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Nanorobot: Modelling and Simulation

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Abstract

This research addresses the state of the art in nanorobot design and simulation focusing on the leukemia disease as well as ongoing applications on addressing the challenges posed by cancer treatment, especially chemotherapy. Nanotechnology and cancer biology, along with a new concept to leukemia treatment are the basis for nanorobot design. Robot architecture consists of Body, Ultrasonic Sensors, Folate material and Flagellas Nanorobot motion planning is done based on path constraint and attachment constraint in blood cells. A free camera is located in the blood vessel and it will move inside the blood vessel in order to determine the path and it is followed by shining of near infrared laser beam on to the blood vessel using lens effect filter for attachment of desired objects. The glow color is used to identify the object and color gradient is applied for the reaction.

1. Introduction

Nanomedicine offers the prospect of powerful new tools for the treatment of human diseases and the augmentation of human biological systems. Diamondoid-based medical nanorobotics may offer substantial improvements in capabilities over natural biological systems, exceeding even the improvements possible via tissue engineering and biotechnology. Nanorobots with completely artificial components have not been realized yet. The active area of research in this field is focused on molecular machines, which are thoroughly inspired by the nature's way of doing things at nano-scale.

One example of the application of nanotechnology in medicine is the nanomedical device known as respirocytes, designed by Feyman in 1995-1996 [1], [2], [3]. He intends to duplicate all the important functions of the most common cells in the human body, the red blood cell. The respirocytes are artificial red blood cells comprising of microscopic diamondoid pressure tanks that can be operated up to 1000atm of pressure. This cell is a hollow, spherical nanomedical device of 1 micron in diameter, much smaller than red cells. The respirocyte is built of 18 billion precisely arranged structural atoms, and holds an additional 9 billion molecules when it is fully loaded. It consists of three main storage tank; one for oxygen (up to ~1.5 billion molecules), another for carbon dioxide (up to ~1.5 billion molecules) and a third tank for ballast water (up to ~6 billion molecules), constructed with diamondoid honeycomb. It is designed to work in a way that it can carry more than 200 times more respiratory gases than an equal volume of natural red blood cells.

Another interesting example of a simple nanorobotic application that provides a unique superbiological capability is the clottocyte, artificial mechanical platelets [4], [5]. The clottocytes are able to function just like any other platelets. However, the artificial platelets could stop human bleeding within 1 second of physical injury even in moderately large wounds. Clottocytes may perform a clotting function that is equivalent in its essentials to that performed by biological platelets, but at only 0.01% of the bloodstream concentration of those cells or 20 nanorobots per cubic millimeter of serum. In other words, nanorobotic clottocytes response would be around 10,000 times more effective as clotting agents than an equal volume of natural platelets.

The scope of this research is confined to nanomedical robots, in which the main objective is to provide a new alternative to chemotherapy treatment as a cure to leukemia. The mechanisms of leukemia, including the signs and symptoms, causes, the various treatments available as well as the sufferings of numerous side effects due to those treatments have to be well understood. Another research that is needed to be done is the concepts behind working principals behind nanorobots. Currently available conceptual nanorobots in the medicine field are used as reference, taking into accounts the assumptions made during the modeling stage. Selection of nanomaterials used in every parts of the nanorobot is essential and it is widely addressed. The key phase of nanorobot development is the navigation of the nanorobot inside the human body, removal of nanorobot from the human body and as well as its power source.

2. Blood components

Blood is much more than the simple liquid that it seems to be. It is a highly specialized circulating tissue consisting of several types of formed elements (cells and cell fragment) suspended in a fluid medium known as plasma. Plasma, when separated from "whole blood" is a clear straw-coloured fluid that consists of about 90% water and 10% solutes. The termed 'formed elements' is used to designate the various kinds of blood cells that are normally present in the blood. Dissolved in the plasma are a large number of proteins, nutrients, metabolic wastes and other molecules that are transported between the organ systems. The measurement of plasma and formed elements is generally expressed as a percent of the whole blood volume. Using these measurement criteria, whole blood composition constitutes about 8% of total body weight having plasma accounting for 55% of the total blood volume and formed elements 45% [4], [5].

