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Nanorobots

State of the Art and Expectations

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IV123 – Future Challenges of Informatics

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Introduction

The line between real science and science fiction is still more and more attenuating and becoming almost indistinguishable. Progress that has been made in literally every branch of scientific research and subsequently in technology in the last hundred years is without reservations astounding and incomparable to anything conceived in recorded human history. Technology owes its huge advancement mainly to collaboration between experts from the whole scientific spectrum. Cooperation between different specialists is also essential to the new promising discipline of technology – *nanotechnology*, operating on the scale of nano- and micrometres.

This essay is mainly concerned with *nanorobotics*, which is perceived as above all medicine altering force by many futurologists. However, influence on the whole society is predicted to be paradigm shifting.

Short Overview of Nanotechnology

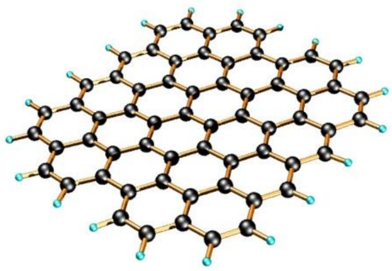
It may seem surprising but the first pioneers in nanotechnology appeared in the middle ages. Medieval nanotechnology, however, it was not called this way, was utilized in creating colourful mosaics in stained glass windows of churches or cathedrals. To achieve various colours of glass, controlled heating and cooling processes that adjusted size of miniscule glass crystals were used. Apparently, medieval glassworkers were not aware of what was actually happening to the glass but today scientists figured out how the changes of the structure of matter affect its attributes.

One of the basic tenets of nanotechnology is that all materials change their properties (e.g. colour) with changing size. This is mainly caused by the event called *quantum confinement*. It takes place when a material size is small enough that its electrons are squeezed into space which is smaller than they prefer and their energetic levels change rapidly.

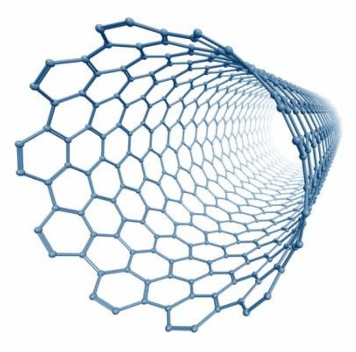
When it comes to the question how to even visualize such miniature sizes, it is almost impossible to answer. The best analogy that many scientists came up with in order to elucidate this topic to uninitiated individuals is comparison to a human hair. If you decrease the width of average human hair 100,000 times (= nine orders of magnitude smaller than a metre), you might get the idea of how small are the dimensions in which the researchers of this area are interested. Obviously, hair analogy is saying that these sizes are unfathomable by conventional, everyday thinking.

Since this branch of technology encompasses teams consisting of experts in computer science, chemistry, biology, physics and other disciplines, it is understandable that it offers very wide range of potential applications. Despite the fact that it is still in its infancy, nanotechnology has already provided us with inventions that would seem almost miraculous twenty years ago. This is mainly due to invention of *scanning probe microscope* (SPM), which was developed by *Binnig* and *Rohrer* (it earned them a Nobel Prize) in the early 1980s. SPM has given scientists foundations for nanomanipulation that covers processes of design validation, parameter optimization and sensitivity studies, all leading to prototyping of nanodevices.

The Nobel Prize in physics in 2010 was awarded to *Andre Geim* and *Konstantin Novoselov* for maybe the most popular contrivance of nanotechnology, the strongest ultrathin material ever created called *graphene*. Basically, it is two-dimensional (the thickness is only one atom, therefore it is insignificant) lattice of carbon atoms. The atoms are arranged in hexagons (polyaromatic carbohydrate) and resemble a honeycomb. Famous futurologist and theoretical physicist *Michio Kaku* described graphene to be strong enough to hold the weight of an elephant placed on a pencil without breaking. The material will undoubtedly have many applications also because of its conductivity. Electric current flows through carbon lattice quicker than through any other known conductor. This property of graphene may launch production of superfast computers, although we have to sufficiently master all of the quantum electrodynamics phenomena that emerge when the electricity is transmitted through the media of graphene. The most astonishing facts about this material are its simplicity and undemanding fabrication. Graphene can be created from whatever piece of graphite one can find (also simple pencil) by reducing its width to a level of single atoms.



