Swarming Robots and Possible Medical Applications

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***Abstract*—In this paper, after introducing a Swarm Intelligence algorithm – Stochastic Diffusion Search (SDS) – the performance of a set of autonomous robots is observed. The goal of the autonomous robots is to agree on a task and, despite the inevitable existence of "organic" noise in the system, accomplish the mission through communication. Dispatching micro-robots inside a human body, the bed of another manifestation of "organic" noise, is an extremely delicate, complicated and expensive process. This work presents the possibility of using swarming robots using SDS in adhering to the great significance of resource allocation and communication in such circumstances. The potential of using SDS algorithm in identifying metastasis from bone scans is also explored.**

I. Introduction

Communication – social interaction or information exchange – observed in social insects is important in all swarm intelligence algorithms, including Stochastic Diffusion Search (SDS)[5], which mimics the recruitment behaviour of one species of ants – *Leptothorax acervorum*. Although as stated in [8], in real social interactions, not just the syntactical information is exchanged between the individuals but also semantic rules and beliefs about how to process this information, in swarm intelligence algorithms only the syntactical exchange of information is considered.

There are different forms of recruitment in social insects: it may take the form of local or global, one-to-one or one-to-many, and stochastic or deterministic mode. The nature of information exchange also varies in different environments and with different types of social insects. Sometimes, the information exchange is more complex where, for example, it might carry data about the direction, suitability of the target and the distance; sometimes the information sharing is simply a stimulation forcing a certain triggered action. What all these recruitment and information exchange strategies have in common is distributing useful information in their community.

In this paper, the behaviour of the robots are explained according to the Mining Game metaphor [1], which provides a simple high-level description of the behaviour of agents in SDS.

II. The Mining Game

This metaphor provides a simple high-level description of the behaviour of agents in SDS, where mountain range is divided into hills and each hill is divided into regions:

A group of miners learn that there is gold to be found on the hills of a mountain range but have no information regarding its distribution. To maximize their collective wealth, the maximum number of miners should dig at the hill which has the richest seams of gold (this information is not available a-priori). In order to solve this problem, the miners decide to employ a simple Stochastic Diffusion Search.

- At the start of the mining process each miner is randomly allocated a hill to mine (his hill hypothesis, h).
- Every day each miner is allocated a randomly selected region, on the hill to mine.

At the end of each day, the probability that a miner is happy is proportional to the amount of gold he has found. Every evening, the miners congregate and each miner who is not happy selects another miner at random for communication. If the chosen miner is happy, he shares the location of his hill and thus both now maintain it as their hypothesis, h; if not, the unhappy miner selects a new hill hypothesis to mine at random.

As this process is isomorphic to SDS, miners will naturally self-organise to congregate over hill(s) of the mountain with high concentration of gold.

In the context of SDS, agents take the role of miners; active agents being 'happy miners', inactive agents being 'unhappy miners and the agent's hypothesis being the miner's 'hill-hypothesis'.

Algorithm 1 The Mining Game

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Initialisation phase

Allocate each miner (agent) to a random
   hill (hypothesis) to pick a region randomly
Until (all miners congregate over the highest
   concentration of gold)
   Test phase
      Each miner evaluates the amount of gold
         they have mined (hypotheses evaluation)
      Miners are classified into happy (active)
         and unhappy (inactive) groups

  Diffusion phase
      Unhappy miners consider a new hill by
        either communicating with another miner
        or,if the selected miner is also
        flow between the miners; instead the
        selecting miner must consider another
        hill (new hypothesis) at random

End
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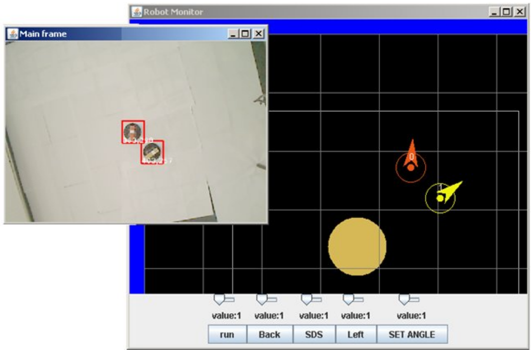
III. Swarming Robots

This work[1] is based on a project that involves the use of autonomous swarm of robots to evaluate their interactions in the physical world (see Figure 1). The main channel of communication (one-to-one/one-to-many) is wireless. The goal of this project is to study and demonstrate the behaviour

[1] http://www.youtube.com/watch?v=bwAlR1VZyYk

Figure 1.

Snapshot of two swarming robots on the ground and in the simulator



of swarm robots using decentralised control mechanism, where intelligence emerges through the interaction and communication among the robots rather than just by the endeavour of one individual robot.

