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A Review on Current Scenario in the Field of Nanorobotics

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Abstract

This paper focusses on the contemporary development of nano-robotics by describing various design models, potential applications and associated issues. Nanorobots are devices at nano (10-9) meters that are composed of nano-sized components. The researches and developments in technologies encouraged researchers to attempt the creation of nano-scale machines. The interface of these machines lies in macro world for controlling them. With the knowledge of large number of natural nano-machines, attempts are made to build human controlled nano-devices. Many design concepts, approaches and mathematical formulations are proposed which shows progression in this field. The names nanobots, nanoids, nanites and nanomites have also been used to describe these hypothetical devices.

Keywords: nanorobots, nano-machines, nanites, bio-nanorobots, design, applications.

Introductions

Nanorobotics is the emerging technology field creating machines or robots whose components are at or close to the scale of a nanometer (10^{-9}m). It refers to the nanotechnology engineering discipline of designing and building nanorobots with devices ranging in size from 0.5-3 micrometers.

The developments in the realm of nanomedicine[1,2]-molecular nanotechnology (MNT) or nanorobotics extend the scope of complexly engineered nano-mechanical systems to medical applications. Molecular nanotechnology enormously increases the effectiveness, range, precision and speed of future medical treatments with significant reduction in cost, risk and invasiveness.

According to Richard Feynman [4], it was his former graduate student and collaborator Albert Hibbs who originally suggested to him (circa 1959) the idea of a medical use for Feynman's theoretical micromachines. Hibbs suggested that certain repair machines might one day be reduced in size to the point that it would, in theory, be possible to (as Feynman put it) swallow the doctor.

The most detailed theoretical discussion of nanorobotics, including specific design issues such as sensing, power communication, navigation, manipulation, locomotion, and onboard computation, has been presented in the medical context of nanomedicine by Robert Freitas. Some of these discussions remain at the level of unbuildable generality and do not approach the level of detailed engineering.

Design of Nanorobots

Designing nanorobotic systems deal with vast variety of sciences, from quantum molecular dynamics, to kinematic analysis. The rules applicable to nanorobotics depend upon the type of nano material being used in the design of such systems. Carbon will likely be the principal element comprising the bulk of a medical nanorobot, probably in the form of diamond or diamondoid/fullerene nanocomposites. Many other light elements such as hydrogen, sulfur, oxygen, nitrogen, fluorine, silicon, etc. will be used for special purposes in nanoscale gears and other components [13].

According to Cavalcanti [9] and Freitas [1], the design of the nanorobot should be carried out in virtual reality approach. Computer graphics can be used in the manipulation of nano particles. The successful development of nanorobot requires the parts of the nanorobot should be designed, created and analyzed. Some nanorobot parts are molecular bearing, molecular gears and nanocomputers. The design of molecular bearing is very easy because of its simple structure and operation. The molecular gears have a central shaft that rotates very fast and the outside shaft rotates slowly. Ring gear is the one that keeps the planet in proper position. Nanocomputer is an important part in the nanorobot. It will be very useful for the doctors to monitor their work and control it [1].

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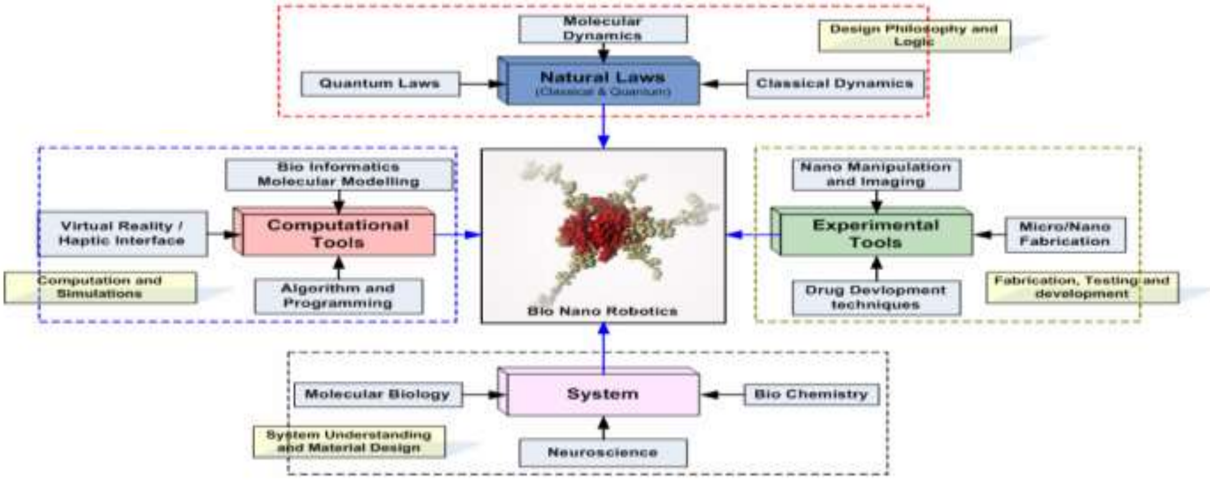

