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Classification of mobile robots for rescue operations

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Abstract. Search and rescue operations in case of disasters are typically time-sensitive and are conducted under hazardous conditions, with limited access to the affected area. Despite the advances in disaster risk management, events such as earthquakes continue to cause significant loss of life, underscoring the need for more effective rescue techniques. In this context, mobile rescue robots are emerging as a promising tool to support traditional search and rescue operations and to reduce the risk to rescue teams. This study proposes a classification of ground-based mobile robots used in rescue missions based on their key technical and functional characteristics. Six main characteristics were identified, which were combined in a multidimensional structure, allowing each robot to be described by several technical and functional features. The proposed classification does not evaluate the performance of individual platforms, but provides a consistent way to organise existing robot types.

Keywords: Rescue robotics, Disaster response, Search and rescue.

1. Introduction

Between 2000 and 2023, five types of disasters accounted for about 90% of disaster-related deaths: earthquakes (50%), extreme heat (18%), storms (14%), floods (8%) and droughts (2%) (UNDRR, 2025). Earthquakes continue to cause a large number of casualties, despite significant progress in understanding earthquake risk and in the application of advanced engineering techniques to reduce loss of life. Since 1900, 12 earthquakes have caused a total of 50,000 or more deaths in a single event, with five of these occurring in 2000 or later. The most recent such event was the series of earthquakes in Kahramanmarash province of Turkey in 2023, which killed over 50,000 people in Turkey and a further 8,700 in north-western Syria. In natural disasters, the search and rescue of trapped victims is a priority, with these tasks being carried out primarily by people and trained dogs in dangerous and high-risk situations. The chances of survival for those trapped decrease after 72 hours spent under the rubble of collapsed buildings, and without access to water, most victims are unlikely to survive for more than 120 hours (Varanasi, 2012), and in many cases, the process of organising and carrying out the rescue of an injured person from the rubble takes between four and ten hours (Barbera et al., 1995). Traditional search and rescue (SAR) methods, although time-tested, are often limited by high risks to the lives of rescue teams, inaccessible terrain or the presence of toxic environments. This has led to significant interest in search and rescue robots in recent years, as they can assist firefighters during their search and rescue missions;

thanks to a range of capabilities, thanks to which they can play an active role in various incidents without putting the lives of rescue teams at risk.

The first academic studies specifically aimed at developing robots for use in rescue operations in urban environments were carried out by two groups at Kobe University in Japan and the Colorado School of Mines in the United States, motivated respectively by the Kobe earthquake and the bombing of the Murrah Federal Building in Oklahoma City, both in 1995. The first real-world application of search and rescue robots took place following the terrorist attack on the World Trade Centre (WTC) in the US, where robots were used to explore inaccessible areas and transmit real-time footage to rescue workers (Davids, 2002).

The aim of this work is to propose a classification of ground-based mobile robots used in rescue operations. This study will not analyse their advantages or disadvantages, but will simply group them according to their distinctive features.

2. Research methodology

The research methodology comprises four distinct stages, as shown in figure 1.

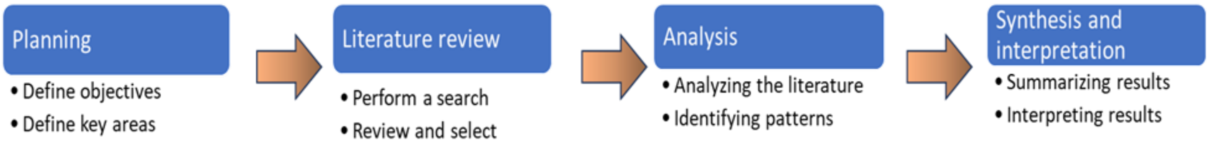

Figure 1. Research methodology

2.1. Planning stage

The planning stage represents the foundational phase of the research process. It involves formulating the research objectives and outlining the key areas of research related to ground-based rescue robots. To structure the research process, a set of key questions has been drawn up to guide the literature search and review.

- What are the main scenarios for the use of rescue robots?
- What are the main locomotion mechanisms used by ground-based rescue robots?
- What control methods and techniques are used?
- What types of power supply systems are suitable?

Formulating these questions facilitates the identification of suitable keywords and search terms necessary for conducting a comprehensive literature review in reputable academic databases and scientific repositories.

2.2. Review stage

A structured search was conducted in reputable academic databases such as IEEE Xplore, ScienceDirect, Scopus, ResearchGate and Google Scholar. Search terms were formulated using relevant keywords. Articles published within the last decade were given priority to ensure the inclusion of the latest developments in the field. The review process involved examining titles, abstracts and full texts to select suitable articles. After that, the selected publications were then examined in detail. This ensured that they matched the aims of the study and were relevant to the research topic.