2.1. Formed elements of blood

The production of formed elements, or blood cells is called hemopoiesis. Before birth, hemopoiesis occurs primarily in the liver and spleen, but some cells develop in the thymus, lymph nodes, and bone marrow. After birth, most production is limited to bone marrow in specific region, but some white blood cells are produced in lymphoid tissue. Formed elements of blood are Red Blood Cells (RBCs) (erythrocytes), White Blood Cells (WBCs) (leukocytes) and Platelets (thrombocytes) [4], [5].

2.2. The Formation of blood cells

The entire process of RBC formation is called erythropoiesis. In the adult, erythrocytes begin their maturation sequence in the red bone marrow from nucleated cells known as hematopoietic stem cells, or adult blood-forming stem cells. The hematopoietic stem cell serves as the original stem cell from which all formed elements of the blood are derived. All five-precursor cells, which ultimately produce the different components of the formed elements, are derived from the hematopoietic stem cell called hemocytoblast. Adult stem cells are cells that have the ability to maintain a constant population of newly differentiating cells of a specific type. These adult blood-forming stem cells are divided by mitosis [4], [5].

2.3. Leukemia

Most blood diseases are disorders of the formed elements. Thus, it is not surprising that the basic mechanism of many blood diseases is the failure of the blood producing myeloid and lymphatic tissues to properly form blood cells. In many cases, this failure is the result of damage by drugs, toxic chemicals, or radiation. In other cases, it results from an inherited defect or even cancer. Cancer develops when cells in a part of the body begin to grow out of control. Although there are many kinds of cancer, all of them start because of the out-of-control growth of abnormal cells.

Normal body cells grow, divide and die in an orderly fashion. During the early years of a person's life, normal cells divide more rapidly until the person becomes an adult. After that, cells in most parts of the body divide, only to replace worn-out or dying cells and to repair injuries. Because cancer cells continue to grow and divide, they are different from normal cells. Instead of dying, they outlive normal cells and continue to form new abnormal cells. Cancer usually forms as a tumor. However, cancer like leukemia does not form tumors. Rather, these cancer cells involved the blood and blood-forming organs and circulate through other tissues where they grow [5].

The word "leukemia" means "white blood" in Greek. This disease usually starts in the white blood cells. It is a cancer of the blood forming tissues in which millions of abnormal white blood cells crowd out normal ones. Though usually considered a childhood disease, leukemia strikes over 25,000 adults annually, compared to 2,500 young people. Leukemia is estimated to cause 18,000 deaths annually. People of all ages and genders are at the risk for leukemia, although those with Down's syndrome and certain other genetic abnormalities tend to experience a higher incidence of this disease. In leukemia, bone marrow produces a large number of abnormal white blood cells. They look different from normal blood cells and do not function properly [5].

2.2. Chemotherapy and nanorobots

Chemotherapy is a systemic therapy, which affects the whole body by going through the bloodstream. The purpose of chemotherapy and other systemic treatments is to get rid of any cancer cells that may have spread from where the cancer started to another part of the body. Chemotherapy is effective against cancer cells because the drugs used love to interfere with rapidly dividing cells. The side effects of chemotherapy come about because cancer cells are not the only rapidly dividing cells in the body. The cells in the blood, mouth, intestinal tract, nose, nails, vagina and hair are also undergoing constant rapid division. This simply means that the chemotherapy is going to affect them too [5].

Nanorobotics defines the most innovative and intelligent biology in today's medical industry. They are miniatures fabricated with the manipulation of common elements, such as carbons and molecules. They are able to monitor diagnose and reconstruct biological structures, providing society with advanced treatments and antidotes to cure and prevent diseases, thus, making medical applications easy and effective.

The laser therapy is introduced in this research an alternative to the cancer patients to lead a better life. It is able to selectively destroy the cancerous cells without harming normal healthy cells granting the cancer patients a new hope to live normally just like any one of us. In most cases, a human patient who is undergoing nanomedical treatment is going to look just like anyone else who is sick.

3. Nanorobot modeling and design

Uncertainty plays a crucial role in nanorobotic systems. The design of nanorobotic systems requires the use of information from a vast variety of sciences ranging from quantum molecular dynamics to kinematics analysis. As the field of nanotechnology is still considered rather new, there is a lot of on going experiments and research done on the issues regarding the implementation of the nanorobot in medicine. Since nanoscale devices have not yet been fabricated, evaluating possible designs and control algorithms is required, using theoretical estimates and virtual interfaces or environments. Due to the lack of expertise and experience in this field, the development of nanorobot can only be made possible taking into account several assumptions made during the design as listed below

- *The patient had already been diagnosed with Leukemia*

As discussed, leukemia itself can be subdivided into various subtypes. Also, there is no standard treatment for all patients. Thus it is rather difficult to implement a nanorobot that is able to differentiate the type of leukemia that the patient is suffering from and the severity of the disease in the given time period. More biological knowledge and support is needed in order to make this criterion possible.