Fig 1 Bio nanorobotics – A Multidisciplinary Field

Organic Nanorobots

Nanorobotics is a field which calls for collaborative efforts between physicists, chemists, biologists, computer scientists, engineers and other specialists to work towards this common objective. Figure 1 shows the details of various fields which come under the field of bio nanorobotics.

Organic nanorobots are the work on ATP and DNA based molecular machines, also known as bionanorobots. In this case, the idea is the development of ribonucleic acid and adenosine triphosphate devices, and even the use of modified microorganisms to achieve some kind of biomolecular computation, sensing and actuation for nanorobots.

Figure 2 shows the flow of protons from the outer membrane to the inner through the F_0 motor. This proton motive force is responsible for the synthesis of ATP in F_1.

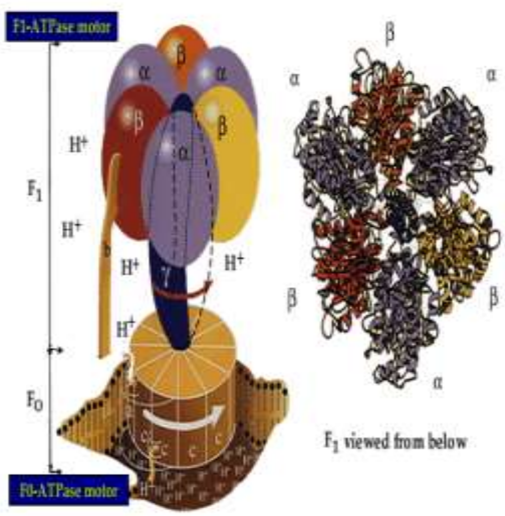

Figure 2: The basic structure of the ATP Synthase. (Source: The Nobel Foundation, 2004)

Inorganic Nanorobots

Inorganic nanorobots manufacturing is based on tailored nanoelectronics. In comparison with bionanorobots, it could achieve a considerably higher complexity of nano scale components. These inorganic machines are easy to synthesize artificially and are generally more robust than the natural molecular machines. Carbon will likely be the principal element comprising the bulk of a medical nanorobot, probably in the form of diamond or diamondoid/fullerene nanocomposites [13]. Many other light elements such as hydrogen, sulfur, oxygen, nitrogen, fluorine, silicon, etc. will be used with the presence of a metal ion being required occasionally for special purposes. Electrostatic interactions, covalent and hydrogen bonding play essential role in the performance of these machines. Such artificial chemical machines are controllable in various ways – chemically, electrochemically and photochemically (through irradiation by light). Some of them are even controllable by more than one ways, rendering more flexibility and enhancing their utility. Rotaxanes [5,6] (fig 3) and Catenanes [5,7] (fig 4) make the basis of many of the molecular machines. These are families of interlocked organic molecular compounds with a distinctive shape and properties that guide their performance and control.

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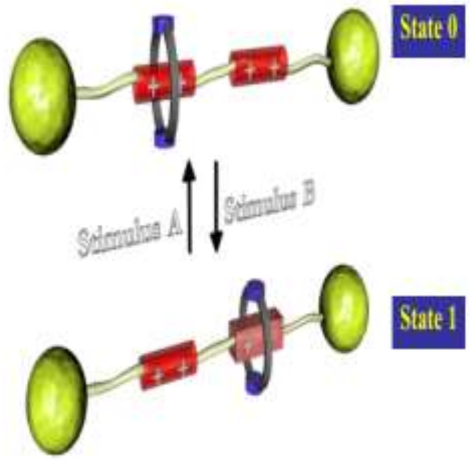

Figure 3: A typical rotaxane shuttle set-up. The macrocycle encircles the thread-like portion of the dumb-bell with heavy groups at it ends. The thread has two recognition sites which can be altered reversibly so as to make the macrocycle shuttle between the two sites.