2.3. Analysis stage

The analysis phase involved a comprehensive examination and synthesis of the selected literature to extract key ideas, trends, and theoretical frameworks related to types of mobile rescue robots. The extracted data was organised thematically to clarify models, challenges, and emerging paradigms in the field. Analytical techniques such as content analysis and pattern analysis were used to identify recurring themes, theoretical models, and empirical conclusions in the reviewed literature. A comparative analysis was conducted to systematise the different types of rescue robots according to key characteristics and to evaluate how different classification approaches relate to one another.

2.4. Synthesis and interpretation stage

The synthesis of the results from the planning, review, and analysis stages resulted in the development of a generalised classification framework. The developed classification is based on present theoretical models, technological developments, and outlined future research directions in the field. Through this methodological approach, the present study aims to contribute to the systematisation of knowledge and a better understanding of rescue robotics

3. Related works

A broad categorisation of mobile robots for rescue operations can be made based on their size. Such a classification has been proposed by Murphy and Stover (2006), where rescue robots are described as one of three sizes: man-packable, man-portable, and maxi. Bruzzone et al. (2012) propose a classification of unmanned ground vehicles (UGVs) based on their mode of locomotion, covering wheeled, tracked and legged robots, as well as combinations of these three types of mechanisms. Dimitrov and Zamanov (2012), and Grueva (2020) propose similar classifications of mobile robots, also based on locomotion mechanisms. Wang and Gu (2007) discuss various types of propulsion mechanisms, including tracked, wheeled, legged, snake-like and brush mechanisms. Liu et al. (2021) examine various types of snake-like robots, whilst Diouf et al. (2024) analyse the design, propulsion and control methods of spherical mobile robots. Another approach to classifying rescue robots is based on the different capabilities and tasks they can perform. Murphy et al. (2008) examined various types of tasks that robots can perform, such as:

- Search for victims;
- Reconnaissance and mapping;
- Rubble removal;
- Structural inspection;
- On-site medical assessment and intervention;
- Medically sensitive extrication and evacuation of casualties;
- Acting as a mobile beacon or repeater;
- Adaptively shoring unstable rubble;
- Logistics support.

Ruangpayoongsak et al. (2005) also propose a set of tasks of high importance for mobile rescue robots, with some of the discussed functionalities overlapping with those listed above. The degree of autonomy is also discussed, by which robots can be classified as remotely controlled, semi-autonomous, and autonomous.

Birk and Condea (2006) note that rescue robots primarily use wireless communication, most often based on the IEEE 802.11 standards, also known as WLAN technology. The authors also propose a method for transmitting data via twisted-pair cable. Another option for a reliable connection is the use of fibre-optic cable Zhao et al. (2017). Khattab et al. (2025) conducted a comprehensive literature review, according to which 46 of 58 analysed sources address wireless communications, with 6 using Wi-Fi and 17 using Bluetooth.

An important aspect in the design of mobile robots for rescue operations is the power supply method. Various power supply methods are used in different platforms, which can be divided into two main types- wired power supply and autonomous power supply (Paunski, 2027; Thangavelautham et al., 2017; Toshiba, 2017). Autonomous power supply, in turn, can be implemented using batteries, an internal combustion engine, fuel cells, or hybrid solutions.

4. Results and Discussion

In line with the aim of this paper, the extracted information was examined using content and comparative analysis. Recurring patterns and key features were identified and organised into six categories. These categories were integrated into a classification system that groups ground-based mobile rescue robots according to their distinctive technical and functional characteristics, as shown in figure 2.

In the created classification, the identified categories are arranged in a multidimensional structure, with each dimension representing a key characteristic. The purpose category describes the specific tasks robots can perform, while locomotion classifies them according to their propulsion mechanisms. The autonomy category distinguishes robots according to the level of operator involvement. The power-supply category outlined the different types of energy sources, while the communication category distinguishes between the methods for data transmission. Additionally, the robots are divided by size into three subcategories.

