Simulation for the Motion of Nano-Robots in Human Blood Stream Environment

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Abstract—this paper is concerned with the problem of demonstrating the motion of a swarm of nano-robots until reaching the unspecified target areas in the human blood stream environment in which the red and white cells worked as obstacles for the nano-robots. Thus, each nano-robot must make predication on the movement of each obstacle as it moves in unknown dynamic environment. Additionally, we have to study the effects of the fluid flow of the blood on the motion of each nano-robot. This problem is solved by combining the modified obstacle avoidance and improved PSO algorithms. In which, the collision avoidance of the blood cells is achieved by modified obstacle avoidance algorithm. Furthermore, the communication, coordination, navigation, and definition of the target areas problems for the nano-robots are carried out in an organized way by applying improved Particle Swarm Optimization (PSO) algorithm to enable nano-robots to make decisions. This research includes a simulation of the performance and behavior of nano-robots. This simulation was designed, implemented and evaluated against the original requirement considerations. The results demonstrating that swarm nano-robots navigation system can be effectively simulated by utilizing the proposed algorithms.

Keywords—nano-robot; swarm intelligence; blood vessel; Reylonds Number; collision time; coverage;

I. INTRODUCTION

Nanomedicine has developed into one of the most capable sides of nanotechnology. [1] Adapted health care and drug design, in addition to targeted delivery of healing agents are just some of the advantages that nanomedicine may supply. [2] As such, the use of nano-robots in biomedical applications is presently a main focus of several research groups. Nano-robotics is a promising area of scientific and technological prospect. It is a new and rapidly growing interdisciplinary field dealing with the assembly, construction and use of molecular devices based on nanoscale principles and/or dimensions. The size-related challenge is the ability to measure, manipulate, and assemble matter with features on the scale of 1–100 nm.

A nano-robot is a controllable machine at the nanometer or molecular scale that is composed of nano-scale components and algorithmically responds to input forces and information. Bionano-robotics, namely biomolecular robots, represents a specific class of nano-robots where proteins and DNA could be used as motors, mechanical joints, transmission elements, or sensors. If all of these different components were assembled together they can form bio-nano-robots with multi-degree-of-freedom, able to apply forces and manipulate objects in the nanoscale world.

These bio-components seem to be a very logical choice for designing nano-robots. In addition since some of the core applications of nano-robots are in the medical field, using bio-components for these applications seems to be a good choice as they both offer efficiency and variety of functionality [3]. This idea is clearly inspired by nature's construction of complex organisms which are capable of movement, sensing and organized control.

The design of nano-robotic systems requires the use of information from an enormous variety of sciences ranging from quantum molecular dynamics to kinematic analysis. Until now, there does not exist any particular guideline or a prescribed manner that details the methodology of designing a bio-nano-robot [4]. As research development is at the interface of physical sciences and biology it requires multi-skilled teams. To achieve this it is essential for the future molecular roboticians to be able to design and prototype the bio-nanomechanics, to develop dynamic and kinematic models, to study their dynamic performances and to optimize their structure.

Although many of the described technologies have been developed into more or less mature products for robots acting in the macro-world, the nano-size of the molecular robots posestreme challenges and requires a complete rethinking of the design and prototyping methodologies.

Nano-robots are visualized to be tremendously connected to medicine, by being coded to perform particular biological mission. The principle aspects such nano-robots must have incorporate [5]: Biocompatibility: The immune system works as an obstacle for any foreign body presented in the living being. So nano-robots must be programmed to avoid it;

Communication: Nano-robots would need to convey with one another and with their external environment; Navigation: To attain focused on activities the nano-robots should incorporate some type of path planner; Coordination: The nano-robots must have the capacity to arrange their activities in a decentralized way.

In this paper, to enable the nano-robots to avoid such immune system we modify the obstacle avoidance algorithm which is presented in [6]. Furthermore, to enable the nano-robots to communicate, navigate, and coordinate cooperatively, the swarm intelligence algorithm called particle swarm optimization (PSO) is improved and utilized.

The paper is organized as follows. Section II provides a brief theoretical background on swarm intelligence algorithms also; swarm nano-robots and PSO algorithm are discussed. Section III presents the modified obstacle avoidance algorithm in details. A description of the complete algorithm that will combine both proposed algorithms follows in Section IV. In Section V the simulation results and subsequent analysis is introduced. Finally, Section VI discusses some brief conclusions and a short discussion for further work.

