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NANOROBOTS: CURRENT STATE AND FUTURE PERSPECTIVES

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ABSTRACT

Nanorobotics is a very recent field that has gained a tremendous momentum of the world scientific community at large. Scientists worldwide are - directing their efforts to develop systematic procedures to synthesize a fully functional autonomous nanorobot in reality. An attempt has been made in this work to show the progress in the research of nanorobots in the last decade. This review paper begins with a brief introduction to the field of nanorobotics and nanorobots. The synthesis of nanorobots is also discussed where the essential structural nanocomponents have been briefly explained and some assembly procedures have also been discussed. The potential applications of nanorobots have also been stated. In conclusion, current challenged and future possibilities are highlighted.

INTRODUCTION

Nanorobotics is emerging as a leading field in the research of robotics at the nanometer scale. Nanorobotics comprises of robots that are at the nanometer scale in size and also larger robots that are able to manipulate the objects that have nanoscale dimensions with nanometer resolution. Many researchers around the world have foreseen a future with tremendous potential in molecular manufacturing using Nanorobots.[1–3] The researchers have also highlighted the numerous applications and the far-reaching effects that nanorobots can have in medicine.[4,5] In his 1959 talk "There's Plenty of Room at the Bottom," the late Nobel physicist Richard P. Feynman proposed employing machine tools to make smaller machine tools, these to be used in turn to make still smaller machine tools, and so on all the way down to the atomic level.[1]The form in which the nanorobots will manifest or the specific task(s) they will actually perform still remain unclear although many scientists have spelled quite a lot number of possibilities regarding their structure and function.

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The major challenge that the scientists are facing in the synthesis of nanorobots is the ability to measure, manipulate and assemble matter with features on the scale of 1-100 nm.[6] There are several opportunities of the small size of the devices such as manipulating nano-objects with nanotools, measuring mass in femtogram ranges, forces at piconewton scales and inducing gigahertz motion.[7]

Nanorobots : What are they ?

A nanorobot is a computer-controlled robotic device constructed of nanoscale components to molecular precision and is microscopic in size.[8]

A nanorobot is a robot with overall dimensions not exceeding a few micrometers and built from nanoscale components.[9] Thus, a nanorobot has a size on the scale of a biological cell. In fact, some researchers say that nanorobots are the adapted versions of bacteria.[10] Constantinos Mavroidis and Antoine Ferreira[6] rightly point out that a nanorobot is any active structure capable of either one or a combination of two or more of the following: actuation, sensing, manipulation, propulsion, signaling, information processing, intelligence andswarm behavior at the nanoscale. Nanorobot is a very broad term. As pointed out earlier, the term nanorobot includes large scale manipulators that have nanoscale precision and also microscopic robotic devices at the nanoscale.[11] The term nanorobot may also refer to molecular machines that are based on biological entities such as proteins and DNA[12] and magnetic nanoparticles that are guided by an external magnetic field.[13] Though biological nanorobots have been developed and tested, nanorobots are generally referred in the sense of mechanical nanorobots and so far, fully functional autonomous mechanical nanorobots have not been synthesized. However, large scale manipulators with nanoscale precision and manipulation capability have been developed and are called nanomanipulators. Several components like nanocomputers, nanosensors etc. that could be used in the assembly of a nanorobot have also been developed.[6] Efforts are now rightly directed in trying to assemble a fully functional autonomous mechanical nanorobot.

Synthesis of Nanorobots

The synthesis of a fully functional autonomous mechanical nanorobot is a fairly tedious task because of the complex manipulations involved at the nanoscale. However, many researchers have tried to provide solutions to the challenges faced in the construction of a nanorobot. In the following paragraphs we briefly discuss the structure of a nanorobot and then move on to talk about very briefly on the assembly procedures of the nanocomponents to form a nanorobot. We also discuss the problems associated with the synthesis.