Each robot is fitted with a controller board (Arduino POP 168 micro-controller), having servo motors and other sensors connected to it. The existing wireless communication is facilitated by Xbee modules. Each robot has a label with a unique colour, giving them distinctive feature. For the system to recognise the robots, OpenCV library is used to detect the colour of each existing robot as well as their moving direction.

Following the Mining Game metaphor, each robot represents a miner and the location of the gold is defined on the search space with a uniquely identifiable label. The robots which set off to search for gold, proceed with the communication and information exchange in wireless mode. At the end of each trial, as expected, the robots congregate around the gold location. In this experiment, the search space is just divided into hills (because of the small search space used for the experiment, the hills were *not* divided into regions).

IV. SDS and Bone Scintigraphy

Bone scan or Bone scintigraphy is one of the most frequently performed of all radionuclide procedures. Radionuclide bone imaging is quick, relatively inexpensive, widely available, and exquisitely sensitive and is invaluable in the diagnostic evaluation of numerous pathologic conditions. Although protocols vary among institutions, imaging is typically performed 2–6 hours after intravenous administration of technetium-99m–labeled diphosphonates. The delay between injection and imaging allows clearance of the radiotracer from the soft tissues, resulting in a higher target-to-background ratio and improved visualization of bone. The degree of radiotracer uptake depends primarily on two factors: blood flow and, perhaps more importantly, the rate of new bone formation [9].

A. Normal Scintigraphic Findings

There is symmetric distribution of activity throughout the skeletal system in healthy adults. Urinary bladder activity, faint renal activity, and minimal soft-tissue activity are also normally present (see Figure 2 left).

The accumulation of radiotracer in bone generally decreases with age. However, there are sites of persistently increased symmetric uptake, such as the acromial and coracoid processes of the scapulae, the medial ends of the clavicles, the junction of the body and manubrium of the sternum (angle of Louis), and the sacral alae. Increased radiotracer accumulation in the jaw may be due to dental disease or to malocclusion of dentures. Symmetric areas of increased calvarial activity occurs in hyperostosis frontalis. In the neck, activity in calcified thyroid cartilage and in the apophyseal joints of the cervical vertebrae in patients with asymptomatic degenerative changes can also be seen[2] (see Figure 2 left).

B. Metastatic Disease

Metastasis is the process by which the cancer spread from the original site at which it started as a primary tumour to other tissues in the body i.e. Prostate cancer metastasizing to the bone tissue.

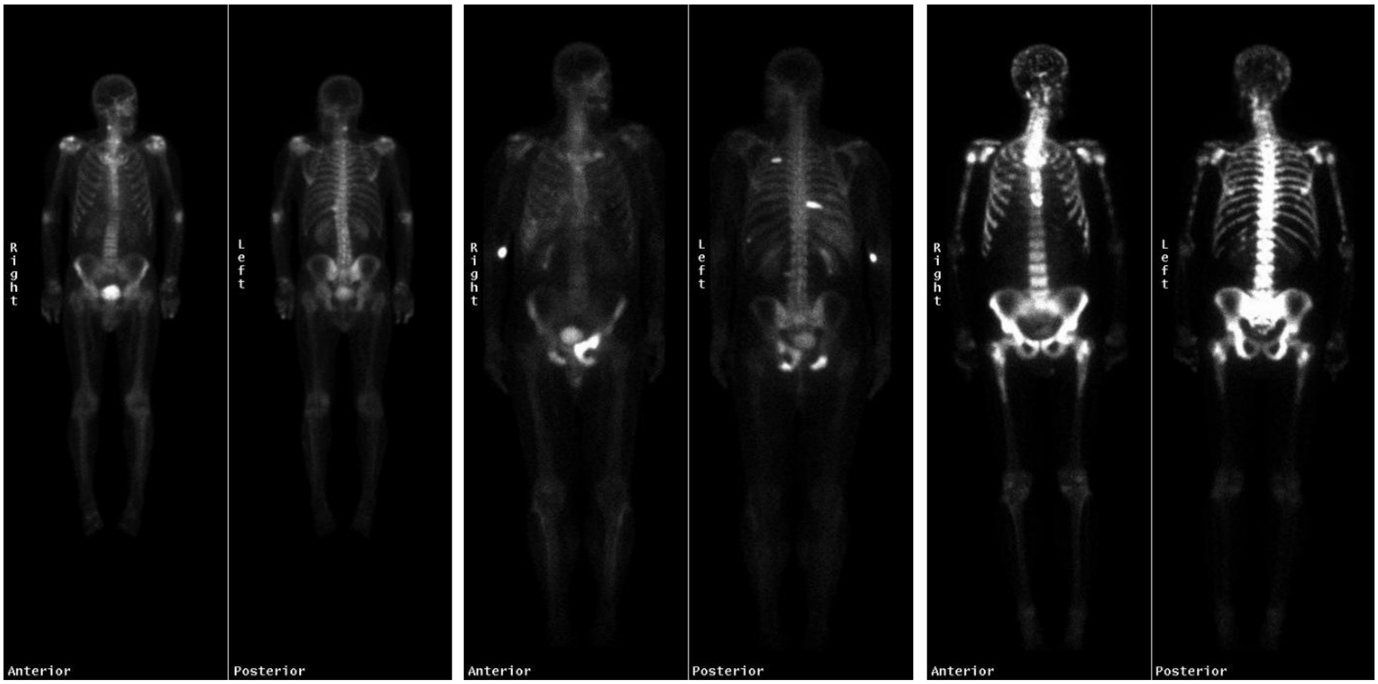
Many if not most bone scans are performed in patients with a diagnosis of cancer, especially carcinoma of the breast, prostate gland, and lung. Radionuclide bone imaging plays an imporant part in tumor staging and management. This imaging technique is extremely sensitive for detecting skeletal abnormalities, and numerous studies have confirmed that it is considerably more sensitive than conventional radiography for this purpose [6]. About 75% of patients with malignancy and pain have abnormal bone scintigraphic findings. The usual pattern consists of increased radiotracer deposition in areas of new bone tissue formation in response to the damaging effect of cancer on the bone [6], [4]. The presence of multiple, randomly distributed areas of increased uptake of varying size, shape, and intensity are highly suggestive of bone metastases (see Figure 3 middle). Although multiple foci of increased activity may be encountered in other pathologic conditions, it is often possible to distinguish metastatic disease from other entities by analyzing the pattern of distribution of the abnormalities. Traumatic injury, in contrast to metastatic disease, generally manifests as discrete focal abnormalities of similar intensity. In older patients, osteoarthritis and degenerative changes may manifest as areas of intense activity on radionuclide bone images. These changes can be distinguished from metastatic disease by virtue of their characteristic location (eg, knees, hands, wrists). Involvement of both sides of the joint is common in arthritis but unusual in malignant conditions [11].