II. SWARM INTELLIGENCE

The term swarm intelligence got more being used throughout the most recent 15 years. "Swarm" is naturally valid to huge random systems that perform something motivating. The idea of swarm seems more to be nearly connected with frameworks prepared to do completing helpful events as well as "intelligent" tasks. From the robotic side, swarms self-organized into particles. The creation of organized particles is a feature of intelligence. Another is the recognition and analysis of particles, which swarms do when they optimize function. So, when swarms doing something intelligent this will lead to "Swarm Intelligence". [7]

Another definition of "Swarm intelligence" in which it handles the developing of the collaborative behaviors of simple agents cooperates with themselves, and their environment. These models are motivated by the collective behavior of insects and other animals [9]. Swarm intelligence handles the developing of the collaborative behaviors of simple agents cooperate with themselves, and their environment [10]. These models are motivated by the collective behavior of insects and other animals [9]. From the algorithmic view point, swarm intelligence models are computing algorithms that are effective for carrying out distributed optimization problems.

The principle of swarm intelligence focuses on probabilistic-based search algorithms. All swarm intelligence models exhibit a number of general properties [11]. There are three commonly used swarm intelligence models which are ant colony optimization, particle swarm optimization, and bee colony optimization.

A. Swarm Nano-robots

Swarm robotics has added a set of "standard" problems. One set of problems is based on pattern arrangement: aggregation, self-organization into a network, deployment of distributed arrays of sensors, covering of areas, mapping of the environment.

A second set of problems focuses on some specific unit in the environment: goal searching, finding the source of a chemical plume, foraging, etc. And another set of problems handle more complex group behavior: collective transport, grouping, etc. other specific robotic tasks, such as obstacle avoidance and all environment navigation, apply to swarms in addition. [8]

A brief review of these problems, as well as their relation to swarming in general, is given in the paper by Passino [12] whose work has focused on swarm robotics control.

For nano-robots, it is possible that each of which encompasses of incomplete capabilities because of small size. This analysis proved that swarm intelligence from social interactions among agents could deal with the limited capabilities that would be inevitable in future nano robots.

The swarm nano-robots system must be designed so that nanoparticles in the swarm cooperate and together organize themselves into structures. Additionally, they are able to repair the structure when damaged as long as they are in the environment. In this research our system aims to demonstrate that a swarm system of nano-robots with some essential characteristics can be communicated, coordinated, and navigated in cooperative way using swarm intelligence algorithm PSO.

B. Particle Swarm Optimization (PSO)

PSO is a swarm intelligence technique derived from the flocking behavior of birds [13]. In PSO, each particle searches through the problem space, improves its knowledge, modifies its velocity based on the information that it gathers, and updates its position.

The position and velocity of each particle are randomly produced. Afterward, using the fitness evaluation function, compare the *pbest* (best found position for a particle) fitness of each particle to its current fitness. If the current fitness is better, so update the *pbest* fitness to the current fitness, and assign the current position to replace the *pbest* position. Likewise, compare the fitness of each particle with the *gbest* (best found position for all particles) fitness. If the recent fitness is better than *gbest*, replace *gbest* with the current position, and assign the current fitness as the *gbest*'s fitness. The associated position and velocity for each particle are updated based on equation (1), and equation (2) respectively.

$$\text{Vel}_m = w * vel_{m-1} + c_1 * rand() * (pbest - Pos_{m-1}) +$$

$$c_2 * rand() * (gbest - Pos_{m-1}) \qquad (1)$$

$$Pos = Pos_{m-1} + vel_m \qquad (2)$$

Where vel and Pos refer to the velocity and position of the particle in the search space, m is the iteration number, w is the inertia weight, c1 is contant factor called cognitive parameter and c2 is constant factor called social parameter, and rand() is a randomly generated value between 0 and 1. Table I, presents the pseudo-code of the PSO algorithm.

TABLE I. PARTICLE SWARM OPTIMIZATION ALGORITHM PSEUDO-CODE

Begin
  (1) Iteration number = 0
  (2) Initialize a population of particles = n
  (3) **While** (termination condition is not reached) **do**
  (4)   **For** each particle
  (5)   Calculate fitness value;
  (6)   **If** the fitness value is better than the *pbest*
  (7)   Set current value as the new *pbest*
  (8)   **End If**
  (9)   **End For**
  (10) Choose the particle with the best fitness value of all the particles as the *gbest*
  (11)   **For** each particle
  (12)   Calculate particle velocity according equation (1)
  (13)   Update particle position according equation (2)
  (14)   **End For**
  (15) **End While**
End

C. Optimizing swarm nano-robots using PSO

The PSO is improved to enable the nano-robots to communicate, coordinate, and navigate to reach the target area in the human blood stream environment. So, each particle becomes a nano-robot. Moreover, the inertial force (f), viscosity (η) of the blood for a nano-robot is influence the new positions. As a result, the Reynolds number R (the ratio of inertial to viscous forces for a nano-robot moving in a blood) which is measured by equation (3) must be added to equation (1) to adjust the velocity of the nano-robot, see equation (4).

