Key Technological Applications and Development Trends of U.S. Ground Unmanned Equipment

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Abstract: With the continuous rise and application of unmanned combat methods, countries around the world have gradually begun to research unmanned combat related technologies, and the US Army has made ground unmanned equipment technology a key area for the continuous development of its weapons and equipment. This article comprehensively uses methods such as analysis, examples, comparison, and induction to start with the technical and tactical performance of typical unmanned equipment in the US Army, and systematically analyzes its key technologies and future development. This paper places emphasis on the current landscape and future trajectories of U.S. ground unmanned equipment, undertaking a comprehensive study of its technical advancements, distinct performance attributes, and defining characteristics. Through an analysis of the strengths and weaknesses evident in the present development phase of U.S. ground unmanned equipment, it critically evaluates the status quo and projects potential pathways for the future evolution of such technology in the U.S. military.

Keywords: U.S. Army; Ground Unmanned Equipment; Key Technologies; Development Trends

1. Introduction

Through establishing a specialized robotics defense systems company dedicated to the research and development of ground unmanned equipment, the U.S. military has underscored its longstanding commitment to the advancement of this field. Concurrently, efforts have been directed towards enhancing capabilities in informatization, intelligence, as well as ground unmanned equipment deployment [1]. Under the overarching guidance of the U.S. Department of Defense, collaborative initiatives such as the "Unmanned Ground Vehicle Program" have been formulated in conjunction with the U.S. Army and Marine Corps, augmenting these efforts with the establishment of an office specifically dedicated to the joint project on "Unmanned Ground Systems". As we progress into the current century, marked advancements in artificial intelligence, control technologies, and computer software [2] have propelled the U.S. military to prioritize the development of ground unmanned combat equipment. To further propel the research and development of ground unmanned equipment, the military has introduced a series of initiatives, including the "Future Combat Systems", aimed at advancing the field.

2. The Utilization of Key Technologies in U.S. Ground Unmanned Equipment

The advancement of ground unmanned equipment is intricately intertwined with the development and support of relevant technologies. Presently, the U.S. military has accumulated a substantial body of theoretical knowledge and practical experience in various technological domains crucial to ground unmanned equipment, including the overall architectural framework, intelligent environmental perception and autonomous mobility, automatic identification and tracking, network communication, and human-machine interaction.

2.1 Environmental Perception and Autonomous Technology

Traditional manned equipment emphasizes the interaction between "person, equipment, and environment", whereas ground unmanned equipment operates independently of direct human control. It must adapt to diverse and

complex battlefield environments to achieve autonomous driving. In order to enhance its survivability while efficiently carrying out missions, ground unmanned equipment not only needs to possess comprehensive environmental perception capabilities but also require the ability to establish complete and reliable battlefield maneuvering maps. This enables them to perform decision-making, route planning, and autonomous obstacle avoidance [3]. The "Crusher" unmanned vehicle (refer to Figure. 1) has been included in the U.S. military's list of next-generation wheeled ground unmanned reconnaissance vehicles. Initially designed with a speed of 50 kilometers per hour, once operational commanders input destination information into the control device, the "Crusher" can operate in a completely unmanned mode. Utilizing various sensors it carries, the vehicle autonomously makes decisions, plans its route, and travels over 400 kilometers until reaching its designated destination.

Figure1. The "Crusher" Unmanned Vehicle

2.2 Automatic Identification and Tracking Technology

Currently, major military powers worldwide are engaged in competitive development of land combat platform weapon control technology centered around automatic target identification and tracking. This technology is also a fundamental requirement for research in digital electronic weapon systems [4,5]. Modern fire control systems operate as part of advanced weapon systems, focusing on processes such as ballistic calculations, ammunition selection, target detection, tracking and identification, and precise aiming. The "Gladiator" unmanned vehicle (refer to Figure. 2) is deployed by the United States Marine Corps. Equipped with day/night cameras, it can conduct continuous reconnaissance, identification, tracking, and monitoring of targets around the clock. Upon confirmation of targeting information, the vehicle can utilize its onboard weapon systems to engage the targets.

Figure 2. The "Gladiator" Unmanned Vehicle

2.3 Network Communication Technology

The reliability of ground unmanned equipment hinges on the sophistication of network communication technology. Command and control devices transmit instructions to ground unmanned equipment using network communication technology, while the equipment, in turn, sends back images, voice, and other data to the command and control devices. In the modern information warfare environment, various electromagnetic interferences are encountered. These include not only electromagnetic interference signals from adversaries but also signals emitted by various civilian devices in the area. Given the large volume of data transmission in a battlefield, ground unmanned equipment needs to possess larger bandwidth, robust communication self-repair capabilities, interference resistance, and rapid networking abilities among different systems compared to traditional manned equipment. The U.S. military's "Ripsaw" unmanned vehicle (refer to Figure. 3) can reach speeds of up to 96 km/h, boasting high information transmission reliability. Commanders can sit in another vehicle one kilometer away and issue remote control commands to operate the unmanned vehicle. On the other hand, the "Black Knight" (refer to Figure. 4) can achieve a maximum speed of 77 kilometers per hour, demonstrating excellent maneuverability. It can conduct coordinated operations alongside main battle tanks. However, its reliability is not high, posing a risk of causing harm to friendly forces if control is lost.