When the metastatic process is diffuse, virtually all of the radiotracer is concentrated in the skeleton, with little or no activity in the soft tissues or urinary tract. The resulting pattern, which is characterized by excellent bone detail, is frequently referred to as a superscan (see Figure 2 right) [4], [11], [12].

Bone scintigraphy is a popular and important imaging modality and will likely remain so for the foreseeable future. Although bone scintigraphy is not specific, its exquisite sensitivity makes it a useful screening procedure for many pathologic conditions, especially for the detection of prostate, breast and lung cancer metastasis.

[2]ibid.

Figure 2.
Bone images: typically 2–6 hours after intravenous administration of technetium-99m–labeled diphosphonates. Brigher areas indicate a higher radiotracer uptake.
Left: Healthy; middle: partially affected; right: metastatic disease spread.



C. *Swarm Intelligence and Bone Scans*

SDS algorithm demonstrates a promising ability in identifying areas of metastasis in this paper[3]. Each scan in Figure 2 are processed by 10,000 SDS agents, which are responsible for locating the affected area(s). When the activity rate of the agents reaches 80%, the application terminates. The highlighted areas in Figure 3 show the affected regions. According to the description given in the previous section, Figure 3 (Middle and Right) are the areas of metastasis.

This technology can be effectively employed to develop programs for teaching and training medical students and junior doctors. Additionally the reproducibility and the accuracy of the SDS algorithm can be utilized in developing a standardised system to interpret the bone scans preventing operator errors and discrepancies.

V. Possible Medical Application with Swarming Robots

Robotic technology is enhancing invasive medical procedures through improved precision, stability, and dexterity. First experiences of using microrobots in the human body came from the development of technologies to improve endoscopic procedures of the gastrointestinal tract. Endoscopy provides valuable information about any major pathologies such as bleeding, malignancy or precancerous conditions in the gastrointestinal system. Typically the widely used endoscope is composed by the head (active part) that incorporates the camera, optics and illumination and by the shaft that allow the advancement of the instrument. By pushing and pulling over the shaft of the device, the endoscope advances inside the lumen of the gastrointestinal tract; however these actions stretch the colon and cause pain during the endoscopic examination. Also, despite advances in endoscopic technology still early precancerous conditions are missed with fatal consequences [10].

Robotics research have provided a solution for one of the major limitations of the conventional endoscopy by splitting the system and making the active part of the endoscope (camera, light) self propelling inside the lumen while the control and energy equipments are left outside of the body, thus avoiding to stretch the colon and limiting the abdominal pain. This is intended to minimise the pain that often limits complete examination of the colon.

