Robots in Surgery

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Topics Covered

1. Abstract

A new era on medicine are expected to happen in the coming years. Due to the advances in the field of nanotechnology, nanodevice manufacturing has been growing gradually. From such achievements in nanotechnology, and recent results in biotechnology and genetics, the first operating biological nanorobots are expected to appear in the coming 5 years, and more complex diamondoid based nanorobots will become available in about 10 years. In terms of time it means a very near better future with significant improvements in medicine. In this work we present a practical approach taken on developing nanorobots for medicine in the sense of using computational nanomechatronics techniques as ancillary tools for investigating manufacturing design, nanosystems integration, sensing and actuation for medicine applications. Thus the work describes pathways that could enable design testability, but also help scientists and profit corporations in providing the helpful information needed to test and design integrated devises and solutions towards manufacturing biomedical nanorobots.

2. Introduction

The use of robots in surgery has provided additional tools for surgeons enabling minimally invasive intervention or even long distance tele-operated surgeries [1]. Indeed we may trust on human creativeness and technical capabilities that can ever be improved in terms of technical achievements [2], [3], [6]. In recent years the medicine has enabled significant wellness for the life quality and longevity of the world population [11]. And for the coming years, we may be prepared to experiment even more benefits, as results from advances that are being pursued step by step in new fields of science, such as nanobiotechnlogy [9], [13]. With the expected miniaturization of devices provided by several works on

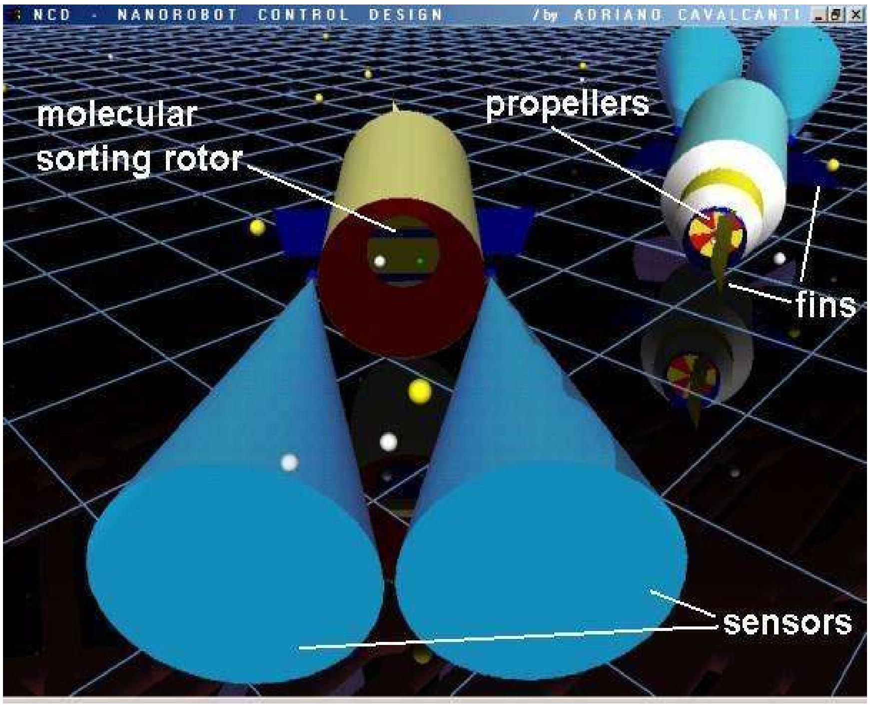

Figure 1. The depicted blue cones shows the sensors "touching" areas that triggers the nanorobots' behaviors.

nanoelectromechanical systems (NEMS), nanomanufacturing has actually become a reality [12], [14].

