IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 10, May 2026
Impact Factor: 8.2

An Review on New Insights in Drug Delivery System

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Abstract: *Nanorobots have emerged as a groundbreaking advancement in the field of targeted drug delivery systems, offering unprecedented precision and efficiency in therapeutic applications. These nanoscale machines are engineered to navigate through the human body, identify diseased cells or tissues, and deliver therapeutic agents directly to the targeted site, thereby minimizing systemic side effects and enhancing drug efficacy. Utilizing technologies such as molecular recognition, bio-sensing, and autonomous navigation, nanorobots can respond to specific biological signals, allowing for controlled and site-specific drug release. This paper explores the design, functionality, and biomedical applications of nanorobots in targeted drug delivery, highlighting current advancements, potential challenges, and future prospects in clinical translation. The integration of nanotechnology with medicine through nanorobotics holds the promise of revolutionizing modern therapeutics, especially in the treatment of cancer, infections, and neurological disorders.*

Nanorobots are advanced nanoscale devices designed to perform precise and controlled functions within the human body for therapeutic and diagnostic applications. In recent years, nanorobots have emerged as a promising technology in targeted drug delivery systems due to their ability to deliver drugs directly to specific tissues, cells, or diseased sites with high accuracy. These nanosized robotic systems are engineered using biocompatible materials and can be guided through the bloodstream using magnetic fields, chemical signals, or artificial intelligence-based navigation systems. Nanorobots help overcome limitations associated with conventional drug delivery methods such as poor bioavailability, non-specific distribution, systemic toxicity, and adverse side effects.

In drug delivery applications, nanorobots can transport therapeutic agents to target sites including tumors, infected tissues, and damaged organs while minimizing exposure to healthy tissues. They possess unique capabilities such as controlled drug release, real-time monitoring, biosensing, and minimally invasive operation. Nanorobotic drug delivery systems have shown significant potential in the treatment of cancer, diabetes, cardiovascular disorders, neurological diseases, and infectious conditions. Advanced nanorobots may also integrate sensors, microprocessors, and molecular recognition systems for intelligent diagnosis and precision therapy.

Recent developments in nanotechnology, artificial intelligence, microelectronics, and biomedical engineering have accelerated the research and development of nanorobots in modern medicine. Despite their promising advantages, challenges related to safety, large-scale production, biocompatibility, ethical concerns, and regulatory approval remain significant barriers to clinical application. However, future advancements are expected to make nanorobotic drug delivery systems more efficient, safer, and commercially viable for personalized medicine and targeted therapy. Thus, nanorobots represent a revolutionary approach in the field of advanced drug delivery systems and precision healthcare

Keywords: Nanorobots, Targeted drug delivery, Nanomedicine, Stimuli-responsive systems, Controlled drug release, Biomedical nanotechnology, Tumour targeting Site-specific therapy, Smart drug delivery systems, Micro/nanorobotics, Biocompatibility, Drug delivery nanocarriers, Autonomous navigation,

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DNA nanorobots, Precision medicine

I. INTRODUCTION

Nanorobots are minute mechanical structures that are inserted in the living cells (1). In recent years, nanotechnology has opened exciting possibilities in medicine. One of the most promising developments is the creation of nanorobots—tiny machines so small that they can move through the human body at the scale of cells and molecules. These nanorobots are designed to carry medicines directly to the part of the body where they are needed most. They are engineered specially with sensing, decision making, and actuation properties (2). By doing this, they can increase the effectiveness of treatment while reducing harmful side effects that often come with traditional drug delivery methods. Nanorobots work by using advanced designs and materials that allow them to move, sense, and respond to their surroundings inside the body. They can be controlled in different ways, such as by magnetic fields, changes in pH, or even by detecting specific chemicals in diseased tissues (3) For example, in cancer treatment, nanorobots can be programmed to recognize tumor cells and release their medicine only when they reach those cells. This makes treatment more precise and reduces damage to healthy tissues. Researchers are also exploring biohybrid nanorobots, which combine tiny machines with living organisms like bacteria to help them move more effectively through the body (4). Some teams are using artificial intelligence (AI) to guide nanorobots so they can work together in swarms, improving their ability to find and treat diseases. Although progress has been impressive, there are still challenges. Scientists need to make sure nanorobots are safe, biodegradable, and do not trigger harmful immune reactions (5). They also need to find ways to produce them on a large scale and ensure they can work reliably in the complex environment of the human body. This review will give an overview of how nanorobots are designed, how they work, the different ways they can deliver drugs, and the medical problems they could help solve. We will also discuss the current challenges and the future possibilities for this exciting technology in precision medicine.