If we fold carbon lattice to cylindrical shape (however, it is quite difficult process), which makes the carbon on the opposite sides of the lattice to create bond, we will get carbon *nanotube*. Carbon nanotubes are tubes with the greatest length to diameter ratio (up to 132,000,000:1). Their ability to connect to each other by van der Waals forces is remarkably convenient for its possible applications. The future of nanotubes seems bright, they will probably find their usage in construction of waterproof and tear-resistant fabrics, artificial muscles, displays or solar collectors. One ambitious project claims that nanotubes will provide us with force sufficient enough to build space elevators.



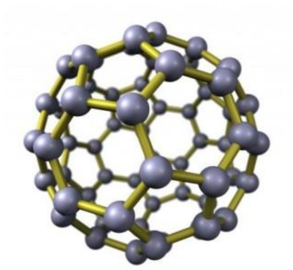
Basics of Nanorobotics

One of the most ingenious and promising subbranches of nanotechnology is represented by nanorobotics. It encompasses the design, fabrication and programming of robots of overall dimensions below a few micrometres, which is comparable to those of biological cells and organelles. Order-of-magnitude feasibility calculations have shown that the fabrication of them is not impossible and that there are no physical laws violated by these ideas. There is also plenty of evidence of nanoscale living organisms in the nature. Successfully operating nanorobots have to be assembled from nanoscale objects which are also programmable. Nanorobotics raises important issues, for instance actuation, control, communications or interfacing of machines on such a small scale.

Interest in nanorobotics grows rapidly as evidenced in increasing number of papers and tutorials on this subject emerging all around the world. Although it is nearly multimillion dollar industry, its true applications are still quite distant from everyday use. However, the idea of for example artificial cells seems to be a good motivation for funding this discipline. There are two main approaches to create nanorobots. First sees them as *NEMS* –

nanoelectromechanical systems and the second views nanorobotic devices as almost complete imitation of a microorganisms based on DNA and limits itself to applications in medicine. Both of these approaches promise to produce useful machines operating on a tiny scale.

There is not much needed to imagine a very simple nanorobot. If we look back at the carbon based nanotechnology from the previous chapter, we can easily imagine a primitive nanodevice. Its "body" would consist from only 60 atoms of carbon which would create bonds to produce the shape of a football. This molecule is called *Fullerene* or *Bucky Ball* (as a tribute to *Buckminster Fuller,* American architect) and it is completely empty inside. Molecule with these properties can be used as a tiny container for another chemical. Fullerene itself has no propulsion or actuation systems built in but a lot of other possibly more complex nanorobots may use similar mechanisms of transport.



NEMS nanorobotics

One of the leading researchers in the area of nanorobotics based on nanoelectromechanical systems is Portuguese engineer *Aristides A. G. Requicha* who is currently the Professor of Computer Science and Electrical engineering at the University of Southern California, Los Angeles and also chief of the Laboratory of Molecular Robotics. He has written numerous scientific papers on the subject, therefore the main source for this chapter are his works [1].

Sensors

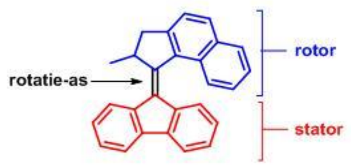
The closest to true *nanosensors* up to date are the devices that exploit changes of conductivity in nanotubes or nanowires. Although they are still several micrometres in size, it should be possible to make them shorter and still keep their sensing capabilities. We can even achieve sensitivity to different chemicals by suitably functionalizing the sensing elements. This can be done by attaching various chemical groups to them.

Possible chemical sensors should also work on the principle of microscopic cantilevers with two primary functions: 1) detection of the deflection of a cantilever caused by surface stresses (when a chemical binds on one of the two sides of the cantilever) and 2) measure the shift in the resonance frequency of a vibrating cantilever when its mass increases. Tactile sensing may be used for instance for identifications of marine microorganisms. Cantilevers with resonance frequencies over 1 GHz have already been developed by using lithographic processes but they are still too large to be called nanoscale. Submicrometre cantilevers tend to display elastic instabilities which still present problems.

Flourescent probes have also been demonstrated but most probably they will not be used as sensors in autonomous or semiautonomous nanodevices. It is mainly due to fluorescence detector which they have to contain and which are almost impossible to miniaturize.