Hence, with the NEMS recent advances on building nanodevices, and the development of interdisciplinary works, altogether may be translated in few years through the development of integrated nanomachines, also known as nanorobots. With the use of techniques that are advancing rapidly, such as nano-transducers [22], [5], and biomolecular computing [2], [13], nanorobots are expected to be able to operate in a well defined set of behaviors performing pre-programmed tasks [7], [4]. Thus in the coming few years, nanorobots being tele-operated to perform surgery, or even nanorobots continually supervising the human body in order to assist organs that may require some kind of repair, is one of the most expected revolutionary tools for biomedical engineering problems.

The development of nanorobots is an emerging field with many aspects under investigation. Simulation is an essential tool for exploring alternatives in the organization, configuration, motion planning, and control of nanomachines exploring the human body. The work we have been done concentrates its main focus on developing nanorobot control and design applied to nanomedicine. Nanorobot applications could be focused mainly on two major areas, as follows: nanorobots for surgical interventions, as well as their utilization for patients that need constant monitoring. The nanorobots require specific controls, sensors and actuators, basically in accordance with each kind of biomedical problem.

Advanced simulations can include various levels of detail, giving a trade-off between physical accuracy and the ability to control large numbers of nanorobots over relevant time scales with reasonable computational effort. Another advantage is that simulation can be done in advance of direct experimentation. It is most efficient to develop the control technology in tandem with the fabrication technologies, so that when we are able to build these devices, we will already have a good background in how to control them.

We propose computational mechatronics approaches as suitable way to enable

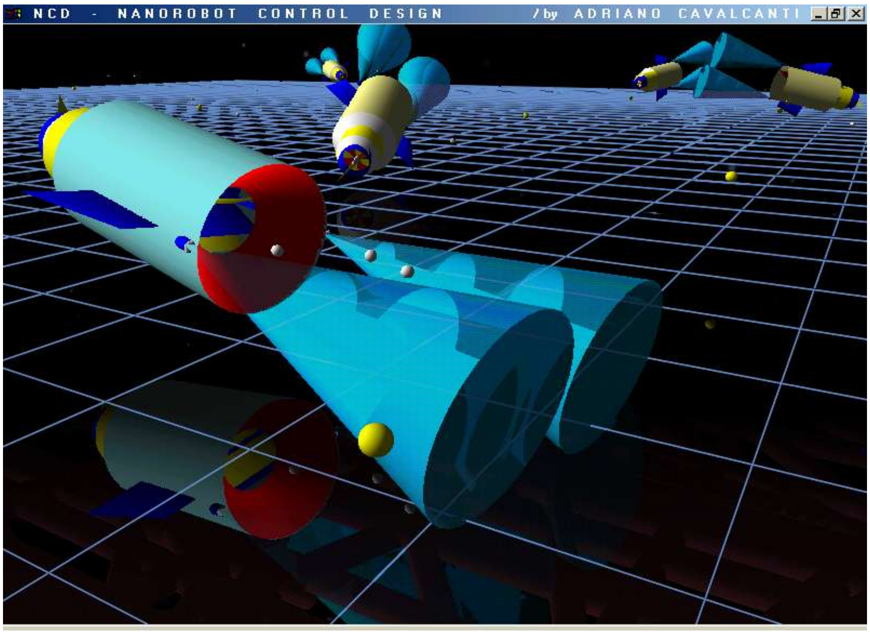

Figure 2. Rendering schematically the nanorobot sensors' collision detection for chemical signals molecular identification.

the fast development of nanorobots operating in a fluid environment relevant for medical applications. Unlike the case of larger robots, the dominant forces in this environment arise from viscosity of low Reynolds number fluid flow and Brownian motion and such parameters are been implemented throughout a set of different investigations. We have been developing practical and innovative paradigms based on the Nanorobot Control Design (NCD) simulator that allows fast design testability comparing various control algorithms for nanorobots and their application for different tasks. Also such information generated by the NCD can be useful as parameters for building nanodevices, such as transducers and actuators.