Types of Nanorobots

Biohybrid nanorobots – It is combined manmade nanorobots with micro-organism to target and movement. The advantages are natural mobility, high biocompatibility, ability to sense biological signals. Examples- Sperm-based microrobots that deliver drugs to the female reproductive tract.

Magnetically controlled nanorobots – External magnetic fields are used to provide guidance and power. The advantages are precise remote control, deep tissue penetration without direct contact. Example -Magnetic helical nanorobots coated with drugs can swim through blood vessels and target tumor sites.

Chemically propelled nanorobots – In order to produce propulsion chemical reactions are made. The advantage is that it can move autonomously in biological fluids. Examples - Platinum-coated Janus particles that propel in hydrogen peroxide and carry drugs

DNA origami based nanorobots – Folded DNA structures are used to form nanocarriers that open or close in response to specific signals. The advantages are highly specific targeting, programmable drug release. Example- DNA nanorobots that open in response to tumor-specific molecules to release anticancer drugs

Mechanism of action

Target Identification - Nanorobots deliver drugs with high precision by identifying and homing in on specific target sites inside the body—such as tumor tissues, inflamed areas, or infected cells—before releasing their therapeutic cargonic.

Navigation and movement - Nanorobots move through the bloodstream or tissue using propulsion mechanisms.

Drug release mechanism - The nanorobot releases its drug payload in response to internal or external triggers.

DOI: 10.48175/IJARSCT-35750

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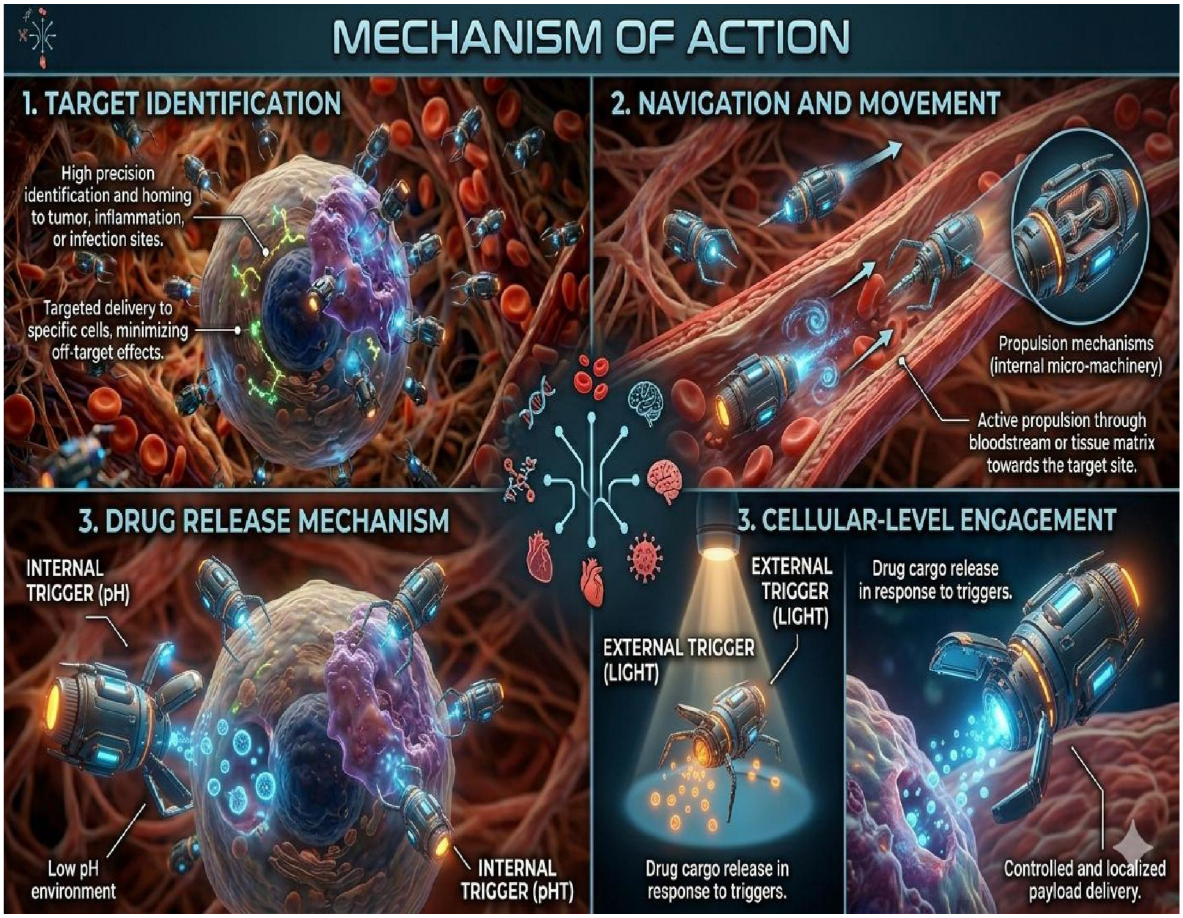