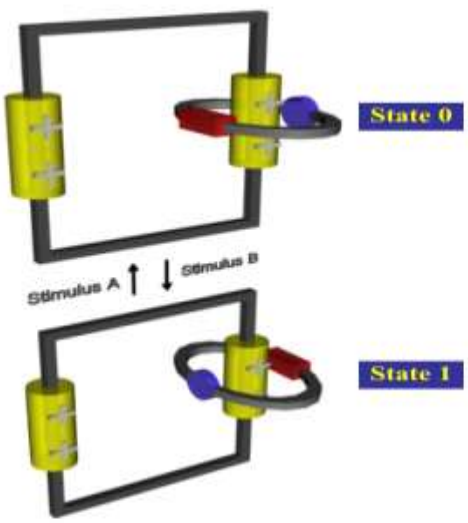

Figure 4: A non-degenerate catenane. One of the rings has two different recognition sites in it. Both sides can be turned 'off' or 'on' with different stimuli. When the green site is activated, the force and energy balance results in the first conformation, whereas when the red one is activated, the second conformation results. They can be named states 0 and 1 analogous to binary machine language.

Approaches in Nanorobotics

Biochip

The joint use of nanoelectronics, photolithography, and new biomaterials provides a possible approach to manufacturing nanorobots for common medical applications, such as for surgical instrumentation, diagnosis and drug delivery [8,9] . Biochips not only consist of immobilized bio molecules spatially addressed on planar surfaces, but also contain bio molecules fixed in micro channels or microcells or on an array of beads or sensors. Nanotechnology has made biochips more applicable for commercialization purpose where biochips could be implanted inside body to dynamically transmit the information and monitor any biological changes in vivo.

Nubots

Nubot is an abbreviation for "nucleic acid robot." They are organic molecular machines [10]. DNA structure can provide means to assemble 2D and 3D nanomechanical devices. DNA based machines can be activated using small molecules, proteins and other molecules of DNA [11]. Nubots have DNA structure used for targeting drug delivery as a carrier.

Bacteria-based

This approach proposes the use of biological microorganisms, like the bacterium *Escherichia coli*. Thus the model uses a flagellum for propulsion purposes. Electromagnetic fields normally control the motion of this kind of biological integrated device.

Open Technology

A document with a proposal on nanobiotech development using open technology approaches has been addressed to the United Nations General Assembly. According to the document sent to the UN, in the same way that Open Source has in recent years accelerated the development of computer systems, a similar approach should benefit the society at large and accelerate nanorobotics development [12].

Nanobearing and Nanogears

In order to establish the feasibility of molecular manufacturing, it is first necessary to create and to analyze possible designs for nanoscale mechanical parts that could, in principle, be manufactured. Notes Drexler [4] "Our ability to model molecular machines (systems and devices) of specific kinds, designed in part for ease of modeling, has far outrun our ability to make them. Design calculations and computational experiments enable the theoretical studies of these devices, independent of the technologies needed to implement them."

Simple structure and operation of molecular bearings makes it the most convenient class of components to be designed. One of the simplest examples is Drexler's overlap-repulsion bearing design [4] shown with end views and exploded views

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in Figure 5 using both ball-and-stick and space-filling representations. This bearing has 206 atoms of carbon, silicon, oxygen and hydrogen, and is composed of a small shaft that rotates within a ring sleeve measuring 2.2 nm in diameter. The atoms of the shaft are arranged in a 6-fold symmetry, while the ring has 14-fold symmetry, a combination that provides low energy barriers to shaft rotation. Figure 6 shows an exploded view of a 2808-atom strained-shell sleeve bearing designed by Drexler and Merkle [4] using molecular mechanics force fields to ensure that bond lengths, bond angles, van der Waals distances, and strain energies are reasonable.