- *The nanomaterials needed in the design are available*

On going research is still being carried out in search for nanomaterials that can be used in human bodies. It is also assumed that the components of a nanorobot are made of biological components.

- *The nanorobot will not replicate*

This is to prevent the replication of nanorobots to be out of control. This may cause more harm to the patients rather than providing them with a more effective treatment. As the saying goes, too much of a good thing might not do you good.

- *The nanorobot will not react with the human body immune system*

In most cases, the body's immune system will react to any foreign matters that are introduced into the body, as its main function is to act as a protection mechanism to the body. It is specifically designed to defend the body against millions of bacteria, microbes, viruses, toxins and parasites that invades into the body. More research is needed to actually understand to what extent our body will react with the nanorobot, which is considered as a stranger to the body.

- *Primarily focusing on cancerous cells*

The main focus of this thesis is to focus on designing a nanorobot model that is able to kill cancerous cells, living the normal cells unharmed, as an alternative to chemotherapy.

3.1. The architecture of nanorobot

The architecture is based on two criteria, which are means of nanorobot navigation and methods to attach to the cancerous cells. The way a nanorobot moves in a liquid environment is the main consideration during the design. It is important that the device is able to have a smooth trajectory path while navigating in the blood environment and at the same time does not cause any damage to other cells.

Another judging criterion is the method that the nanorobot use to attach to the cancerous cells before the near infrared laser is shone. The tentacles need to have a very high responsive rate in order to move its tentacles forward just in time to capture the cancerous cell once it is detected. On the other hand, a microcomputer consisting of a miniature processor might be needed to provide a 'brain' to the nanorobot.

Therefore, the architecture proposed in this research is shown in figure 1.

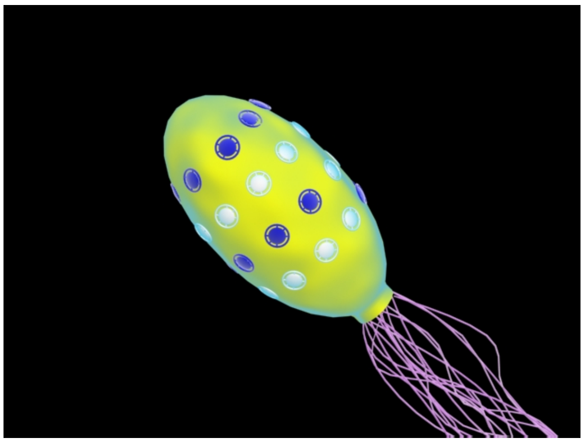

Figure 1. Architecture of nanorobot

Robot architecture consists of Body, Ultrasonic Sensors, Folate material and Flagellas as shown in figure 1.

The body of the nanorobot will be constructed from carbon nanotube due to its intrinsic property where they tend to absorb near infrared light waves, which are slightly longer than visible rays of light, and pass harmlessly through human cells. Ultrasonic sensors are attached around the body of the nanorobot for collision avoidance purposes. This is to prevent nanorobot from knocking onto each other as well as other cells in the blood vessels. Folate materials on the body of the nanorobot act as an agent that will cause the attraction of the nanorobot to the cancerous cells, which is also known as the folate-receptor cells. For modeling purposes, the folate material is modeled as an object attached to the nanorobot, rather than a coating so that the viewer can have a better visualization of the treatment process. The flagella provide the movement the nanorobot in the blood environment. It is powered by flagella motors, which is a set of rotary motor that is able to generate an impressive torque, driving a long, thin, helical filament that extends several cell bodies into the external medium. These are necessary to help the cell decide which way to go, depending on the change of concentration of nutrients in the surroundings.

The rotary motion imparted to the flagella needs to be modulated to ensure the cell is moving in the proper direction as well as all flagella of the given nanorobot are providing a concerted effort towards it. When the motors rotate the flagella in a counterclockwise direction as viewed along the flagella filament from outside, the helical flagella create a wave away from the cell body. Adjacent flagella subsequently intertwine in a propulsive corkscrew manner and propel the nanorobot. When the motor rotates clockwise, the flagella fly apart, causing the bacteria to tumble, or change its direction. The flagella motors allow the nanorobot to move at speed as much as 25 μm/sec with directional reversals occurring approximately 1 per sec.