Applications-

1. Cancer Therapy-

2. Neurological Disorder

3. Cardiovascular Disease-

4. Infectious disease-

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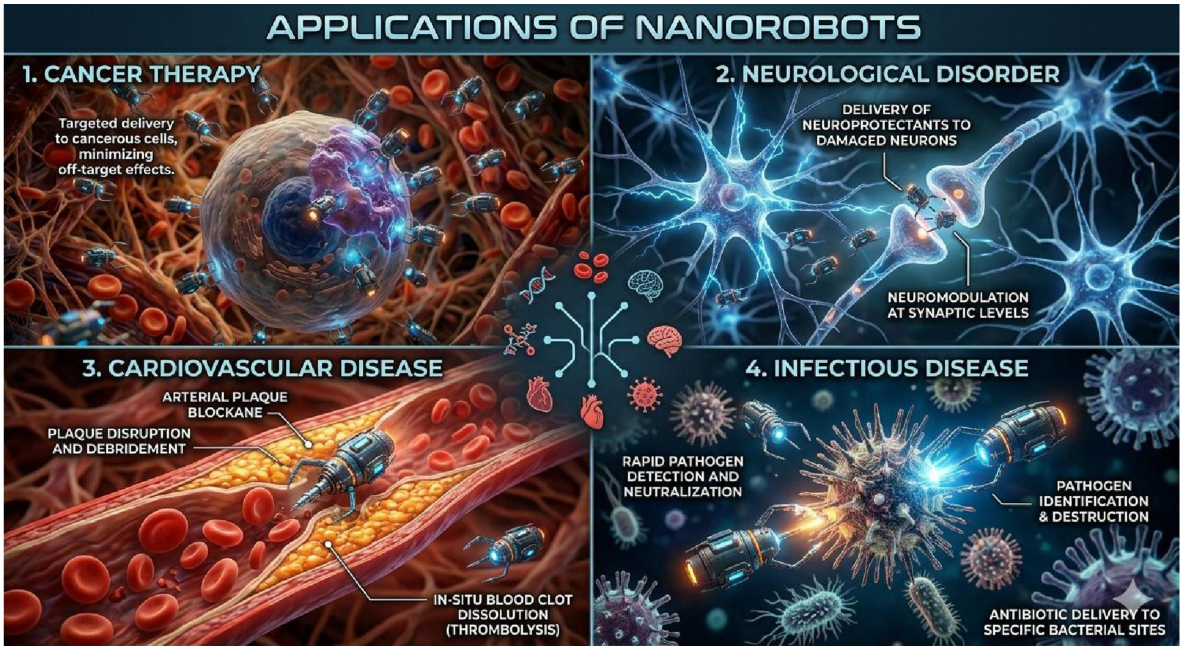