Actuators

Actuation of nanorobots may be achieved by multiple ways. One of them is actuation by artificial molecular machines. The most promising seems to be *Feringa's molecule* which represents a tiny rotary motor. Under irradiation with suitable wavelength of visible spectrum, one part of a Feringa's molecule (the rotor) rotates continuously with respect to another one (the stator, the fixed part) around the carbon-carbon double bond in the center of it. This process is caused by cis-trans isomerization which is a result of the irradiation. The conformation of the irradiated molecule changes from a state when two groups of the atoms are on the same side of a bond (cis) to another, unstable state in which the two groups are on the opposite sides of the bond (trans). Continuing works of Feringa's team at the University of Groningen, Netherlands, have shown other molecules whose rotors are substantially different from their stators and, therefore, should fabricate selective attachment to other molecules and use them as ultimate nanorobot actuators.

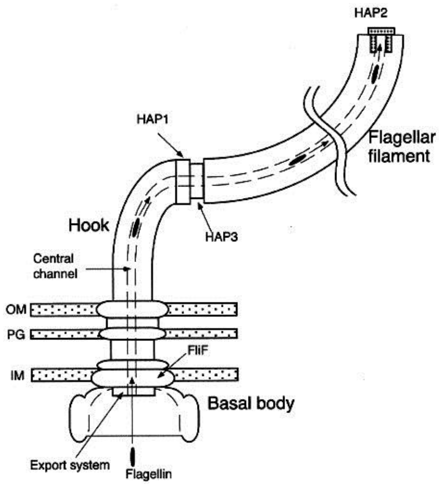


Another demonstrated approach to possible nanorobot actuators involves *biomotors*. Their common properties are: 1) they run on chemical fuel (usually ATP), 2) they are made of soft materials of limited durability, 3) they operate in a narrow range of environmental conditions such as temperature and pH, 4) they are hard to control and finally 5) they are very complex. Much is still unknown about their structure and possible operations and there are still problems with detecting how much chemical fuel has already depleted.

Other actuating nanomachines have also been demonstrated, for instance Scandinavian *nanotweezer* presents very interesting possibility in this area.

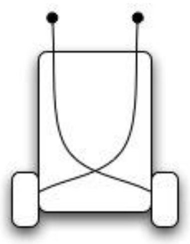
Propulsion

It seems that swimming and flying are more attractive ways for nanorobots to move than walking or crawling. Scientists are inspired by natural unicellular microorganisms and their propulsion systems to overcome liquid viscosity. One of the most profound mechanisms that evolved in nature for this purpose is undoubtedly *flagellum*. It is a lash-like (flagellum in Latin literally means whip) appendage of some prokaryotic and eukaryotic cells. By creating similar structure on the bodies of future nanorobots, we may not only achieve propulsion system able to swiftly move through the liquids but also create device capable of steering and manipulating its way through the environment. Very profound property of synthetic flagellum is that only a simple continuous rotation is needed to coil it into a helix shape and then it works just like the macroscopic motor comparable to boat engine. This simple device used in a nanorobot with functioning controllers will create agile machine able to carry out easy orders.



Control

Controllers for nanoscale robots can be implemented using emerging nanoelectronic technology. An easy to understand controlling mechanism is for example *Braitenberg's vehicle*. It is a device capable of steering towards a light source using two sensors and two motors. Left sensor is connected to the right motor and vice versa. When the left sensor sees the light it sends a signal to the right motor telling it to move faster. A result of this procedure is that the nanodevice steers just like macroscopic tanks do with their tracks.



Bacteria such as E. coli provide another example of simple control system. It moves in a series of "runs" and "tumbles". The procedure of its movement is always longer run followed by a tumble. In "tumble" stage, the bacterium rotates itself towards higher concentration of nutrients.

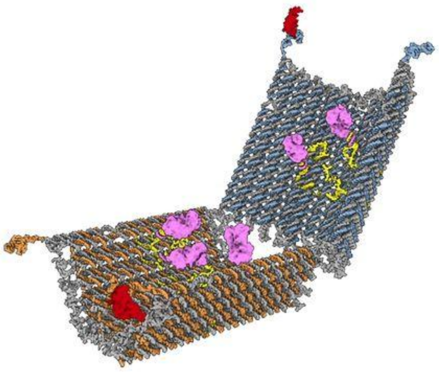
Communication

Because of the small antenna sizes it is hard to establish stable communication among nanorobots by means of waves (sonic, electrical and optical). Possible ways of communication based on what we observe in the nature are for example release of chemicals (pheromones, in nanorobotics field it is called stigmergy). This behaviour is called *quorum sensing* and it might be used for activation of a nanorobot swarm after it reaches certain amount of its members.

