Applications of robotics in dentistry and medicine - A review.

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Abstract

Purpose: The present review paper deals with the various and vast applications of robots and the discipline of robotics, by highlighting the variations in the design and configuration of robots and focusing a glimpse on the molecular level systems.

Data Sources: The electronic databases (PubMed), ClinicalTrials.gov, EBSCO (dentistry and open science access), Scopus, Web of Sciences, Cochrane database were searched to retrieve all data related to Nanotechnology and Dentistry and Medicine.

Study Selection: The grey literature (Google scholar) was searched on 18th September 2021 and updated till 15th October 2022. The following keywords were utilized for data collection: "Nanotechnology OR "[All Fields] AND "DENTISTRY" [All Fields]. The search was complemented by hand-searching of the reference lists of included articles and performing a citation search for any additional reviews. Articles written only English were included.

Data extraction: All invitro, and in vivo studies including observational studies (cohort, case-control, cross-sectional), experimental and randomized and non-randomized analytical studies in humans or animals, letters to the editor or case series (with any patient-related information or data), case reports, literature reviews, editorials, book reviews were reviewed. The results of the searches run on the above-mentioned databases were compiled in the Mendeley reference manager (version 1.19.4) and duplicates were removed. Two members of the team (A.B, R.R) independently screened the articles to exclude those that do not meet the eligibility criteria.

Results: With the advent of technology, the new era has witnessed an amalgamation of nano-robotic devices and the macro-world. There might be an existence of subtle scale differences in the working algorithm of nano & micro robots, but many similarities exist between the design, software, and working principle of these two robotic systems.

Conclusion: This review paper gives a projection of the two main types of robotic algorithms and the same is illustrated with relevant examples. The applications of nano-robotic systems are vast and widespread. The literature review shows only a few papers discussing the configuration of these nano-robots and listing the same applications in medicine and dentistry. Hence, this paper focuses on the applications in medicine and dentistry.

Keywords: Dentistry, Medicine, Nanorobotics, Micro robotics.

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Introduction

"Nanotechnology- a fiction" - "nanotechnology- a reality." The multidisciplinary approach combining the technology of computer science as well with the field of engineering comprises the discipline of robotics. The design, construction, operation, and use of robots, all together comprise the branch of robotics. The main objective behind the surge in research in the field of robotics is to create machines that will help and assist humans and will mimic human intelligence by the terminology of artificial intelligence (AI).

Multiple works at minimal scales can be performed with the help of nano-robots, for example, minimally invasive diagnostic procedures, targeted and local drug delivery, and surgery focused on a particular site. One of the major transformations that the field of robotics has witnessed is the shift from hard structures to soft architectures. Flexible microorganisms and their vast scope have inspired researchers around the world to develop small-scale miniaturized parts such as hinges, distinct types of joints, actuators and their composite machineries, sensors, and reservoirs to create soft micro- and nano swimmers. More complex organic structures such as improved and more technically sound locomotion strategies and shape changes in response to stimuli are being integrated with nano-robots with the advent of technology.

In this review paper, various dimensions of soft nanorobots have been described in words of their structure and orientation, and their locomotion technologies and uses have been thoroughly illustrated.

Research in the branch of robotics at the dimension of nanometer along with the identification and discussion in depth, regarding the size of robots in nanoscale, i.e., nanorobots (which needs yet considerable research), and massive scale robotic machineries with the potential of operating structures and machineries at the nanoscale is called Nanorobotics.

There happened a change from just thinking about Nanotechnology to making it practically feasible. The shift from "Nanotechnology- a fiction" - "nanotechnology- a reality".

Two major achievements made this change possible, which were based more on science rather than being entirely conceptual. Binnig and Rohrer in 1981, discovered for the first-time scanning tunneling microscope (STM) which became a landmark in identification of discrete atoms. It had some limitations which were improved by inventing the microscope based on the principle of forces of atom which could be imaging structures which are non-conducting, for example, molecules and particles which are organic in nature. Research with buckyballs comprised of carbon, conducted at The Rice University in 1985-1986 as well as with nanotubes made of carbon formed the basis of the improvements in the field of limitations of nanotechnology.[1] These discoveries were the main scaffold for the invention of "Nanotechnology," which provided the framework for robotics or nanorobotics to evolve.