Advantages over conventional drug delivery system-

Feature	**Nanorobots**	**Conventional Drug Delivery**
Targeting	Highly targeted — can recognize specific receptors, pH, temperature, or biomarker signals	Non-specific — affects both healthy and diseased cells
Drug Release Control	Controlled or on-demand release triggered by external signals (magnetic field, ultrasound, light) or internal cues	Passive release, often uncontrolled once administered
Dosage Efficiency	Lower dose needed due to direct delivery to disease site	Higher doses required to ensure therapeutic levels reach the target
Side Effects	Minimal — reduces systemic toxicity and off-target effects	Higher risk of side effects due to drug exposure throughout the body
Overcoming Barriers	Can cross biological barriers (e.g., blood-brain barrier) with surface modifications	Many drugs can't cross barriers without invasive procedure
Multifunctionality	Can combine diagnosis, imaging, and therapy in a single device ("theranostics")	Primarily therapeutic — diagnosis requires separate tools
Response Time	Can respond in real-time to disease markers or environmental changes	Fixed release profile, no adaptive behavior
Resistance Management	Can bypass resistance mechanisms (e.g., biofilms, efflux pumps)	May be less effective against resistant strains or protected cells

Limitations and Challenges –

Complex Design and Manufacturing

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Making nanorobots is extremely complicated. They need to be tiny, precise, and made from materials that are both safe for the body and functional for their task. Current manufacturing methods are expensive and time-consuming.

Power Supply

Nanorobots need a way to move and perform tasks, but finding a safe and reliable power source at such a small scale is difficult. Some use chemical reactions or magnetic fields, but these methods have limitations.

Navigation and Control

Directing nanorobots to the exact location in the body is a big challenge. While external magnetic or ultrasound guidance exists, controlling movement in complex biological environments is still not fully perfected.

Biocompatibility and Safety

The body's immune system may see nanorobots as foreign objects and try to destroy them. Materials must be non-toxic and biodegradable to avoid long-term harm.

Clearance from the Body

After their job is done, nanorobots should safely break down or exit the body. Ensuring complete removal without leaving harmful residues is essential.

Risk of Unwanted Effects

If nanorobots deliver drugs or perform actions in the wrong place, they can damage healthy tissues. Precision is vital to avoid such accidents.

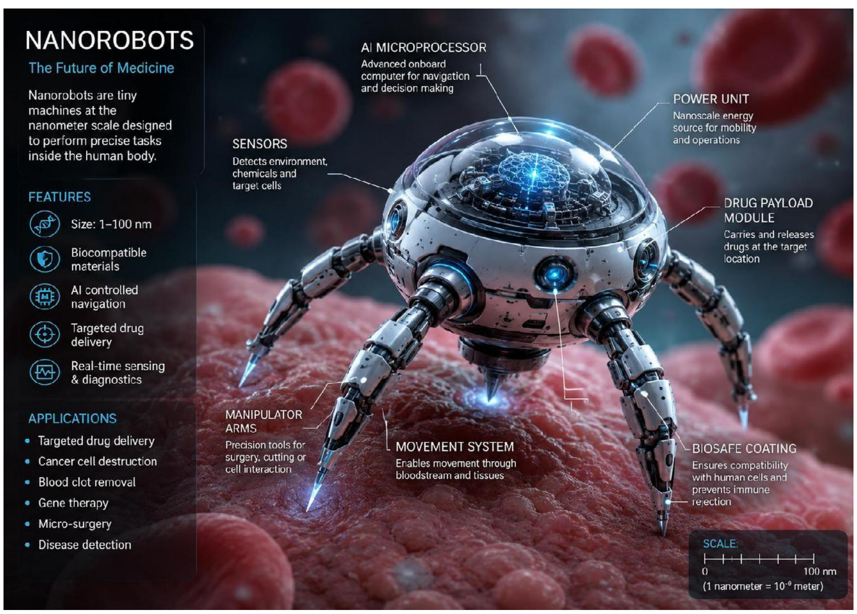
Regulatory and Ethical Issues

Since nanorobots are a new technology, there are no universally accepted safety rules yet. Questions about long-term effects, privacy (in diagnostic use), and ethical limits still need answers.