3. Nanorobots for Medicine

In future decades the principal focus in medicine will shift from medical science to medical engineering, where the design of medically-active microscopic machines will be the consequent result of techniques provided from human molecular structural knowledge gained in the 20th and early 21st centuries [11]. For the feasibility of such achievements in nanomedicine, two primary capabilities for fabrication must be fulfilled: fabrication and assembly of nanoscale parts. Through the use of different approaches such as biotechnology, supramolecular chemistry, and scanning probes, both capabilities had been demonstrated to a limited degree as early as 1998 [11]. Despite quantum effects which impart a relative uncertainty to electron positions, the quantum probability function of electrons in atoms tends to drop off exponentially with distance outside the atom. Even in most liquids at their boiling points, each molecule is free to move only ~0.07 nm from its average position [11]. Developments in the field of biomolecular computing [2] have demonstrated positively the feasibility of processing logic tasks by bio-computers [13], a promising first step toward building future nanoprocessors with increasing complexity. There has been progress in building biosensors [22] and nanokinetic devices [21], [3], which also may be required to enable nanorobotic operations and locomotion. Classical objections related to the feasibility of nanotechnology, such as quantum mechanics, thermal motions and friction, have been considered and resolved and discussions of techniques for manufacturing nanodevices are appearing in the literature with increasing frequency [14].

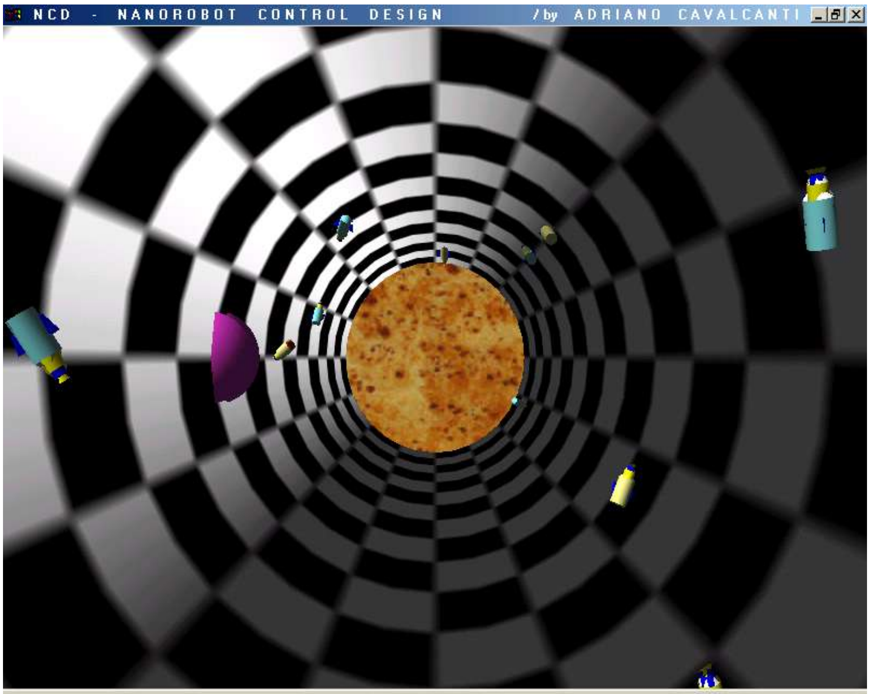

Figure 3. Textured vein inside view without the red cells. The tumor represented by the pink sphere is located left at the wall. All the nanorobots swim near the wall searching for the abnormal tissues.

4. Motivation

One important challenge that has become evident as a vital problem in nanotechnology industrial applications is the automation of atomic-scale manipulation. The starting point of nanotechnology to achieve the main goal of building systems at the nanoscale is the development of control automation for molecular machine systems, which could enable the massively parallel manufacture of nanodevice building blocks. Governments all around the world are directing significant resources toward the fast development of nanotechnology. At least 30 countries have initiated activities in this field, and beyond that, with government investments to nanotechnology of US$ 800 million in Japan and US$ 774 million in USA [19]. The U.S. National Science Foundation has launched a program in "Scientific Visualization" [18] in part to harness supercomputers in picturing the nanoworld. A US$ 1 trillion market consisting of devices and systems with some kind of embedded nanotechnology is projected by 2015 [16], [10]. More specifically, the firm DisplaySearch predicts rapid market growth from US$ 84 million today to $ 1.6 billion in 2007 [17]. A first series of commercial nanoproducts has been announced as foreseeable by 2007. To reach the goal of building organic electronics, firms are forming collaborations and alliances that bring together new nanoproducts through the joint efforts of companies such as IBM, Motorola, Philips Electronics, Xerox/PARC, Hewlett-Packard, Dow Chemical, Bell Laboratories, and Intel Corp., among others [12], [17]. For such goals, new methodologies and theories to explore the nanoworld are the key technology [9].