There is an ardent desire for man to continue researching and creating technologies and materials with better-improved properties, being equally still pursuing and long-lasting, Nanotechnology has the potential of fulfilling this desire with the simple ability to change the way the atoms or molecules are attached. [2.3]

Incorporating all these technologies, as science advanced the world witnessed a new era – An era of nanotechnology – nanorobotics!! the prefix "nano" is derived from the greek word "dwarf." So, Nano Science refers to Nano and the discipline & Nanotechnology- the applied aspect of it. The scale is referred to as the Nanoscale or Atomic scale or Molecular scale. The word was initially coined by famous scientist, Norio Taniguchi in the year 1974, although mass popularity took some more time. K. Eric Drexler, motivated by this concept, later in 1986 coined the term nanorobotics.[4]

Discovery of scanning tunneling microscope and nanotubes comprised of carbon and fullerenes made nanotechnology widely accepted by 1990. Nanotechnology corresponds to science of manipulation of single atoms, and not groups of atoms. A wider scope of nanotechnology with increased zones where it finds its role in the healthcare industry includes structures at the combined atom level up to about 100 nm. The potentiality to manipulate structures at the molecular level (with characteristic length scales of 1–100 nm) and the capacity to combine such technology with the newest types of machinery for medicine, dentistry, and other industries are two of the signature definitions and aspects of nanotechnology, nanoscience, and nanorobotics.

Structure & composition of nanorobots

Nanorobots are scaled-down devices ranging from 10-100nm.[2] Carbon, in various anatomies like fullerene or diamond nanocomposites forms the basis of the structure. There occurs incorporation of other light elements such as Hydrogen, Sulphur, Oxygen, Nitrogen, Fluorine, and Silicon as nanoscale gears. The diameter of the nanorobots ranged from 0.5-0.3 microns. They have a spider-like configuration with the incorporation of several structural parts as (Figure 1):

Manipulator's gripper - The main function of the manipulator's gripper is to grasp the object of manipulation, hold the object of manipulation during the process of manipulation, and release the object at the desired destination. They can be broadly classified into broad types: active and passive grippers. The main difference between an active and passive gripper is that the former requires constant application of force and pressure, where-as the later uses considerable amount of energy at the time of discharge. Because of the configuration and the mechanism of action, it requires objects with flat surfaces or flat objects. One type of a robot end effector is called adhesion gripper which attaches to structures by adhering to those structures. The earliest type of this gripper consisted of a particular dimension of rod, sphere, various other solid structures wrapped with the use of double-sided tape. The most emerging subject in the present world is the advent of soft grippers. They consist of four fingers which are attached, and a finger is also attached which helps in attaching the gripper to the robot (Figure 2a and 2b).[5]

Telescopic micromanipulator - Robotic micromanipulators demand micromanipulation with a sub-micrometer resolution at a reference position and a radius of proposition that equals to hardly-any millimeters. They are necessary to manipulate objects in millimeters and localize a viewing area with an optical microscope to cover a field of view under one which equals either few micromilleters or is even smaller. DC (Direct Current) micromanipulators are loops (close-controlled) and those operated by AC (Alternate Current) motors are open-controlled loops. There is a commercially available stepper motor micromanipulator that has a resolution of .002 - .005 micrometer (Figure 3).[6]

- **Nanomanipulator** - There occurs vertical projection from the main body of the robot which has a dimension of about 0.2 microns and serves and functions as the nanomanipulator. It has the function of detecting and grasping finer resolutions which at times may go unnoticed by the micromanipulator.

- **Main nanomanipulator** - Lateral to the origin of the nanomanipulator from the body of the robot, there occurs another slender projection facing the apex of the robot interface which has an inbuilt nanomanipulator that functions as the principal recognition face worded as the main nanomanipulator.