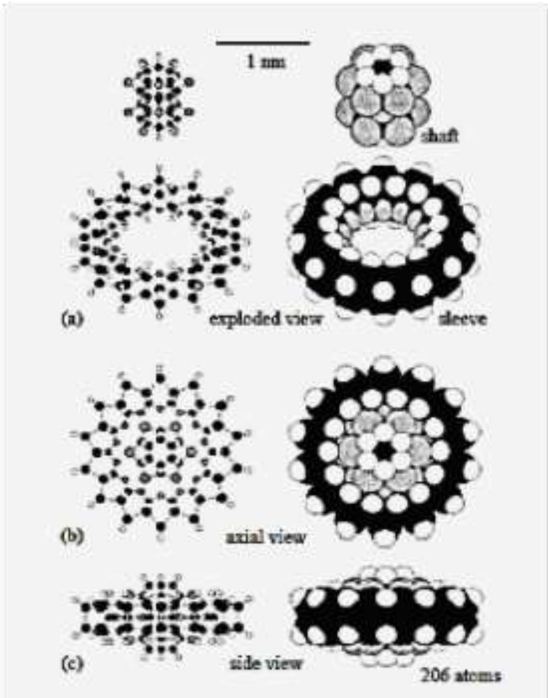

Figure 5: End views and exploded views of a 206-atom overlap-repulsion
Source (K. Eric Drexler.© 1992, John Wiley & Sons, Inc.)

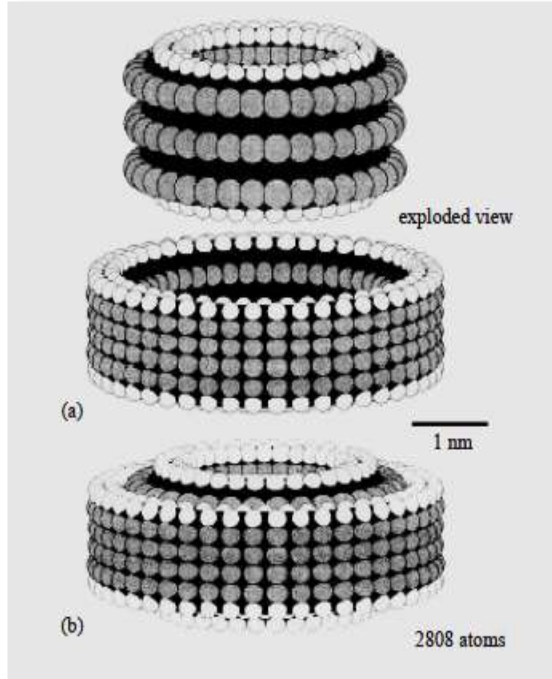

Figure 6: Exploded view of a 2808-atom strained-shell sleeve bearing
Source (K. Eric Drexler.© 1992, John Wiley & Sons, Inc.)

Molecular gears are another convenient component system for molecular manufacturing design-ahead. For example, Drexler and Merkle126 designed a 3557-atom planetary gear, shown in side, end, and exploded views in Figure 7.The entire assembly has twelve moving parts and is 4.3 nm in diameter and 4.4 nm in length, with a molecular weight of 51,009.844 daltons and a molecular volume of 33.458 nm3 The ring gear is a strained silicon shell with sulfur atom termination; the sun gear is a structure related to an oxygen-terminated diamond (100) surface; the planet gears resemble multiple hexasterane structures with oxygen rather than CH2 bridges between the parallel rings; and the planet carrier is adapted from a Lomer dislocation[14] array created by R.Merkle and L.Balasubramaniam, linked to the planet gears using C--C bonded bearings.