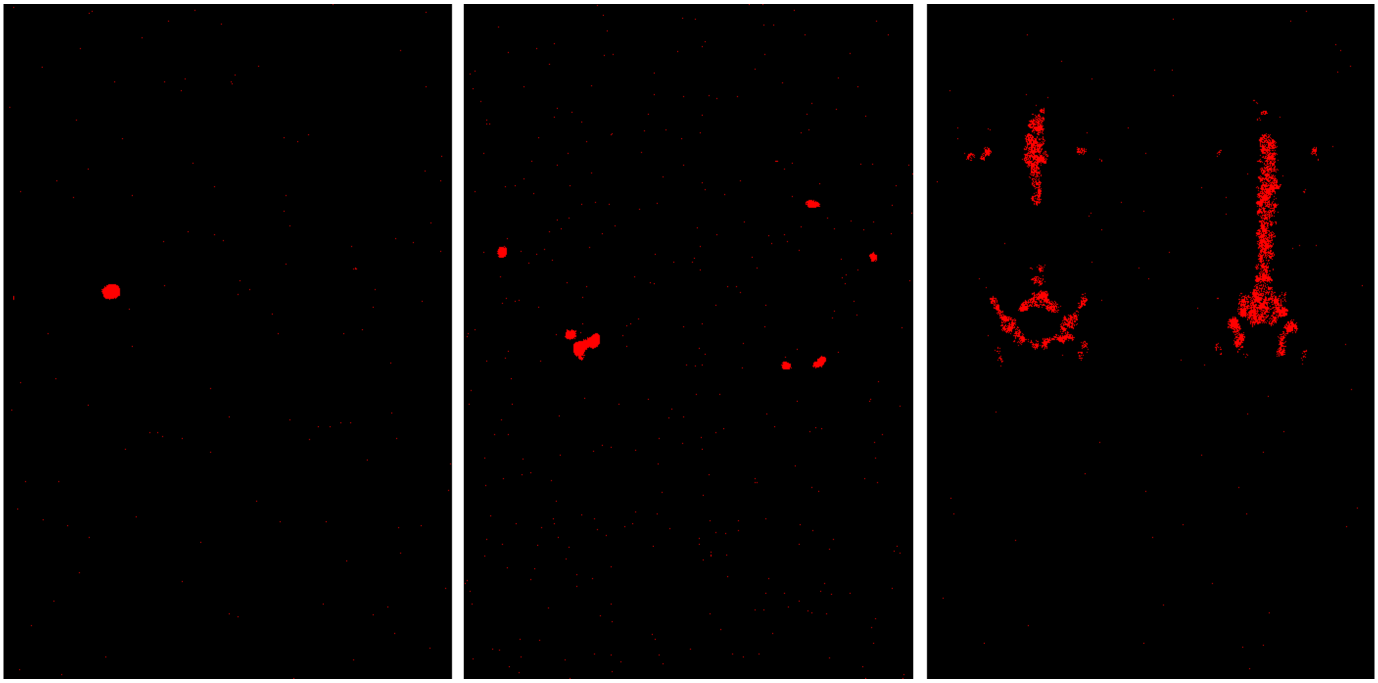
For instance, in an advanced robotic system that is currently in use for in vivo endoscopic exploration of the gastrointestinal tract, a completely un-tethered camera pill is swallowed by the patient then it naturally moves through the lumen of the GI tract. This micro-robot contains an imaging device and light-source on one-side and transmits images at a high rate in a matter of seconds to a control device outside the patient's body. This generates a wealth of data over a few hours period. The images are sent from the capsule wirelessly to the control device. Images of the gastrointestinal lumen can then be analyzed either in real-time for immediate localization of the micro-robots or off-line for detailed diagnosis [7].

As for the future medical experiments, micro-robots with similar properties will be utilized; these agents (robots or

[3]To see the video of the performance of SDS agents, visit: http://www.youtube.com/watch?v=GtvEnuBIxjQ

Figure 3.

The results returned by SDS agents after reaching 80% of activity.
Left: Healthy; Middle: partially affected; Right: metastatic disease spread.



miners) would be identifying areas in the gastrointestinal lumen with any pre-cancerous pathology. In the initial experiments, the simplified case of having a pre-malignant condition, which is confined to an area in the gastrointestinal system, is explored. Micro-robots interacting based on the SDS algorithm provide a promising tool to identify pathological areas in the gastrointestinal system with greater precision enabling a better a diagnosis and management plan for the patients. When optimisation is involved, the integration of SDS with other swarm intelligence and evolutionary algorithms has shown promising results [3], [2].

VI. Conclusion

This paper introduced SDS, a swarm intelligence algorithm, through a social metaphor and presented some of its possible applications. The applicability of SDS algorithm in identifying areas of metastasis are discussed and the potential of deploying SDS in developing programmes for teaching and training medical students and junior doctors is also considered. Possbile future research in using SDS with swarming robots are also explored.

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