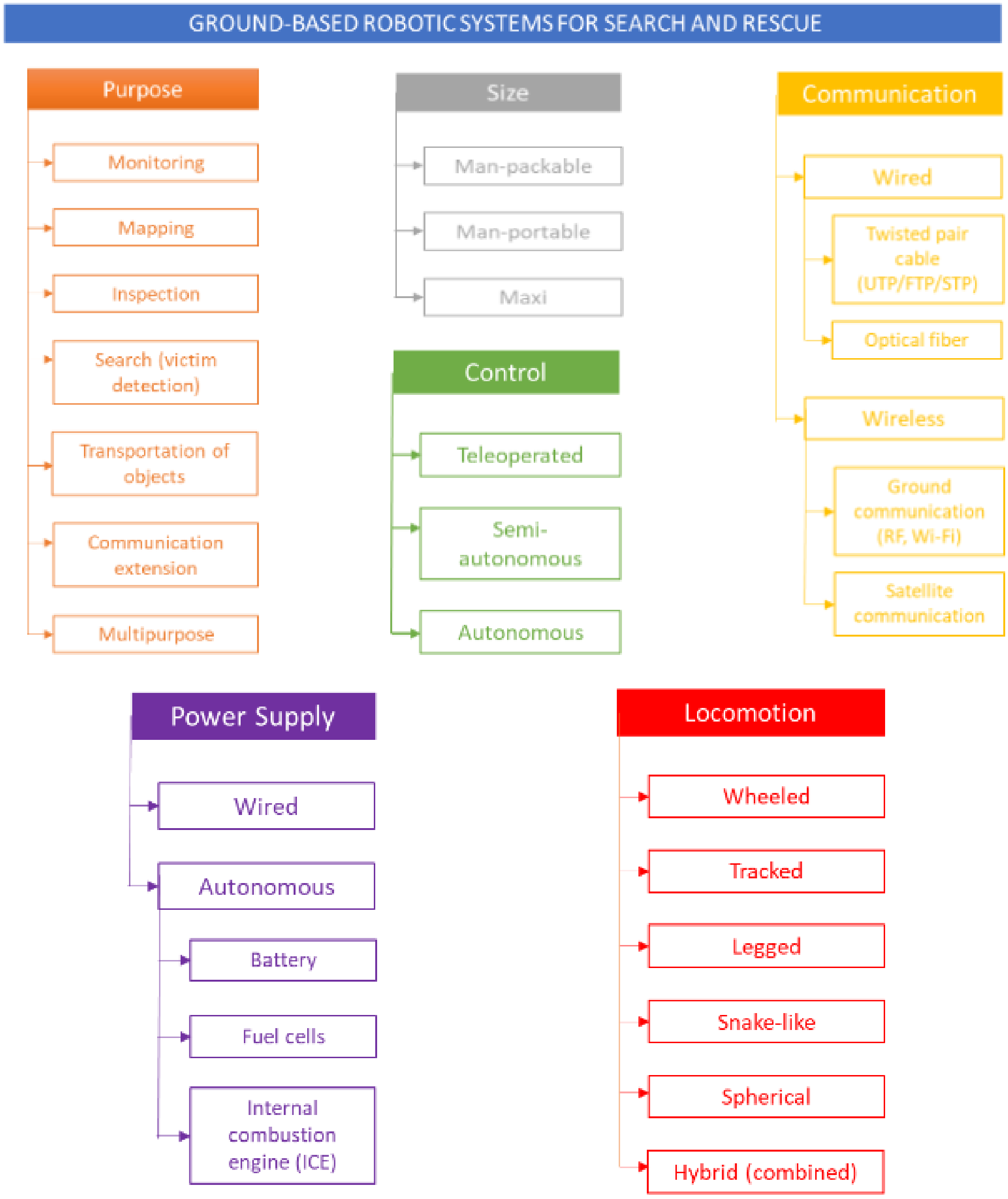

Figure 2. Classification of ground-based robotic systems for search and rescue

Unlike classifications based on a single feature, the developed framework describes mobile robots through several independent characteristics. This multidimensional approach reflects the fact that a single feature cannot adequately describe the design of a rescue robot. While most previous studies examine these criteria separately, this paper synthesises them into a unified framework. The authors' contribution, therefore, lies not in introducing new robot categories but in integrating existing classification approaches into a single structure adapted to ground-based search and rescue robots.

Several limitations of the proposed classification should be noted. It is based on published literature and depends on the scope and quality of the available sources. As a result, emerging technologies or novel industrial solutions may not be fully represented. Also, the study considers only ground-based mobile robots and excludes aerial and underwater platforms, which are widely used in rescue operations. Additionally, while the classification outlines the core characteristics of rescue robots, it does not evaluate their operational performance or determine the optimal platform for specific mission scenarios. The advantages and limitations of mobile rescue robots are examined in greater detail in the authors' previous study (Boyanov et al., 2025). Furthermore, some categories may require revision in the future, as robotic technologies continue to develop.

5. Conclusions

The study developed a classification of ground-based mobile robots for search and rescue operations based on available literature. The robots were grouped according to six characteristics: purpose, locomotion, size, degree of autonomy, power supply, and communication. The classification brings together criteria that are often discussed separately and presents them in a common structure.

The observed diversity of ground-based rescue robots reflects the different tasks and operating conditions encountered during disaster response. No single characteristic is sufficient to describe a rescue robot. Instead, each platform should be defined by a combination of functional and technical features. For example, two robots intended for victim search may differ considerably in size, locomotion, communication method, and autonomy.

The proposed classification is descriptive and does not assess the effectiveness of individual platforms or their suitability for particular missions. Its main contribution is therefore the organisation of existing robot types using a consistent set of criteria. This structure can support the comparison of rescue robots and provide a basis for future studies.

Author contributions:

- Conceptualisation: Y.B. and O.P
- Methodology: T.G. and O.P
- Investigation: Y.B.
- Writing original draft: Y.B.
- Writing review and editing: O.P. and T.G
- Supervision: O.P. and T.G.

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