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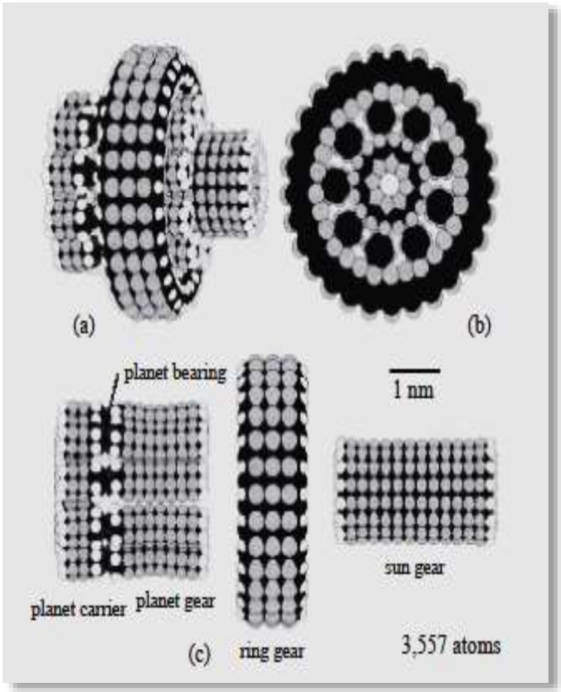

Figure 7: End, side, and exploded view of a 3557-atom planetary gear
Source (K. Eric Drexler.© 1992, John Wiley & Sons, Inc.)

Potential Applications

Nanorobots in Cancer Detection and Treatment

The development of nanorobots may provide remarkable advances for diagnosis and treatment of cancer. Nanorobots could be very helpful and hopeful for the therapy of patients, since current treatments like radiation therapy and chemotherapy often end up destroying more healthy cells than cancerous ones. The Nanorobots will be able to distinguish between different cell types that is the malignant and the normal cells by checking their surface antigens [15] (they are different for each type of cell). A major problem with cancer treatments is the ability to more directly and specifically deliver anti-cancer drugs to cancer metastases. Using the nanorobots, it is more effective to treat cancer metastasis with fewer side effects compared to current chemotherapy [16].

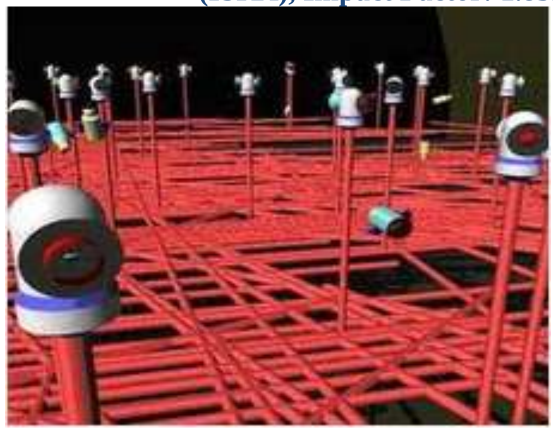

Figure 8: Nanorobots search for organ-inlets demanding protein injection (virtual 3D simulation).
Source (IEEE Journal, Nanorobots in Cancer Treatment, Mithra Venkatesan, Bhuvaneshwari Jolad)

Pharmacyte is a self-powered, computer controlled medical nanorobot system capable of digitally precise transport, timing, and targeted-delivery of pharmaceutical agents to specific cellular and intracellular destinations within the human body. Pharmacytes escape the phagocytic process as they will not embolize small blood vessels because the minimum viable human capillary that allows passage of intact erythrocytes and white cells is 3–4 micrometer in diameter, which is larger than the largest proposed Pharmacyte[15].

The software NCD (nanorobot control design) is a system implemented to serve as a test bed for nanorobot 3D prototyping. It is an advanced nanomechatronics simulator that provides physical and numerical information for nanorobot task-based modeling. Serving as a fast development platform for medical nanorobots investigation, the NCD simulations show how to interact and control a nanorobot inside the body.

Nanorobots in Dentistry

Nanorobots induce oral analgesia, desensitize tooth, manipulate the tissue to re-align and straighten irregular set of teeth and to improve durability of teeth. Further, nanorobots are used to do preventive, restorative and curative procedures[13].

To induce oral anesthesia in the era of nanodentistry, a colloidal suspension containing millions of active analgesic micron-size dental nanorobots will be instituted on the patient’s gingivae. After contacting the surface of the crown or mucosa, the ambulating nanorobots reach the dentin by migrating into the gingival sulcus and passing painlessly through the lamina propria or the 1-3 µm thick layer of loose tissue at the cementoedentinal junction. Upon reaching the dentin, the nanorobots enter 1-4 µm diameter dentinal tubule holes and

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proceed toward the pulp, guided by a combination of chemical gradients, temperature differentials, and even positional navigation, all under onboard nanocomputer control[17].