5. Developed Simulations

A useful starting point for achieving the main goal of building nanoscale devices is the development of generalized automation control for molecular machine systems which could enable a manufacturing schedule for positional nanoassembly manipulation. In our work we consider more specialized scheduling problems with a focus on nanomedicine: describing in a detailed fashion the nanorobot control designs and the surrounding virtual workspaces modelling that

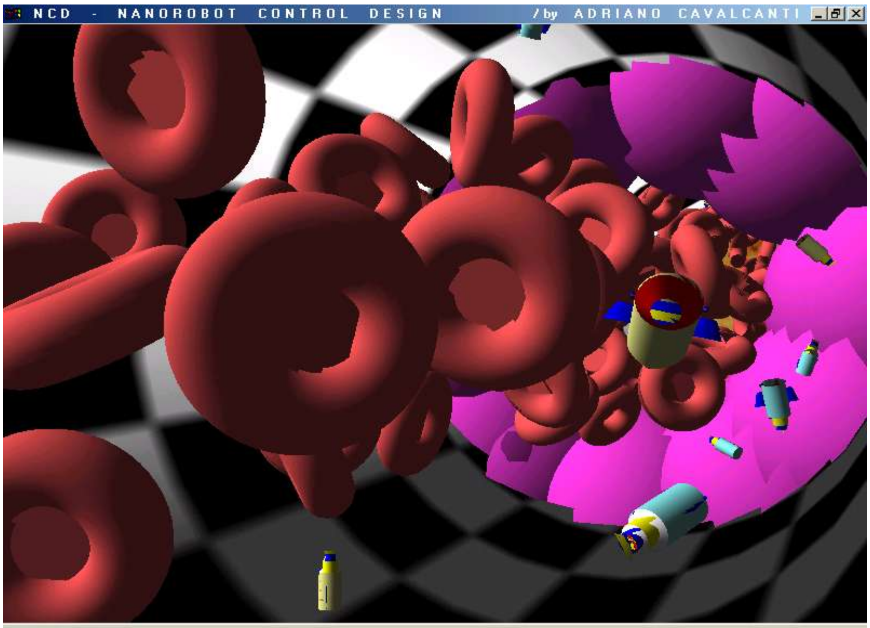

Figure 4. View of the NCD simulator workspace showing the cardiovascular occlusion, red blood cells and nanorobots.

are required for the main kinematics aspects in the physically-based simulations (figure 1). Here the biomolecular assembly manipulation could be automatically performed by smart agents, which are given a set of possible tasks for biomedical engineering problems, embedded in a complex 3D environment. Virtual Reality could be considered as a suitable technique for nanorobot design and for the use of macro- and micro-robotics concepts given certain theoretical and practical aspects that focus on its domain of application.

The collective nanorobotics approach proposed is one possible method to perform a massively-parallel positional nanoassembly manipulation (figure 2). We constructed and demonstrated the applicability of multi-robot teams in timely sequenced set of works with practical applications that could enable the establishment of generalized control guidelines for nanorobotics. The use of multi-robot teams working cooperatively to achieve a single global task applied to nanotechnology is a field of research that is very new and challenging [8]. Research on collective robotics suggests that we should consider emulating the methods of the social insects [20] to build decentralized and distributed systems that are capable of accomplishing tasks through the interaction of agents with the same structures and pre-programmed actions and goals. Thus a careful decomposition of the main problem task into subtasks with action based on local sensor-based perception could generate multi-robot coherent behaviors [15]. Several techniques was applied for such aims, as Neural Networks algorithms [4], Evolutionary computation [7], chemical based sensors and actuators (figure 3) [5], and even temperature time-gradients (figures 4 and 5) [6], just to quote a few.