$$R = \delta f / \eta \qquad (3)$$

(Where δ is the blood density)

$$Vel_m = R + w * vel_{m-1} + c_1 * rand\,() * (pbest - Pos_{m-1}) +$$

$$c_2 * rand\,() * (gbest - Pos_{m-1}) \qquad (4)$$

In PSO, the path is relied on the fitness value. For swarm nano-robots, the fitness value indicates how well each nano-robot is directed to the target area. So, it will be evaluated for each nano-robot over its neighborhoods based on the coverage of the target area.

III. OBSTACLE AVOIDANCE ALGORITHM

Every nano-robot inside the human body environment will encounter red and white cells as obstacles during moving within blood stream. Therefore, nano-robot must apply algorithm for avoiding the colliding of such obstacles. We modify the obstacle avoidance algorithm which is presented in [6].

Assume that the obstacles are represented as circles so the configuration of each obstacle is described by its center, the radium and the velocity. Note that obstacles and nano-robots have the same fluid velocity.

When nano-robot moves on a new location, and verifies that there are moving obstacle in the target area. Then, the modified obstacle avoidance algorithm is started which is shown in Table II.

Based on the distance between the nano-robot and the obstacle, nano-robot is headed to the collision free direction θ, and using the value of θ we can calculate the new velocity v consequently, calculate the collision free position p based on the value of v .

TABLE II. MODIFIED OBSTACLE AVOIDANCE ALGORITHM PSEUDO-CODE

Begin
  (1) Calculate d the distance between nano-robot and encountered obstacle

  (2) Calculate θ the angle between the centroid of nano-robot and the centroid of obstacle

  (3) **If** the distance d less than the threshold value

  (4) Nano-robot steps on the opposite direction of obstacle (counter clock wise) and θ is calculated by:

$$(\theta = \theta + 180^\circ)$$

  (5) **If** the distance d greater than threshold value and the target area in the positive y-axis direction

  (6) Nano-robot steps on the perpendicular direction on the obstacle and θ is calculated by:

$$(\theta = \theta + 90^\circ)$$

  (7) **If** the distance d greater than threshold value and the target area in the negative y-axis direction

  (8) Nano-robot steps on the perpendicular direction of the obstacle and θ is calculated by:

$$(\theta = \theta - 90^\circ)$$

  (9) Else

  (10) Randomly calculate θ by adding or subtracting 90°

  (11) Calculate new velocity for nano-robot using the value of θ where

$$v\,x = \cos(\theta) \text{ and } v\,y = \sin(\theta)$$

  (12) Calculate the new position of nano-robot using the value of the velocity where pos = pos + v;

  End

IV. CONTROL ALGORITHMS FOR SWARM NANO-ROBOTS

In this section the nano-robot must use control algorithms to enable them to move around the human blood stream environment without colliding any obstacles while travelling to find the target areas, and in an efficient way.

The control algorithms mainly are the combination of the improved PSO algorithm and the modified obstacle avoidance algorithm which are discussed in details in the previous sections.

The control algorithm will proceed as follows, in the case of a nano-robot not detect an obstacle, it moves according to the improved PSO algorithm. Where while a nano-robot moves randomly, it can find the target area, and then it shares the best value with its neighbor (so it will move to the best location based on this best value). Otherwise, if an obstacle is encountered, a nano-robot follows the obstacle avoidance algorithm. After the nano-robot avoids the obstacle, a nano-robot moves again according to the PSO algorithm. Table III shows how to combine improved PSO algorithm, with obstacle avoidance algorithm.

TABLE III. CONTRO ALGORITHMS FOR NANO-ROBOT PSEUDO-CODE

```
Begin
 (1)  For each nano-robot s_i
 (2)    If an Obstacle is encountered
 (3)      Run modified obstacle avoidance algorithm
 (4)    Else If nano-robot find target
 (5)       Update gbest value
 (6)    End if
 (7)    For nano-robot s_i and its neighbor nano-robot s_j
 (8)       Update gbest of nano-robot s_i and nano-robot s_j
        with max value
 (9)    End for
 (10)   If time <  T_free
 (11)     Move randomly
 (12)   Else
 (13)     Calculate new velocity v using gbest position
 (14)     Calculate new position using v
 (15)   End if
 (16) End for
End
```

V. SIMULATION RESULTS AND ANALYSIS

This section incorporates the simulation results of the behavior of swarm nano-robots moving in the blood stream environment until finding the target area. The environment will include red and white cells as obstacles that must be avoided by the nano-robots.