- **Biomolecular nano sensor** – A device which uses biological identification structures or bioreceptor (e.g., a protein, a nucleic acid, an antibody or antigen on the surface structures, an enzyme, cells, tissues, or complete organisms) and a signal transducer is called a bio-sensor. Once the analyte interacts with the biosensor, a configurational change in the complex is converted into a change that the transducer can measure. The most common types of biosensors are based on antigen-antibody reactions, nucleic acid interactions, enzymatic reactions, cellular interactions, and interactions using biomimetic materials (synthetic receptors). Among the signal transduction methods used, the most common are optical, electrochemical, and mass-sensitive measurements. Antibody-based biosensor, used for the identification of benzo pyrene tetrol (BPT) - a marker used for the diagnosis of human carcinogen Benzo[a]pyrene (BaP), remains the most primitive application in the discipline of biologically mediated sensors.[7]

- **Acoustic sensor** - Acoustic sensors and devices creates a wave of sound with the use of materials that works on the principle of piezoelectricity. An oscillating electric field is produced by these piezoelectric acoustic wave sensors which in turn results in formation of mechanical waves that travels along the medium, which is then reverted to an electrical field used to measure and analyze. However, with the development, the use of acoustic sensors is not only limited to detecting sounds. Recently, they are increasingly used to detect mechanical vibrations in a solid medium to fabricate sensors as in microbalances and surface acoustic–wave (SAW) devices. now comes, another word referred to as “acoustic location.” so, this is the use of sound to approximate the distance and direction of the source and the reflector. It can be done either actively or passively.

- **Environmental sensor -** Dental nanorobots also have in-built environmental sensors which have the potential to move through a predetermined path to mark or map the data like a navigation stack. They also include sections that determine the humidity sensor, temperature sensor, and a sensor for locating different gases like CO, methane, propane, and LPG.

- **Dipole antenna - Heinrich Hertz** is attributed to the discovery of dipole antennas. A dipole antenna is a remarkably simple and basic design type of radio antenna that consists of a conductive wire rod that is equal to half the length of the maximum wavelength the wire must generate. There is a split in the middle of a wire rod and the two sections are separated by an insulator. Now, this dipole antenna produces horizontal polarization. So, horizontal polarization means this form of polarization has horizontal elements attached to it. So, it only catches and radiates horizontally polarized signals which signifies an electromagnetic plane with an electric field in the horizontal plane. Dipole antennas are more frequently referred to as resonant antennas. The is the most used antenna by virtue of its dominance is the half-wave dipole antenna. The half wavelength resonant frequency real part of the impedance should be 73 ohms, and the imaginary part should be 42.5 ohms.[8]

- **Link-up connector -** The rigid members connecting the joints are referred to as links. These joints, also called the axes, are the movable components of the robot which help create relative motion between adjacent links.

- **Locomotion flagella -** Like flagella as seen in bacterial species, there are flagella-shaped structures that facilitate the robots to move around from one site to the other. Bi-directional pistons can be used to move around the robots. All the functions in relation to things attached to the circuit are controlled by the computer installed within the robotic structure. In-order to displace the robot, all the switches are switched on by the computer. As a stated distance is covered by the robot, there occurs minimal displacement or one full turn of the slotted wheel. The displacement or the turn depends upon the robotic configuration. Steady tangential displacement and oscillations of minor amplitude are the two basic motions. They somehow resemble the common motion of microorganisms based on flagella or cilia, which leads to fouling due to large exposed surface area. These robots do not require covering extensive distances and hence are called Self-propelled robots. They could travel through a few 100 microns by Injection conversely by Passive flow.

- **Flagella pneumatic connector -** These are oval-shaped knob-like projections that are found at the end of the locomotion flagella. These enable the creation of a vacuum and help the robots to get organized on the surface of the desired object with proper stability.

- **Nanomanipulator's sites –** These are the structures found at the apex of the body of the robot, which serve as points of origin of the nanomanipulator.