Various possible uses of nanorobots in dentistry are:

- Major tooth repair
- Tooth durability and appearance
- Nanocomposite
- Nano impression
- Maintenance of oral hygiene
- Cavity preparation and restoration
- Dentin hypersensitivity

Nanorobots in Gene therapy

Medical nanorobots can readily treat genetic diseases by comparing the molecular structures of both DNA and proteins found in the cell to known or desired reference structures. Any irregularities can then be corrected, or desired modifications can be edited in place. In some cases, chromosomal replacement therapy is more efficient than in cytorepair. Floating inside the nucleus of a human cell, an assembler-built repair vessel performs some genetic maintenance. Stretching a supercoil of DNA between its lower pair of robot arms, the nanomachine gently pulls the unwound strand through an opening in its prow for analysis. Upper arms, meanwhile, detach regulatory proteins from the chain and place them in an intake port. The molecular structures of both DNA and proteins are compared to information stored in the database of a larger nanocomputer positioned outside the nucleus and connected to the cell-repair ship by a communications link. Irregularities found in either structure are corrected and the proteins reattached to the DNA chain, which re-coils into its original form. With a diameter of only 50 nanometers, the repair vessel would be smaller than most bacteria and viruses, yet capable of therapies and cures well beyond the reach of present-day physicians. With trillions of these machines coursing through a patient's bloodstream, "internal medicine" would take on new significance. Disease would be attacked at the molecular level, and such maladies as cancer, viral infections and arteriosclerosis could be wiped out.

Nanorobots in Surgery

Surgical nanorobots could be introduced into the body through the vascular system or at the ends of catheters into various vessels and other cavities in the human body. A surgical nanorobot, programmed or guided by a human surgeon, could act as a semi-autonomous on-site surgeon inside the human body. Such a device could perform various functions such as searching for pathology and then diagnosing and correcting lesions by nanomanipulation, coordinated by an on-board computer while maintaining contact with the supervising surgeon via coded ultrasound signals.
The earliest forms of cellular nanosurgery are already being explored today. For example, a rapidly vibrating (100 Hz) micropipette with a less than 1 micron tip diameter has been used to completely cut dendrites from single neurons without damaging cell viability. Axotomy of roundworm neurons was performed by femtosecond laser surgery, after which the axons functionally regenerated. A femtolaser acts like a pair of “nano-scissors” by vaporizing tissue locally while leaving adjacent tissue unharmed[13].

Nanorobots Used In Blood Cell to Detect Pathogens Role in Diabetes

Medical nanorobots monitor diabetes by controlling nutrient concentrations in human body including blood glucose levels in diabetic patients. Patients with diabetes must take small blood samples many times a day to control glucose levels. Such procedures are uncomfortable and extremely inconvenient. Serious problems may affect the blood vessels if the correct target levels of glucose in the blood are not controlled appropriately. The level of sugar in the body can be observed via constant glucose monitoring using medical nanorobotics. This important data may help doctors and specialists to supervise and improve the patient medication and diary diet.

Conclusion

The study of nanorobotics gives us a glimpse of their design, approaches, kinds and applications. The ultimate goal is to design autonomous nanosystems that are capable of carrying out complex tasks. Nanorobotics is an inter-disciplinary research in the area of man-machines communication, i.e. learning machines with miniaturization of computer communication network. This field is in very early stage of development and there are numerous questions to be answered before any substantial outcome is produced.

Significant discoveries in molecular biology assisted researches in nanotechnology to create bio-nanorobotic systems. The function of various biological elements at cellular level creates a motion, force or a signal. Hence, they act as nanorobotic components that perform the same function in response to the same biological stimuli but in an artificial setting. Thus, proteins and DNA could act as motors, mechanical joints, transmission elements or sensors that on assembling can form nano devices,

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with ability to apply forces and manipulate objects in the nano-world.

The pioneering efforts have provided a glimpse into the future of nanorobotics. We are at the verge of the beginning of a new era in which many disciplines will merge including robotics, mechanical, chemical and biomedical engineering, chemistry, biology, physics and mathematics for the development of fully functional systems. However, there are many challenges in the field on nanotechnology that provide exciting opportunities for researchers.

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