High Cost

Developing and testing nanorobots requires advanced labs, expensive materials, and long research periods. This makes them costly and currently impractical for large-scale use.

Future Prospects-



Here's a projected market growth graph showing the future prospects of nanorobots from 2025 to 2045, based on hypothetical data.

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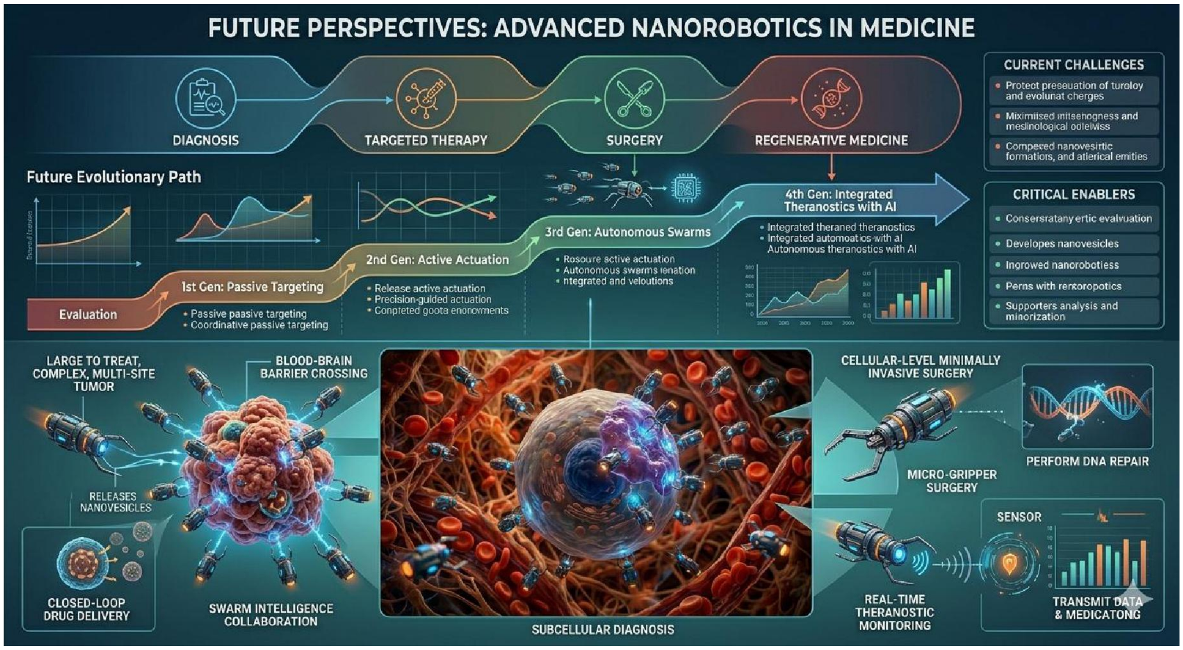

II. CONCLUSION

Nanorobots represent a groundbreaking advancement in science, with the potential to transform medicine, industry, and environmental management. Their ability to work at the molecular and cellular level offers unique opportunities for precise drug delivery, early disease detection, and targeted therapy. While research has shown promising results, challenges such as complex design, high costs, and safety concerns must still be addressed. With continued innovation and collaboration between scientists, engineers, and medical professionals, nanorobotics could move from experimental stages to widespread real-world applications, bringing significant benefits to society in the near future.

ACKNOWLEDGMENT

The author sincerely thanks the respected teachers and faculty members of the Department of Pharmacy for their valuable guidance, support, and encouragement during the preparation of this review paper. The author is also grateful to the institution for providing the necessary academic facilities and resources. Special thanks are extended to all researchers and authors whose published literature has contributed to the successful completion of this student review paper.

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