The assembled nanorobot is roughly approximate to be within the range of 0.5 microns to 0.8 microns, taking into consideration the size of the smallest blood vessels, which is the capillary. The size of a capillary is found to be around 5 to 10 μm in diameter. Having to design a nanorobot within that range, the nanorobot can definitely navigates in the blood stream.

3.2. Modelling environmental objects

Modeling the nanorobot itself is not sufficient to completely visualize the task of destroying the cancerous cells in the virtual world. Hence, there is a need for other environmental objects such as the erythrocytes (red blood cells), leukocytes (white blood cells), and platelets in order to have a more realistic and comprehensive representation of the blood environment in which the nanorobot navigates. The main objective is to model all environmental objects to be as close as its actual microscopic view. Figure 2, 3, 4, 5 and 6 are shown modeled objects.

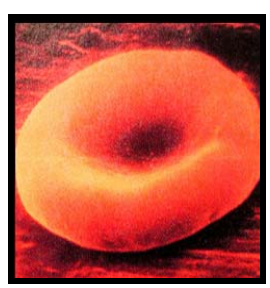

Figure 2. Microscopic View of the Red Blood Cell (left), Modeled Red Blood Cells (right)

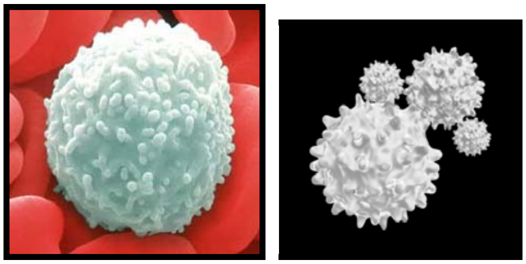

Figure 3. Microscopic View of the White Blood Cell (left), Modeled White Blood Cells (right)

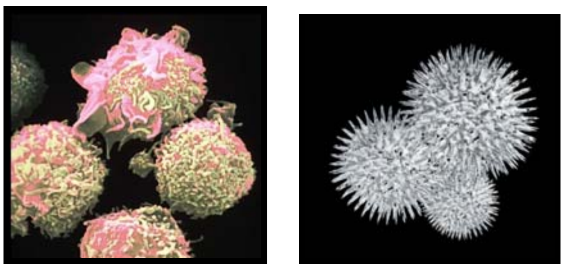

Figure 4. Microscopic View of the Cancerous Cell (left), Modeled Cancerous Cells (right)

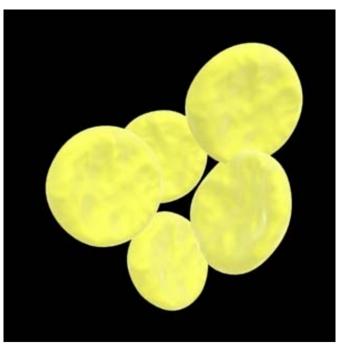

Figure 5. Modeled Platelet
(The Microscopic View of the platelet is similar to the Red Blood Cell. The only difference is that the size of a platelet is ⅓ the size of a Red Blood Cell)

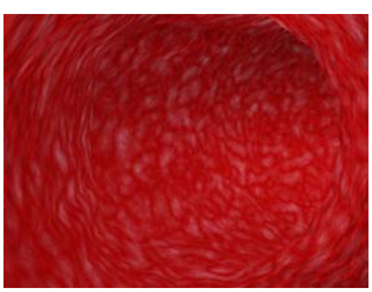

Figure 6. Blood Vessel (Camera View)

4. Nanorobot simulation

Simulation is an essential tool for exploring alternatives in the organization, configuration, motion planning, and control of nanomachines exploring the human body. The main purpose of this work is to give a better understanding on the working principle of the nanorobot through the use of the animation techniques provided by the 3Dstudio MAX software. The technique used will be explained with reference to the working principle of the nanorobot.