Among other interesting nanorobot applications, we could foresee their use to process specific chemical reactions in the human body as ancillary devices for injured organs. Nanorobots equipped with nanosensors could be used to detect glucose demand in diabetes patients. Moreover, nanorobots could also be applied in chemotherapy to combat cancer through superior chemical dosage administration, and a similar approach could be taken to enable nanorobots to deliver anti-HIV drugs [11].

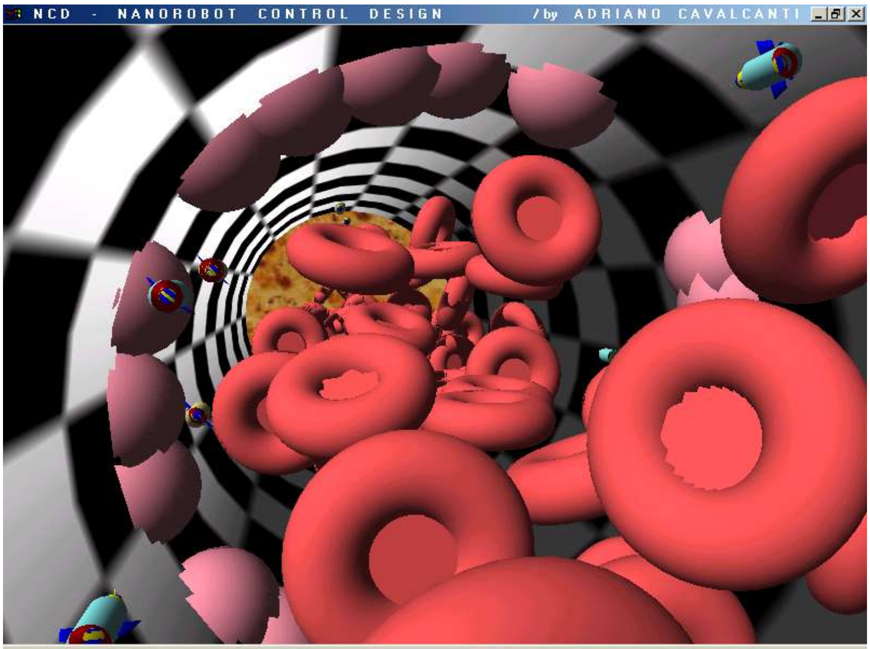

Figure 5. The atherosclerotic lesion was reduced due nanorobots activation. The temperatures in the region turn in expected levels.

6. Conclusion

Successful nanorobotic systems must be able to respond efficiently in real time to changing aspects of microenvironments not previously examined from a control perspective. Unlike some prior simulators for simple robots, in the present work we have developed nanorobots that are not restricted to a fixed grid nor behave as simple cellular automata with very simple environments. Also by contrast, most CAD approaches provide only animation or visualization tools, while the NCD is a physically-based simulator.

The set of experiments we have carried out include the main physical properties existent in the environment where the nanorobots are being currently projected to be operating in the coming years. Hence the majority of results from our investigation should be useful as well on analysing integrated manufacturing capabilities. In fact, including aspects of the physical environment in conjunction with graphical visualization provide a feasible approach for automation and control design. Furthermore, the architecture that was developed intended to enable the incorporation and evaluation of several control methods and distinct nanorobot shapes analyses.

The automation, control, and manufacturing of nanorobots is a challenging and very new field. Realizing revolutionary applications of nanorobots to health or environmental problems raises new control challenges. The design and the development of complex nanomechatronic systems with high performance should be addressed via simulation to help pave the way for future applications of nanorobots in biomedical engineering problems.

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