Figure 3. The "Ripsaw" Unmanned Vehicle

Figure 4. The "Black Knight" Unmanned Vehicle

2.4. Human-Machine Interaction Technology

Regardless of how the form of future warfare evolves, the involvement of combat personnel is essential. On one hand, unmanned equipment serves combat personnel and does not exist independently. On the other hand, granting final decision-making authority to unmanned equipment goes against ethics. Therefore, regardless of the level of scientific and technological development, the ultimate decision-making authority of unmanned equipment must rest with humans. It is imperative to enhance the manifestation of human-machine interaction technology in ground unmanned equipment, enabling these systems to better serve combat personnel. Human-machine interaction technology in ground unmanned equipment involves operators controlling the equipment through independent control devices, with the equipment transmitting information back to the control devices [6]. Currently, human-machine interaction technology has been identified by the Technical Committee for Unmanned Ground Vehicles of the U.S. Army as one of the five key supporting technologies for the development of ground unmanned vehicles. The PackBot ground robot currently utilized by the U.S. military (refer to Figure. 5) is lightweight and portable by a single soldier. Operators can remotely control the PackBot and interpret real-time target data transmitted back by the robot through a touchscreen control device, providing decision-making support to commanders and facilitating operations such as reconnaissance, strike missions, and explosive ordnance disposal.

3. Analysis of Key Technologies of U.S. Ground Unmanned Equipment

The U.S. Army has continuously invested significant human and material resources in the development of ground unmanned equipment and validated these advancements in actual combat scenarios. Consequently, the technological progress of U.S. ground unmanned equipment has achieved a series of significant advancements. Upon comprehensive analysis, the development of U.S. ground unmanned equipment presents the following strengths and weaknesses:

Figure 5. PackBot Ground Robot

3.1 Strengths

Firstly, there is rapid technological innovation. Over the years, the development of ground unmanned equipment has garnered high attention and priority from the U.S. military. Leveraging the national advantage in the advanced artificial intelligence industry, a synergy of technological forces has been fostered. Drawing upon its strengths in key high-tech sectors such as artificial intelligence and communication network technologies, the United States continuously attracts high-tech talents and collaborates with ground unmanned equipment research and development companies, propelling the advancement of ground unmanned equipment to new heights. Throughout the years, the development of U.S. ground unmanned equipment has consistently followed a path of parallel development and application, directly implementing research and development achievements from the laboratory into real battlefield environments with high efficiency in equipment transformation[7]. By leveraging technological advantages and long-term technical accumulation, the U.S. military has elevated the situational awareness capabilities of unmanned platforms, bolstered the collaborative combat capabilities among various platforms, and fundamentally altered the future landscape of warfare.

Secondly, the wealth of technical practical experience sets the U.S. Army apart in the development of ground unmanned equipment.

Over the past 20 years, the U.S. Army has accumulated extensive experience in the realm of ground unmanned equipment. Through the testing and operation of thousands of ground unmanned units, the U.S. military has developed a relatively comprehensive application training model for ground unmanned equipment. Numerous workshops dedicated to training and maintenance of unmanned equipment have been established, nurturing a considerable cohort of skilled and experienced equipment operators [8]. Moreover, the U.S. military has deployed a substantial number of advanced ground unmanned equipment in various regions worldwide, where they play crucial roles. Extensive operational deployment and utilization of ground unmanned equipment have taken place in the battlefields of Iraq and Afghanistan, where they have proven instrumental in executing a wide array of missions for the U.S. military. These deployments have not only been pivotal in mission execution but have also amassed a wealth of practical experience in the effective use of ground unmanned equipment.

3.2 Weaknesses

While the U.S. military has accumulated a wealth of experience in the development of ground unmanned equipment, certain shortcomings persist, which can be summarized in the following three aspects:

(1) Insufficient Research and Development Funding: In recent years, amidst the global economic downturn caused by the COVID-19 pandemic, the U.S. military has faced financial constraints, leading to a relatively sluggish pace in the development of ground unmanned equipment. Particularly in the face of the current complex and rapidly evolving global landscape, the U.S. military must ramp up its research and development investments to maintain its current edge. This necessitates prudent financial planning by the U.S. military, prioritizing key projects and promptly discontinuing less critical ones. While the operational and maintenance costs of ground unmanned equipment are generally lower than those of traditional manned equipment, the immense upfront research and development costs associated with ground unmanned equipment cannot be circumvented given the current financial constraints of the U.S. military.