TECHNIQUES OF NANOROBOTS

The principle of nanotechnology incorporates two major techniques[9]:

1. **Top-Down Technique** – The main mechanism that this technology relies on is to create minimalized and small devices with the help of larger cones. Hence, to make small features, it is initially started with massive scale particles to make precise dimensions and patterns of nanoscale. However, sometimes structures miniaturized to nanoscale can vary from their original properties which enables unique applications. As there occurs a decrease in size, there is a generalized rise in surface area to volume ratio.
2. **Bottom-up Technique** – The main mechanism that this technology relies on is the creation of composite structures by aggregating smaller components. These techniques are widely used today in various fields. They are much more reasonable compared to top-down techniques, but the only disadvantage is the complex architecture which is primarily because of the increase in size.

Mechanism of action

So, the mechanism of action of these robots is remarkable to GPS (Global Positioning System) devices which we use regularly in our lives. It is a navigation device that keeps track of all these nanorobots. These distinguish one type of cell from the other by analyzing the antigens present on the cell's surface, which helps them distinguish between self- and non-self-cells. An especially important property of these nanorobots is that they are safely auto-deactivated once they are swallowed or start too dysfunctional (Figure 4 and 5).

Nanorobotics in Dental Science:
Nanotechnology has vast scope in different branches of Dentistry starting from diagnosis, and assessment to a proper treatment plan.[2]

- **Dentinal Hypersensitivity management** – With the use of dental robots, there is selective tubule occlusion technology, that occludes dentinal tubules in minutes and gives relief to patients.
- **Nanorobotic Dentifrices -** Dentifrobots as mouthwashes & toothpaste. Move fast and safely deactivated when swallowed
- **Local Drug Delivery -** Triclosan loaded nanoparticles by emulsion-Diffusion process is used for treating diseases of the periodontium. Time release of the drug occurs from biodegradable materials.
- **Bone Grafts –** Nanostructure forms the scaffold of Nano bone. Nanoscale particles are used to create alloplastic bone graft materials. One example of such type of bone graft is Nano-HAP bone grafts. These grafts are commercially marketed in various forms like titanium modified, crystalline and reinforced with chitosan.
- **Implants -** 1. The change in the surface topography of implants
- With the change in surface topography, there is improved rate of attachment and adherence of peripheral tissues, increasing the rate of osseointegration.
- **Imaging -** Pygelated gold nanoparticles and Surface-Enhanced Raman Scattering (SERS) form the basis of localization and detection of the tumor. There is a brighter and sharper appearance of the tumor in pegylated SERS in comparison with the quantum dots in infrared light.
- **Management of Oral Cancer –**The use of nanoshells of 120 nm diameter, with a coating of gold to kill proliferative cancer cells in mice was first used and introduced by Rice University. The main mechanism of action of these nanoshells is to bind glycoprotein to the surface of cancerous cells by adhering with antibodies or peptides to the surface of the nanoshell. Whenever the area of the tumor is irradiated with the use of an infrared laser, the temperature on the surface increases drastically, and this increased temperature is sufficient to kill the cancer cells.[10]

Nanorobotics in Medical Science:

The current treatment options in literature for determining the diagnosis, prognosis, and treatment plan of severe diseases like cancer possess various shortcomings such as poor sensitivity or specificity, severe allergic reactions to unknown medications, and various toxicities related to certain drug abuse. Hence, there was an urgent need and research produced improved ways of detection of cancers based on the use of nanoparticles. Some of the nanoparticles used for diagnosis include paramagnetic nanoparticles, quantum dots, nanoshells, and nanosomes. Also, the concept of nanotechnology acts as a boon in reducing the toxic potential of certain drugs. They act at the desired site of action by various mechanisms. Killing of cancer cells using heat with nanoshells and gene therapy, shows promising as a treatment modality. However, to date, there is a concern regarding the safety index of these nanomaterials. Nevertheless, Nanomedicine holds encouraging prospects as treatment options of a wide range of conditions and paves path for future research. Research is ongoing in a hope to develop medicine carrier systems, using the principle of nanotechnology for serious health issues like carcinomas, diabetes mellitus, infections of fungal, bacterial, and viral origin, gene therapy. One of the major upper hands in treating diseases incorporating nanotechnology is specific site of action of the drug and a more shielded drug dosage. Nanotechnology has gained importance in diagnostic medicine.[11]