Structure of a nanorobot

In order to explore the possibilities of molecular manufacturing, it is necessary that first the nanocomponents be created, analyzed and tested. Many researchers say that silicon can be used as the primary material. However, constructing these components using silicon would mean that these components would be non-biodegradable.[14]

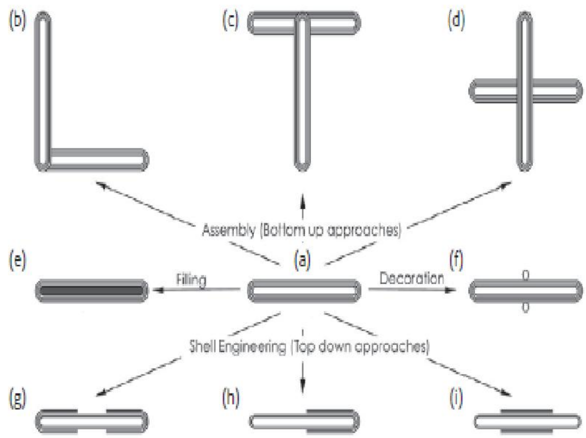

Fig. 1. CNT-based building blocks. Starting from (a) as-grown CNTs, nanostructures can be created by the bottom-up approaches of (b–d) assembling, (e) filling, or (f) decorating them, or in a top-down fashion by (g–i) engineering their shells/caps.[7]

As recent as of 2004, such materials were not existent. Hence, scientists could use only theoretical computation techniques to analyze the possible materials and structures.[15] However, in 2007, a design for these components using carbon nanotubes (CNTs) has been proposed owing to their various enhanced properties.[7] CNTs can serve in nanorobotic systems as structural elements, tools, sensors, and actuators. Shown in Fig. 1, is the shell engineering concept, starting from as-grown CNTs, nanotubes can be assembled into more complex structures using bottom-up approaches or engineered to achieve secondary building blocks using top-down approaches.[7] We now briefly discuss the essential components of a nanorobot.

Nanobearings and Nanogears

Molecular bearings and gears are one of the most convenient classes of components to design because of their simple and straightforward structure and operation. One of the simple yet remarkable design examples is Drexler's overlap-repulsion bearing design.[16] This bearing is composed of a small shaft that rotates within a ring sleeve of 2.2 nm in diameter, has 206 atoms of carbon, silicon, oxygen and hydrogen. 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.[16] Fig. 3 shows a 2808-atom strained-shell sleeve bearing designed by Drexler and Merkle[16] using molecular mechanics force fields to ensure that bond lengths, bond angles, van der Waals distances, and strain energies are reasonable. This 4.8-nm diameter bearing features an interlocking-groove interface which derives from a modified diamond (100) surface.

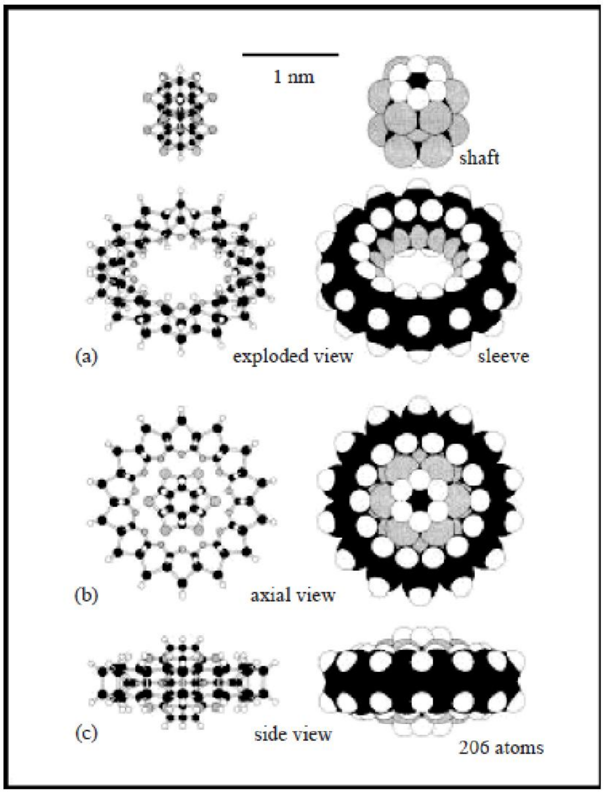

Fig. 2: End views and exploded views of a 206-atom overlap-repulsion bearing.[15] Image courtesy of K.Eric Drexler.© 1992, John Wiley and Sons, Inc.