(2) Lack of Clear Development Direction: Since the inception of ground unmanned equipment, the future trajectory of its development has been the most significant point of contention. From the evolution of theories such as “human-machine fusion” to “manned/unmanned coordination” and further to the latest “unmanned equipment swarm” concept, there has been ongoing debate and evolution. On one hand, the rapid evolution of equipment application theories stimulates and propels the development of ground unmanned equipment. On the other hand, it disrupts the U.S. military’s existing plans for the development of ground unmanned equipment [9].

(3) Entrapment in Narrow Weapon Determinism Ideology: Over the course of prolonged warfare experiences, the U.S. military has ingrained a fixed mindset that high-tech weaponry is the definitive factor determining the success or failure of warfare. Within the strategic backdrop of the “Third Offset”, the U.S. military prioritizes the development of high-tech weaponry as a crucial project, establishing practical implementation plans for various key aspects within the realm of cutting-edge technology. However, there is a lesser emphasis on non-equipment factors, posing a significant challenge for the subsequent coordination between U.S. military ground unmanned equipment and combat personnel, as well as the integration and application synergy between ground unmanned equipment and traditional manned equipment.

4. Development Trends in U.S. Ground Unmanned Equipment

(1) Adaptation to Integrated All-Domain Coordinated Operations: The U.S. Army, through continuous practice and exploration, has forged a path in ground unmanned equipment development that surpasses what other nations can envision. Rooted in the most challenging and intricate battlefield environments and formidable adversaries, the U.S. Army, leveraging an information-driven, unmanned, and all-domain warfare backdrop, has crafted a roadmap for the development of ground unmanned equipment. The U.S. military steadfastly believes that equipment serves as the bedrock for securing victory in

future warfare. Therefore, in the future, the U.S. military will dedicate itself to developing an integrated unmanned combat system that spans across land, sea, air, space, and cyberspace domains. This integration aims to establish seamless connectivity between ground unmanned equipment and unmanned systems in other domains, fostering a high degree of fusion. In future combat scenarios, various unmanned combat equipment will share intelligence information across all domains, enhancing comprehensive combat capabilities of all elements and nodes, including ground unmanned equipment.

(2) Heightened Autonomy: With battlefield dynamics rapidly changing, the application model of information "transmission-analysis-decision-processing-de ployment" has hindered the development of unmanned equipment. Currently, various U.S. ground unmanned combat equipment heavily relies on remote control to carry out tasks, lacking the ability to execute missions based on fully autonomous decision-making. The latest roadmap released by the U.S. Army places significant emphasis on technological factors, prioritizing artificial intelligence technology and machine autonomous learning capabilities as key aspects in the development of ground unmanned equipment. This initiative aims to accelerate the evolution of ground unmanned equipment towards autonomous decision-making in combat operations while leveraging commercial technological innovation to propel the rapid advancement of ground unmanned equipment [10].

(3) Transition to Unmanned Force Reshaping: While ground unmanned equipment technology continues to progress, the U.S. military faces limitations within its current force structure and organization, preventing the optimal utilization of rapidly evolving ground unmanned equipment capabilities. This has led to practical issues within combat units, such as a lack of variety and quantity in unmanned combat system deployments, highlighting a noticeable gap in establishing a comprehensive structure for unmanned combat forces. To enhance the future role of unmanned combat forces, the U.S. Army will further develop a systematically rational and refined unmanned combat force structure, aiming to elevate the combat capabilities of its forces.

5. Conclusions

The evolution of U.S. ground unmanned equipment spans a considerable period, propelled by the nation's formidable defense technology prowess, positioning it at a level beyond the reach of many other nations. Broadly speaking, U.S. ground unmanned equipment has made remarkable progress in areas such as environmental awareness and autonomous technology, automatic identification and tracking capabilities, network communication proficiency, and human-machine interaction sophistication. A range of sophisticated ground unmanned equipment has been engineered to undertake diverse tasks including mine clearance, explosive detection, casualty care, early warning reconnaissance, search and surveillance operations, vigilant patrols, urban combat support, and logistical services, solidifying a substantial operational footprint. Presently, the sector is in a phase marked by rapid expansion. Looking ahead, the trajectory of U.S. ground unmanned equipment will heavily emphasize the development of autonomous navigation, communication, power, visual, system architecture, human-machine interface, manipulation control, terrain mobility, and payload technologies. Analysis of overarching U.S. military directives concerning ground unmanned equipment development unveils a pronounced trend towards comprehensive interconnectivity, bolstering the autonomous combat capabilities of ground unmanned systems, and fostering the emergence of a novel force configuration tailored for ground unmanned operations.

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