Conclusion

The most important defiance for systems incorporating nanotechnology are the manipulation of substance at the molecular scale and influence the way these machines work. This field of nanomedicine is still in its inception stage and plenty of research scope is still there. The urge to develop newer treatment modalities using nanotechnology has led researchers to produce the concept of bio nanorobotic systems.

Nanorobots/ Molecular robots have a propitious future. Research is set to witness the amalgamation of various streams including robotics, mechanical, chemical, and biomedical engineering, life sciences and mathematics to create fully automatic machineries. To achieve this feat, challenges will arise. The research will look forward to addressing some of the limitations of this technology and producing a complete bio-nanorobotic ecosystem.

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FIGURES

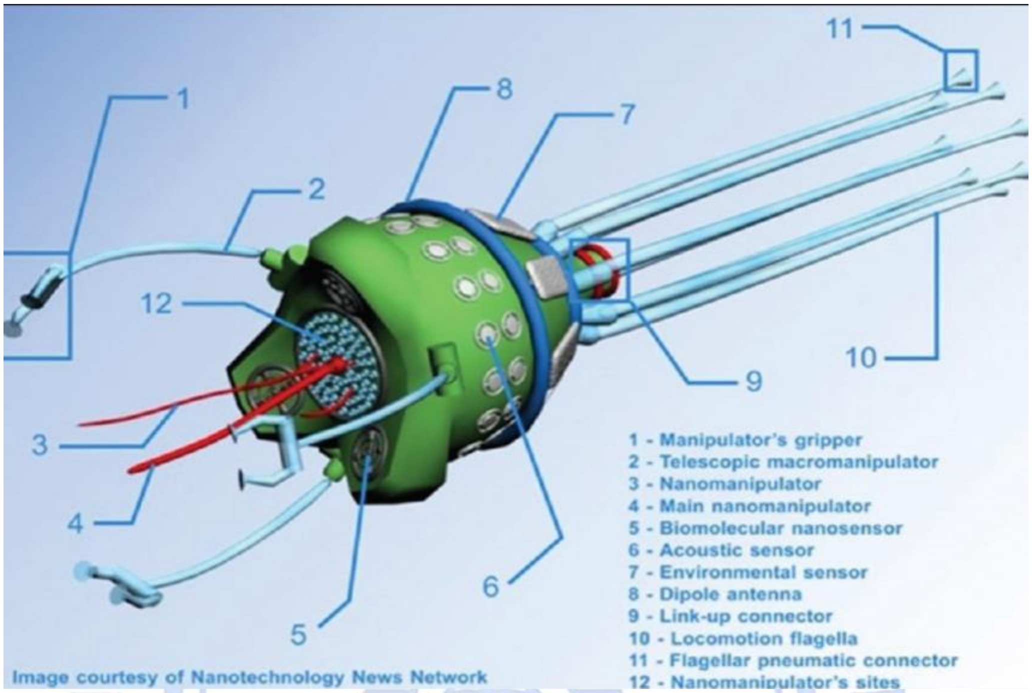
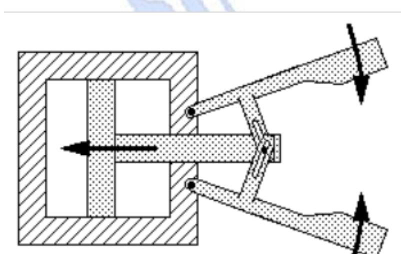