DNA nanorobotics

The difference between nanoelectromechanical nanorobots and their DNA counterparts lies in the structure of their bodies. While NEMS devices are composed mainly of various carbon based compounds, the only building elements in DNA nanorobotics are DNA molecules. This is due to the technique of folding DNA into arbitrary shapes called DNA origami. There are a lot of software tools for folding DNA designed for amateur users free on the Internet. The principles of these programs are utilized also in creating autonomous programmable nanodevices.

DNA nanorobotics is mainly oriented on medicine applications. The team around Professor *George Church* at the Harvard University created a cage or basket-like mechanism for transporting certain chemicals with the ability to open itself when activated by some chemical or certain event [2].



Besides their structure elements, properties of these machines remain almost exactly the same as in NEMS nanorobots.

Potential Applications

Medicine

The most anticipated applications of the nanorobotics are without any doubt healing patients with various diseases and mending wounds. The potential of such robots in medical applications is huge. It is possible that in the near future the regular health check will encompass also injecting a dose of these machines into patient's bloodstream. With specific sensors, they will be able to distinguish various pathogens and send the data about health condition to the doctor for immediate selection of appropriate treatment. The robots will then either safely disintegrate or remain patrolling the body in order to find any abnormality that might later appear and inform the patient about it.

Professor Church conveys that nanorobots will be very potent also in healing cancer. We already have very powerful drugs for such a task but they have been withdrawn from the use because they jeopardize healthy cells. Searching for more effective drugs without mechanisms for their safe propagation through the body is therefore a dead end road. *Ido Bachelet* from Hebrew University in Jerusalem compare this endeavour to attempting to invent guns that only kill the enemy which is much more complicated than training a specialized weapon wielding squad. This is a nice analogy to a swarm of nanorobotic units localizing the tumour cells based on specific markers and injecting the drugs right into them. The whole swarm can be controlled with a variety of different controllers. When connected to *Kinect sensor* (videogame controller by Microsoft that is scanning body motion), it is possible to destroy cancer just by simple hand gesture [3]. *Arthur C. Clarke's* quote: "Any sufficiently advanced technology is indistinguishable from magic." applies to this kind of healing perfectly.

Another very profound property of nanorobots is the ability to cooperate within the swarm. This might help to repair mechanical damages in living organisms. For example damaged spinal cord can be mended by a group of connecting nanodevices on the both sides of the damaged tissue. After that, they apply growth factors and start to heal this deformity. When the spinal cord is complete again, it is possible to restore feeling to paralyzed limbs.

Even though nanorobots that circulate in a bloodstream of a patient will provide very convenient way for stabilizing his/her health condition, the question appears whether this treatment will be secure from outside attackers.

Warfare

It is not a secret that almost every promising technology is either developed entirely or to some extent used for army purposes. Nanorobotics is not an exception. Hollywood entertainment studios used the idea of nanoscale military device threat in various ways. The most interesting feature of these machines for army is their ability to decompose almost every material on molecular scale. Invisible swarms of nanorobots travelling through the air may pose a serious danger to enemy structures and victorious advantage to the side in control of these machines.

Social influence

Although nanorobots have potential application in military, they can be used much more diplomatically. Michio Kaku suggests that this is the first technology able to get humanity rid of poverty. After a progressive research in this area, we can achieve nanolevers and other tools capable of rearranging atoms of material to another material.

One episode of Star Trek series narrates a story about people who had had themselves frozen in the 21st century in order to prevent themselves from dying from incurable diseases of that time and were unfrozen and healed by the Enterprise starvessel crew in 23rd century. One of the people then asks about his money. No member of the crew knows money because in the world of 23rd century when somebody wants something he/she just asks for it and gets it. According to Kaku, this state of society can be achieved with nanorobotics. Questions emerged immediately what would be a motivation for the people in the era of abundance without money. It is understandable that introduction of this technology would need a social revolution and reconsideration of traditional human values [4].

Conclusion

Nanorobotics is extremely ambitious discipline of nanotechnology with possibility to influence almost every aspect of our future lives. *Ray Kurzweil* assumes that in the year 2020 it will become everyday reality for us to alter our performances with bloodstream full of nanodevices. Some people still consider this possibility of technological development to be deplorable because it might provide potential criminals with yet unimaginable ways to harm others. The concerns are in some measure legitimate, it would be really naive and unintelligible to think that nobody would find some way to abuse these technologies to perpetrate crime. On the other hand, the idea of machines healing cancer with such simplicity is more than tempting and thus the research in this area will undoubtedly continue.

Sources

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