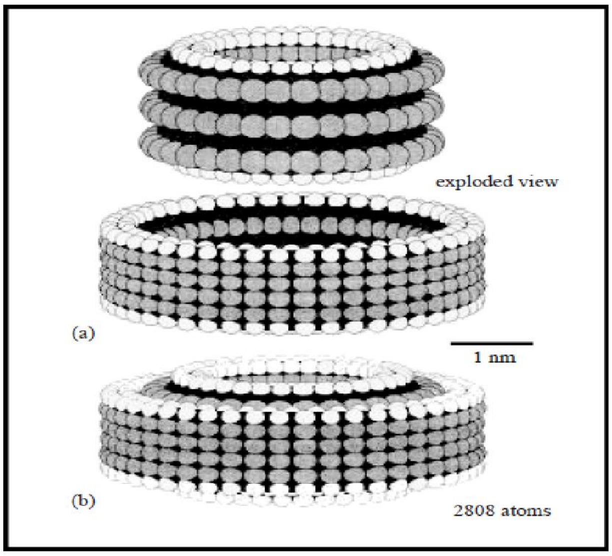

Fig. 3: Exploded view of a 2808-atom strained-shell sleeve bearing.[15] Image courtesy of K.Eric Drexler.© 1992, John Wiley and Sons, Inc.

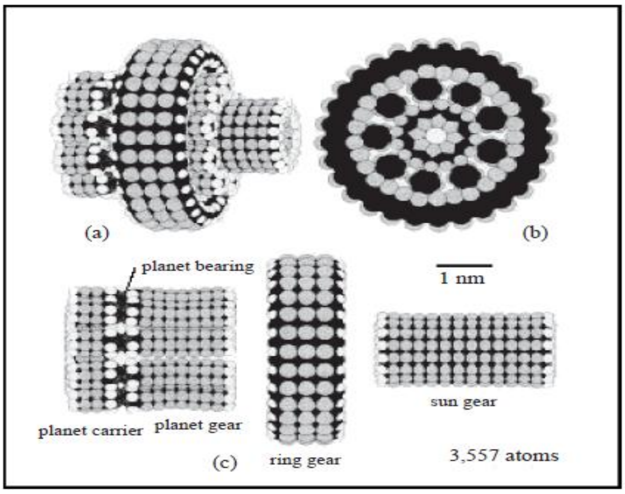

Fig. 4: End-, side-, and exploded-view of a 3557-atom planetary gear.[15] Image courtesy of K.Eric Drexler.© 1992, John Wiley and Sons, Inc.

Ridges on the shaft interlock with ridges on the sleeve, making a very stiff structure. Attempts to bob the shaft up or down, or rock it from side to side, or displace it in any direction (except axial rotation, wherein displacement is extremely smooth) encounter a very strong resistance.[17] Molecular gears are another convenient component system for molecular manufacturing design. For example, Drexler and Merkle[16] designed a 3557-atom planetary gear as shown in Fig. 4. 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 nm^3. The small planetary gears, rotating around the central shaft, are surrounded by a ring gear that holds the planets in place and ensures that all components move in proper fashion. 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 CH_2 bridges between the parallel rings. The planet carrier is adapted from a Lomer[18] dislocation array created by R.Merkle and L.Balasubramaniam, linked to the planet gears using C-C bonded bearings. Newer studies suggest the use of CNTs for this purpose.[7] These bearings and gears serve the purpose of the body of a nanorobot.

Nanomotors and Power Sources

Another class of theoretical nanodevice that has been designed is a gas-powered molecular motor or pump.[19] The pump and chamber wall segment shown in Fig. 5 contains 6165 atoms with a molecular weight of 88,190.813 daltons and a molecular volume of 63.984 nm^3. The helical rotor has a grooved cylindrical bearing surface at each end, supporting a screw threaded cylindrical segment in the middle. Goddard[20] reported that preliminary molecular dynamics simulations of the device showed that it could indeed function as a pump, although it is not very energy-efficient. Supplying power to such a complex system is not trivial. For fuelling and propelling nanorobots, hybrid solutions must necessarily be found. For instance, Montemagno and Bachand have reported the construction of nanomechanical devices powered by biomolecular motors[21], Kim and Breuer have described the successful use of live bacteria as mechanical actuators in microfabricated fluid systems[22], and Behkam and Sitti have exploited bacterial flagella for propulsion and motion control of microscale objects[23]. An enormous advantage of this solution is the fact that the motion does not require an alien input of energy for that the chemical energy available in the organism (in the form of adenosine triphosphate, ATP) can be exploited.