Figure No. 1



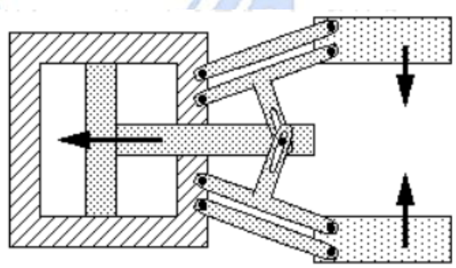
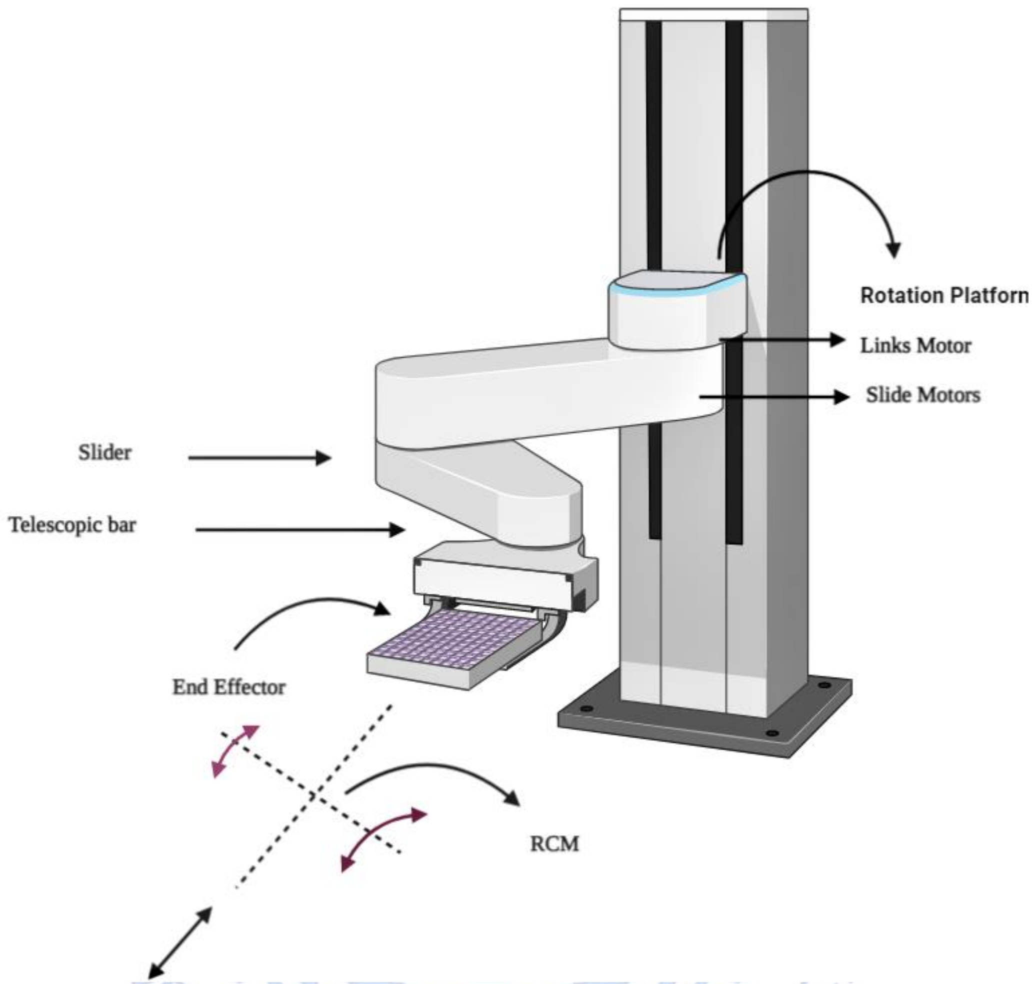


