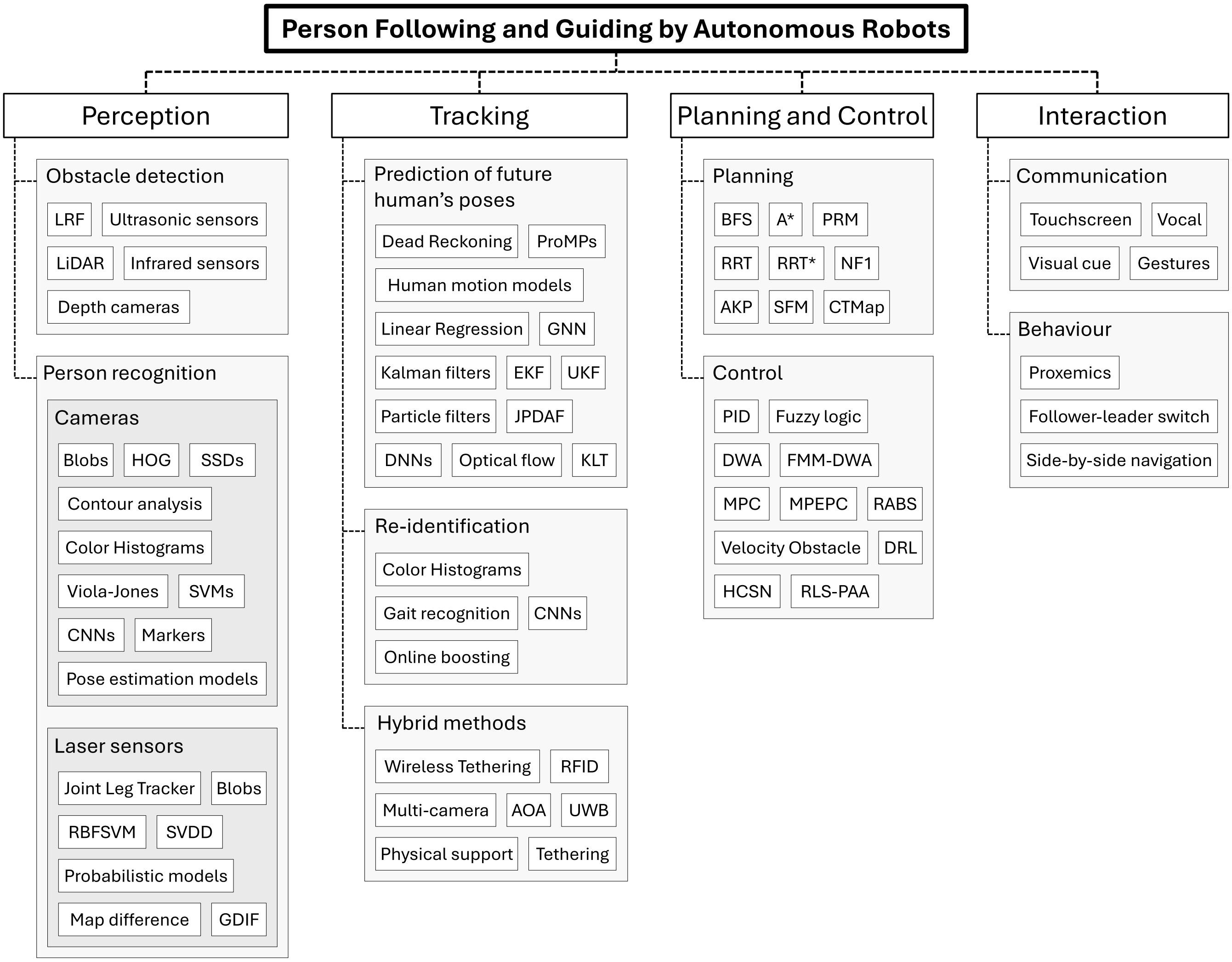

FIGURE 2. A categorization of the state-of-the-art methods and approaches for person following and guiding autonomous robots, divided in four main key areas: perception, tracking, planning and control, and interaction. For acronyms, refer to Section VI.

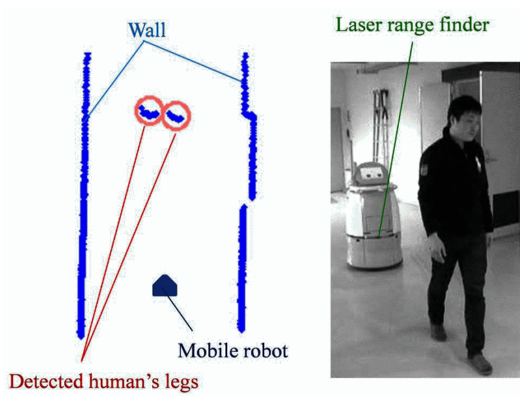

FIGURE 3. An example of 2D Laser Range Finder detection, including obstacles such as walls and human legs. [3].

and wide field-of-view capabilities, making them effective for both indoor and outdoor navigation, even in cluttered environments. Figure 3 represents a typical LRF detection.

Ultrasonic sensors are another popular choice for obstacle detection, particularly in environments where cost and simplicity are critical factors. Although ultrasonic sensors provide lower resolution compared to LRF or LiDAR, they are effective at short distances and can detect objects in various lighting conditions [4], [36], [41], [79], [80], [81]. They are often combined with other sensors to enhance the overall reliability of the perception system. Similarly, infrared sensors, though less common, are employed in some applications where low-cost and simple obstacle detection are sufficient [82]. These sensors are particularly suited for detecting objects with strong thermal signatures or reflecting properties. In addition to traditional TOF sensors, some works leverage depth cameras, which generate detailed 3D depth maps by analyzing stereo images or structured light patterns. Depth cameras provide rich spatial information that enables the detection of obstacles at varying heights, making them particularly useful for complex environments such as urban areas or indoor spaces with multiple levels of objects [22],