4.1. Moving blood cells

As there is no define path for any particular blood cell to move inside our body, they are animated by using a pre-defined path, which is randomly drawn in the blood vessel. 3-D splines are drawn inside the blood vessels. Then, the 'path constraint' method in 3Dsmax is used selecting a spline for the object to follow, as illustrated in Figure 7. Some of the objects are made to be static, however, the same result can be obtained because as the camera moves in the blood vessels, the static objects seems to be moving as well.

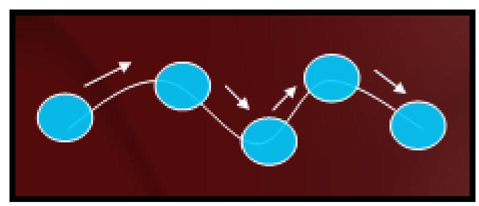

Figure 7. Path constraint

4.2. Attachment of Nanorobot to the Cancerous Cells

This effect can be shown using a combination of both methods; which is the 'path constraint' and the 'attachment constraint'. The usage of path constraint will be the same as above. However, in this case, both the Nanorobot and the blood cells will be following the same path. Once the path constraint is set, the timing for the movements of both cells can be manually defined by setting the starting and end position of the object for a set of key frames. The software will then interpolate the values for each intermediate frame. Once both the objects are arranged to be near each other, the 'attachment constraint' is used. The attachment constraint is set on the nanorobot so that it will attach to the surface of the cancerous cells and move together as an entity.

4.3. Shinning of near infra-red laser beam onto the blood vessel

The shining of laser beam onto the blood vessel can be done using the lens effect filter. This technique is applied onto the entire scene for only a few key frames. The glow color is set with the use of color gradient, where the color is set from light red to a darker red as shown in figure 8.

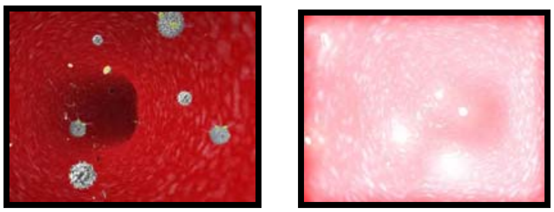

Figure 8. The Laser Beam Effect; Before (left), After (right)

4.4. Heat Generated on the Cancerous Cells

The technique that is being implemented to provide such effects is also through the use of lens effect filter, but in this case, the targeted objects will be the cancerous cells. To be able to apply the techniques onto specific objects, the object must be given an identification (ID), which can be set in the object properties. Once the ID is set, effects can be added specifically. The glow color used for this effect, as seen in the picture below, is the default setting where the glow is red in color, as shown in the figure on the left. The glow color for the figure on the right however uses a color gradient that changes from orange to red, to presents a fiery effect, as though the cells is burning.

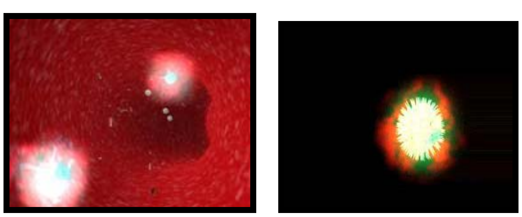

Figure 9. Destroying of Cancerous cells with different Glow color

4.5. Destroyed Cancerous Cells

The destroyed cancerous cell is animated to be disappeared from the scene. This can be done setting the visibility track of the object. After that, the tracking curve is change to step and at the same time assigning the on/off controller to the track. This simply means that the object will be visible at the value of 1, and invisible at the value of 0 as shown in figure 9.

5. Conclusions

The investigation and implementation of Nanorobot have many advantages in reducing human burdens on illnesses as well as helping them to lead a better life. The ability to determine the structure, behaviour and properties of the nanocomponents is the first step, which requires focused research thrust. Before proceeding to the next stage in building complex assemblies of nanorobot, those preliminary results on appropriate nanocomponents have to be achieved.

We are at the dawn of a new era in which many disciplines will merge, including robotics, mechanical, chemical, and biomedical engineering, chemistry, biology, physics, and mathematics, so that a fully functional system will be developed. As far as nanotechnology is concerned, this field is still considered new. Upon completion of this article, all the objectives set are achieved. A new design of a nanorobot is developed, which is able to kill cancerous cells without harming normal tissue. This research topic is just to provide a stepping stone for more research and findings regarding the field of nanotechnology in hope to achieve nanodreams in years to come where nanorobots will be able to eliminate virtually all common diseases, medical pain as well as suffering, theoretically, to help human lead an eternal life.

6. References

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