Figure No. 2a

Figure No. 2b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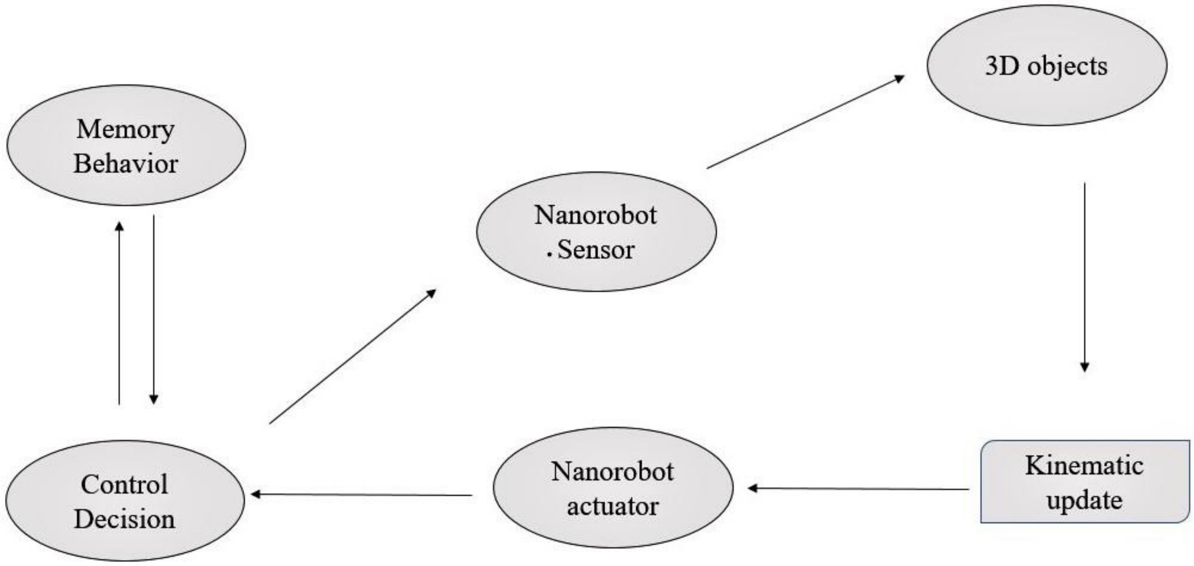
Telescopic bar
End Effector
RCM

Figure No. 3



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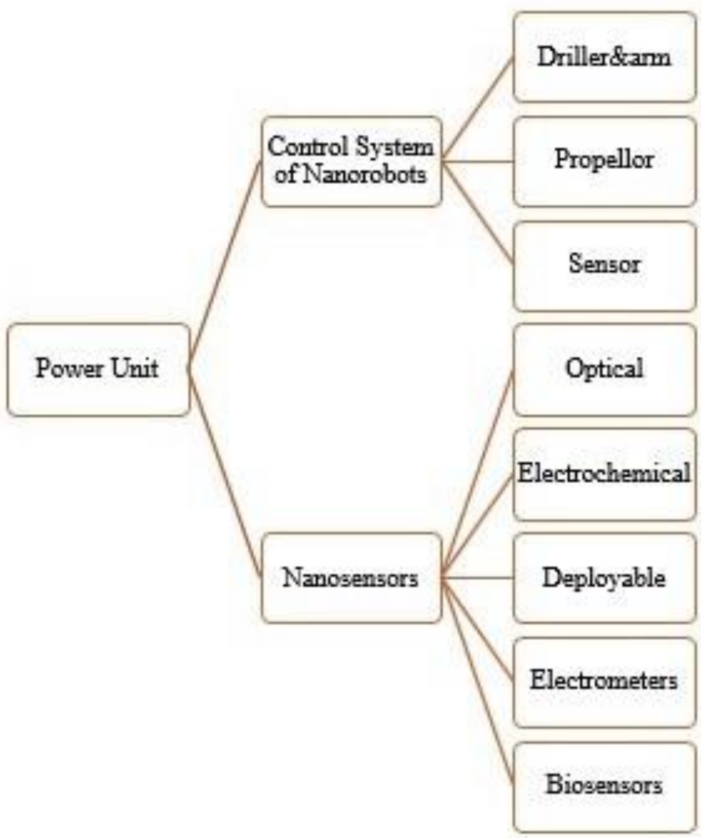

Figure No. 5