The movement plan composes of swap short movements with random changes in direction. Each time obstacles are recognized, the nano-robots move to the new obstacle free positions based on the obstacle avoidance algorithm.

After obstacle is avoided, each nano-robot will change its position based on the PSO algorithm so that the new position information is transmitted to the others. To investigate the efficiency of control algorithms, several simulation parameters shown in table IV are used.

TABLE IV. SIMULATION PARAMETERS

Parameter	Value
Radius of Nano-robot	$3\mu m$
Radius of Red Cell	$7\mu m$
Radius of White Cell	$12 \mu m$
T_{free}	20s
Fluid Velocity	$100 \mu m /s$
Density	1 g/cm3
Viscosity	10^{-2} g/cm.s

A. Interface validation

The simulator was implemented in a C programming environment. The validation of the interface was done in many steps with tests of increasing complexity in different environments. The interface composes of main functions for plotting the workspace, initiating the movements of the obstacles and the nano-robots, invoking the control algorithms to allow the swarm nano-robots to reach the target areas without colliding any obstacle, controlling and showing the velocity of each nano-robot, displaying the number of nano-robots that arrived to the target area at a specific time, and demonstrating the time spend by each nano-robot until reach the target area.

B. Simulation Experiments

Some results of the tests with the simulator are presented in Fig. 1. The blue, red, white, and orange circles are corresponding to nano-robots, red cells, white cells, and target areas respectively. Fig. 1 describes the scenario of obstacle avoidance of 25 nano-robots moving according to the inertia and viscosity forces of the blood. Efficiently, all the nano-robots arrived to the target areas after 44 seconds. During motion, if obstacles are detected, the nano-robot can rotate its heading rapidly to avoid the collision by invoking the obstacle avoidance algorithm. After passing the obstacle, the nano-robots locate their positions based on the coverage of the target environment which is based on the PSO algorithm. In this scenario, we can evidently observe that whenever the obstacles are detected, the new obstacle free positions can be located efficiently, and all the nano-robots successes to arrive to the target regions effectively.
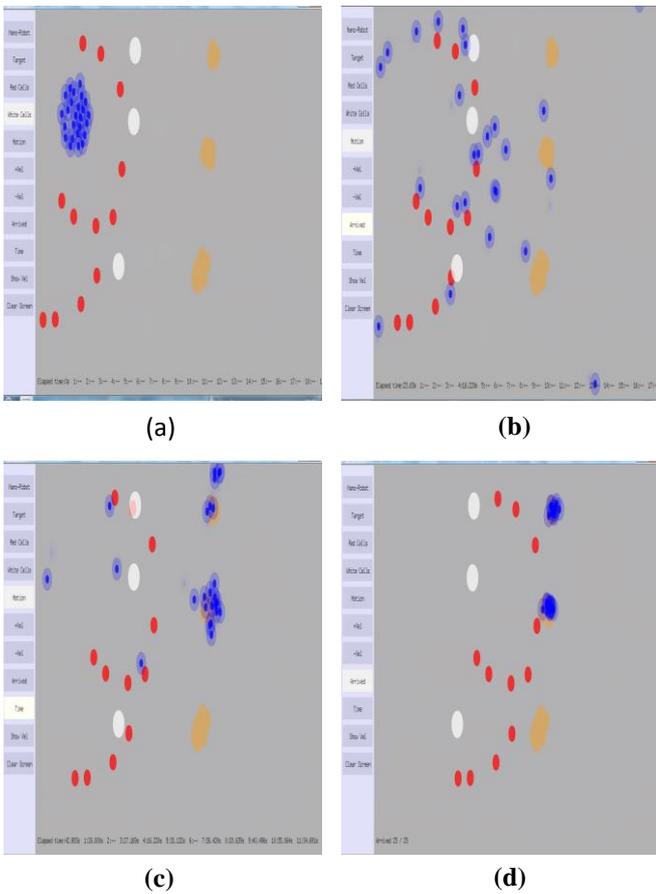
(a)

(b)

(c)

(d)

Fig. 1. Movement control for 25 nano-robots navigating in human blood stream environment

VI. CONCLUSIONS

It is believed that nano-robots can greatly contribute to the evolution of modern medical approaches and practices. In this research, the modified obstacle avoidance algorithm and PSO swarm intelligent algorithm are combined efficiently to allow the nano-robots to investigate within human body until reach the target regions. The simulation results have supported that the proposed representation effectively constructs an obstacle free self-organized path. Our future work would include improvement on the design of the simulator. This could include simulating the drug delivery to the unhealthy cells by set of collaborating nano-robots in 3D virtual reality environment at the nanoscale level.

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