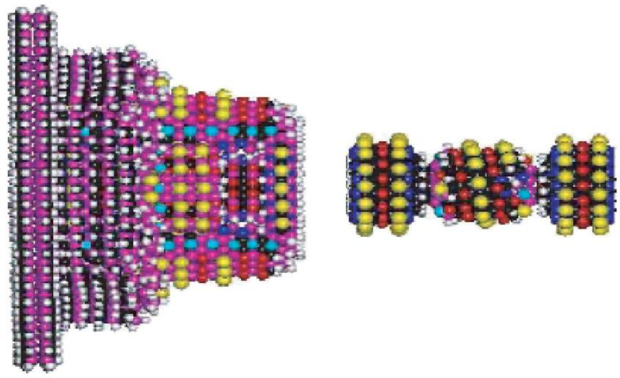

Fig. 5. Side views of a 6165-atom neon gas pump/motor.[19] Image courtesy of K.Eric Drexler. © Institute for Molecular Manufacturing (www.imm.org)

The same form of energy can also be exploited for powering the electrical circuitry, because biomotors are reversible and can operate as engines too. Various other alternative solutions for power sources have also been mentioned. A fine film of radioactive particles can be adhered to the nanobot's body[24]. As the particles decay and release energy the nanobot would be able to use this power source; the size of the radioactive film can be manipulated to any scale without any compromise in efficiency and can be automatically renewed. This fuel cell need not be replaced due to constant supply of circulating nuclear energy. This is much more advantageous than the conventional solar cells or battery packs for equipping nanorobots.

Nanocomputers

A nanorobot, before taking any action, must collect, analyze and if required, transmit the data. This, it must do so to ensure proper control and monitoring and prevent unwanted damages. Thus, a computer at the nanoscale is required for data storage, data analysis and data transmission.

Assembly

Each of the nanocomponents discussed so far need to be assembled in a proper fashion for the creation of a fully functional nanorobot. There are various assembly procedures outlined which are briefly discussed in this review.

Self-Assembly

Some of the best-known self-assembling molecular systems include those which form ordered monomolecular structures by the coordination of molecules to surfaces,[25] called self-assembled monolayers (SAMs),[26] self-assembling thin films or Langmuir-Blodgett films,[27] self-assembling lipidic micelles and vesicles,[28] and self-organizing nanostructures.[29,30] The thickness and composition of the layer of surface molecules are adjusted to 0.1-nm by controlling the structure of the molecules comprising the monolayer. However, controlling the in-plane dimensions to less than 100 nm is relatively difficult. Several attempts have been made to achieve self-assembly of small mechanical parts to avoid direct parts grasping. [31] Saitou[32] gives a simple example of "sequential random bin picking" in which a process of sequential mating of a random pair of parts drawn from a parts bin which initially contains a random assortment of parts can produce the mating of a desired pair of parts. Griffith[33] suggests expanding the toolbox of self-assembly by including dynamic components that imitate enzymatic binding activity. This presents a simple "mechanical enzyme" analog–a 2-bit mechanical state machine that programmatically self-assembles while floating at an interface between water and poly-fluorodecalin. The mechanical state machine has a mechanical flexure that acts as the 'switch' in the state machine, making a mechanical allosteric enzyme.

DNA-Directed Assembly

Earlier nanobots might be assembled from DNA, at least partially. The idea of using DNA to build nanoscale objects has been pioneered by Nadrian Seeman at New York University.[34] Two decades ago, Seeman recognized that a strand of DNA has many advantages as a construction material. The stiffness and it's ability interact with other strands through intermolecular forces can be readily predicted and programmed due to the base-pair complementarity of nucleotides which is the fundamental building blocks of genetic material. DNA also tends to self assemble. Conventional biotechnological techniques can be used to readily manufacture arbitrary sequences. DNA is also readily manipulated and modified by a large number of enzymes.

