Stigmergic Algorithms for Multiple Minimalistic Robots (short paper)

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***Abstract*— This paper is meant to discuss the use of stigmergy in minimalist multi-robotic systems, and to illustrate this approach in three case studies: building a globally optimal navigation map, building a gas concentration gradient map, and updating the above maps dynamically. All case studies have been implemented in a real environment with inexpensive robots, using an RFID floor as the stigmergic medium.**

I. Stigmergy in nature

Engineers have been inspired by nature in many ways. Structure of airplanes drawn inspiration from birds' wings. Robots have been designed to mimic the movement of insects. *Stigmergy* is another inspiring mechanism that can be observed in nature. By stigmergy, insects of same species communicate indirectly with each other to organize their individual or collective work. Communication is performed by releasing and sensing volatile chemicals in the environment called pheromones [1]. The environment and pheromones can be seen as an external memory, whose contents are written by an agent and then read by a different agent, or by same agent at a late time, to decide its behavior. Stigmergy allows simple agents to exhibit complex behaviour without the need of internal memory, planning or direct communication. Stigmergy is the principle at the basis of the seemingly intelligent behavior of many social insects.

II. Stigmergy in robotics

Stigmergy is a very interesting phenomenon to study in robotics and computer science [2], [3]. By stigmergy, many simple robotic devices can exhibit a collective behavior which is significantly more complex than the one of each individual robot. In general, *stigmergic algorithms* can be used to realize complex behaviors with global properties using computationally simple robotic systems with a local view, by leveraging the spatial memory provided by the stigmergic medium [2]. Other examples include ant colony algorithms [4], and their physical realizations [5].

We claim that stigmergic algorithms in robotics should be studied by a combination of theoretical investigation and empirical experimentation. To support this claim, we will present in the full paper three case studies:

1) A stigmergic algorithm by which one or multiple robots can find optimal paths to a target position, even when the robots have no sense of global location and the target is outside from the range of the robot's sensor. This algorithm was first presented in [6].
2) A stigmergic algorithm by which one or multiple robots equipped with gas sensors can generate a gradient map leading to the areas of highest gas concentration, again with no use of global localization. This algorithm was first presented in [7].
3) The (unpublished) extension of the previous two algorithms to the case of dynamic environments, in which obstacles may be added and removed, by adding a time dimension to the stigmergic medium.

The third case is worth a few comments. The algorithm for optimal path planning in [6], outlined in short format below, lets the robot(s) build a distance map to the target location by running a variant of Bellman-Ford algorithm.

Require: All tags initialized to ∞, robot starts at goal

```
distance_count ← 0
while Explore do
    x ← ReadTag()
    if NextTag(x) then
        distance_count ← distance_count + 1
        if distance_count > val(x) then
            distance_count ← val(x)
        else
            WriteTag(x, distance_count)
        end if
    end if
end while
```

Algorithm 1: BuildDistanceMap()

The time dimension can be introduced through an *evaporation* mechanism that mimics the decay of pheromone intensity with time, which is observed in nature and used in ant colony optimization [8]. This, however, would require that the amount $v(x)$ of virtual pheromone in each tag x is updated at each time step, something which cannot be done with passive tags. We have therefore developed a local version of pheromone evaporation, in which pheromone values are associated with a time stamp and discounted accordingly to an evaporation function f whenever the tag is visited. The resulting algorithm is outlined below.

III. Empirical Evaluation

The three test cases mentioned above have been implemented in a physical test-bed. This testbed consists of a set of simple ePuck robots (www.e-puck.org), which navigate in a large apartment-like environment whose floor contains a hexagonal grid of RFID tags. Each ePuck is equipped with a dsPIC microcontroller which has two UARTs. The first one is

Fig. 1. Testbed environment. Left: an ePuck robot equipped with a M1 RFID tag reader. Right: the RFID tags placed under the apartment's floor.

```
Require: All tags initialized with val = ∞, t = 0
distance_count ← 0
while Explore do
    x ← ReadTag()
    if NextTag(x) then
        v ← f(val(x), current_time − t(x))
        distance_count ← distance_count + 1
        if distance_count > v then
            distance_count ← v
        else
            WriteTag(x, distance_count, current_time)
        end if
    end if
end while
```

Algorithm 2: BuildDistanceMapDynamic()

used for communication between the ePuck's microcontroller and an M1 RFID tag reader. The tag reader is set to the maximum allowed baud rate (57600), and takes power from ePuck's battery in order to reduce the weight load. A circular RFID antenna is mounted around the robot. The radius of the antenna is selected in such a way that ePuck can avoid obstacles and other robots on its way using the built-in IR proximity sensors. The second UART is connected to a bluetooth chip which is used for communication to a PC. Each robot can read and write bytes of information from/to the RFID tags while it moves over them. This mechanism mimics the pheromone trails left by ants in one of the most famous example of stigmergy found in nature.

We have performed preliminary experiments aimed at evaluating the map building algorithm with single and multiple robots under real execution conditions. Two builds were performed; one with a single robot, and one with two robots. In both builds a portion of the apartment was selected that consists of bedroom and living room and the goal was located in bedroom. Figure 2 shows the true distance map of this portion, built offline. We calculate the error at time t between true distance map and computed map by equation 1 to show that the computed map converges to the true distance map:

$$Err(t) = \sqrt{\frac{1}{|X_t|}\sum_{x\in X_t}(v_t(x)-d(x))^2} \quad (1)$$

where $v_t(x)$ denotes the value stored in tag x at time t and $d(x)$ denotes the distance of tag x from the goal tag. Figure 2 plots the error function (1) over t during the building process, for the case of using one and two robots, respectively. Convergence has occured at time $(t = 20.9h)$ using one robot, and at time $(t = 10.7h)$ using two robots.

The full paper will show extensive experiments with a variable number of robots, and including the use of "evaporation" to deal with dynamic environmens.

References

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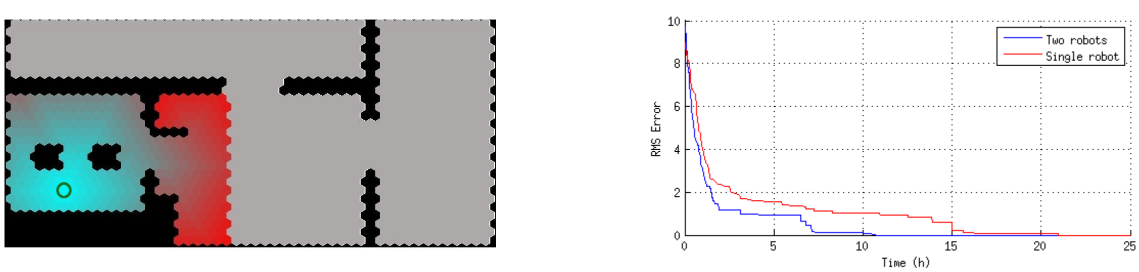

Fig. 2. Map building results. Left: True distance map built offline. Distance increases from blue to red, gray is unexplored area, green circle is a goal position. Right: Error functions.