Protein-Directed Assembly

Many protein manipulators employ "parts insertion" or "threading" maneuvers, such as the process that takes place while transcription of mRNA with the help of RNA polymerase II.[35] Synthetic enzymes called "nanopart synthetases," can be designed using synthetic amino acids by grabbing molecular parts in a solution and then, as the enzyme folds, bringing these parts into proper alignment and causing them to react, exemplifying protein-directed parts assembly.

Microbe- and Virus-Directed Assembly

Artificial microbes might also be employed in molecular parts fabrication. Some strains of bacteria are known to fabricate metal crystals in specific shapes.[36-40] To establish digital control over microorganisms, genetic circuits that can function as switches[28] or computational logic elements such as AND, NAND, and NOR gates can be used. Viral shells also provide useful templates for nanoscale assembly. Belcher [41,42] employs virus capsid shells for the directed nanoassembly of nanoparticles such as quantum dots[43,44]. Engineered viral coat proteins can be used as scaffolds for nanomaterials synthesis[45] and self-assembly[46].

Positional Assembly

As machine structures become more complex, getting all the parts to spontaneously self-assemble in the right sequence is increasingly difficult[4]. To build complex non-periodic structures, it makes more sense to design a mechanism that can assemble a molecular structure by what is called positional assembly—that is, picking and placing molecular parts. A device capable of positional assembly would work much like the robot arms that manufacture cars on automobile assembly lines. In this approach, the robot manipulator picks up a part, moves it to the work piece, installs it, then repeats the procedure over and over with many different parts until the final product is fully assembled.

Applications of Nanorobots[6,34]

Nanorobots find a variety of applications, particularly, in medicine. Due to the specificity of a nanorobot to target a particular cell, nanorobots can be majorly used for 'targeted cell drug delivery' and also to 'identify and isolate cancer/malignant cells'. Nanorobots can also play an important role in Tissue Engineering. They could rebuild tissue molecules in order to close a wound, or rebuild the walls of veins and arteries to stop bleeding. They could make their way through the bloodstream to the heart and perform heart surgery molecule by molecule without many of the risks and discomfort associated with traditional open-heart operations. Likewise, researchers hope that nanorobots will have many miraculous effects on brain research, cancer research, and finding cures for difficult diseases like leukemia and AIDS. Space scientists and researchers are betting a great deal on the use of nanorobots in space explorations and various other related activities. An 'unusual' application of nanorobots is also proposed in the exploration of subterranean oil reservoirs and maximization of hydrocarbon recovery.

Conclusion

The most challenging task to create a nanobot is to be able to create a whole set of specialized machine-tools in order to speed the process of nanobot building. Nanobots measure more like six atoms across, but the design is highly complicated and need to be engineered in such a way that they are autonomous. Typically, ideal nanobot consists of a transporting mechanism, an internal processor and a fuel unit of some kind that enables it to function. The main difficulty arises in shrinking the robotic propulsion system to nanoscale with existing technology. Scientists have succeeded in reducing a robot to five or six millimeters, but this size still technically qualifies it as a macro-robot. Also breaking down materials (metals) to small enough to build nanorobot is an onerous task. According to the researchers, a nanobot with several sets of fast-moving legs and body close to the ground can be created, which would be an efficient machine suitably shaped for introduction into human blood vessels to perform functions such as clearing away built-up cholesterol or repairing tissue damage. It is anticipated that most of the applications of nanorobots would be in medical field as it can interact with materials on molecular and atomic level. They could rebuild tissue molecules in order to repair a wound, or rebuild the walls of veins and arteries to stop bleeding and save lives. They could make their way through the bloodstream to the heart and perform heart surgery molecule by molecule without many of the risks and discomfort associated with traditional open-heart operations. Likewise, researchers hope that nanorobots will have phenomenal effects on brain research, cancer therapy and finding cures for complicated diseases like leukemia and AIDS. Although standardized nanorobot production is still at a nascent stage, scientists are working hard to develop these tiny systems and hopefully come up with functional autonomous nanorobots sometime in the next two decades.

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