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On the Benefits of Cognitive Infocommunication for Mobile Communication Nodes Using Cooperative Concepts

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***Abstract*—The distributed coordination of a group of mobile robots became a widely studied area in the last decades however the communication aided solutions became also popular research. In this paper we present the concept of cognitive swarm which enables to design faster and reliable cooperative groups by the use of cognitive infocommunication. We demonstrate the benefits of our new concept by a scenario in which a swarm of mobile robots had to guard a given area by intercepting eventual intruders. Therefore we introduce the area surveillance problem and we give both a baseline and a cognitive infocommuncation aided solution for that by the use of the basic behaviour set as fundamental. We show through simulation results that the proposed cognitive scheme can reduce the surrounding time by the factor of two leading to faster interception.**

***Keywords*—mobile robots, area surveillance,, intruder problem, cognitive swarm, cognitive infocommunication, basic behaviour set**

I. INTRODUCTION

In the last decades researches related to distributed robotics got even more popular. As the computational capacity of the embedded systems grow not only the theoretical aspects of the field became interesting but also the real life scenarios get more attention. The benefit of a group of individual but less *intelligent* robots is the robustness and the low cost. In contrast with the case of one more effective entity, if a robot in a group get damaged it can be easily replaced and if the size of the group is sufficient it will be transparent to the environment.

A. Localised swarms

If a group of individual robots are performing a cooperative behaviour in order to solve a collective, group related task they are called swarm. In the most cases this global task is unsolvable for a single member, however for the swarm it is possible. As we mentioned the capabilities of the robots are limited. Therefore the used algorithms and rules should be simple and easily adoptable. This serves two purposes: It increases the possibility of real life implementation and it also makes the theoretical validation easier. From now on we will use the term robot and entity interchangeably. In order to keep these swarms *simple*, most of the models are using oblivious entities with limited sensing and communicational capabilities. Therefore the algorithms which are used by the members of the swarm are fully distributed and due to the limited capabilities are also very simple. We should mark that however these algorithms are *simple* most of them are very effective. This is because of the relative easy validation. Due to the lack of communication capabilities each entity makes individual decision based on the gathered information. These decision can be improved by adding better sensor equipments to the entities or by enabling information sharing among the members of the swarm.

B. Cognitive Infocommunication

However the benefits of the above mentioned, distributed algorithms are obvious, the extension of these solutions by adding additional communicational network to them also contains potential. As the communication technologies emerged they slightly infected many different fields which were not using information sharing techniques before. A good example can be the intelligent power networks, which is a very popular research topic. By the use of Cognitive Infocommunication, not the speed of information sharing will be faster but the quality of shared information will be more accurate and easy to *understand*. This latter property makes this concept ideal for *intelligent* swarms. With the capability of information sharing among swarm members the effectiveness automatically emerges but it also makes the possibility to generate a higher level cognitive entity. This inspired us to expand a basic swarm with cognitive communication capability in order to combine the individual decision made by the entities with the collective decisions of the swarm. By the use of this approach we have generated a higher level entity, the *cognitive swarm*, which consists of its members.

C. Our contribution

In this article we will present a basic scenario in which a swarm of mobile robots have to guard a given area by intercepting eventual intruders. We will show two different solutions for this scenario. The first solution will use a conventional, oblivious fully distributed solution, without inter agent communication. The second solution, in contrast with the basic one, will use the benefits of cognitive communication. We will introduce the *cognitive swarm* concept, by which the members of the swarm will be able to consciously share their

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knowledge with the swarm. By this addition we have created a higher-level, intelligent entity from a group of collectively behaving but also individual robots. We will show through our experimental results that the cognitive communication aided solution is much more suitable for this situation and therefore it is more effective than the basic one.

This paper is organised as follows. Section 2 gives an overview of related work. In Section 3 we introduce the test scenario and present the two different solutions. We presents our experimental results in Section 4 and finally, Section 5 summarises the work.

II. Related Work

The filed of cooperative robotics is a well studied research area. Besides the numerous algorithms and theoretical results, there are also many working implementations too. The most popular scenarios of cooperative groups is the cooperative motion. In order to control the formation and the direction of the motion of these kind of asynchronous systems many solutions are using potential or gravitational fields to move the robots [1]. Besides the low computational complexity it is also oblivious, which is ideal for artificial robots with limited *intelligence*. Most artificial potential fields use the long range attraction short range repulsion concept. This prevents the entities to get either too close or too far from each other. However if all robots have the same force or potential field, they will end up in an equilibrium state, where no robots are able to move. Although the this situation does not solve the collective motion problem, fortunately it successfully solves the gathering problem. Therefore this kind of potential field based approaches are still dominating in the solutions of the gathering problem. Like in [2]. Regarding the formation problem, in the work of Leonard et al. [3] a concept was proposed for the collective motion problem. They introduced virtual leaders, that move "independently", while they are followed by the rest of the robots. By the use of the leader the entities will gather around the leader while they are moving on the desired path. Gervasi and Prenciepe [4] have presented a solution for the *intruder* problem. They have proposed an algorithm by which a group of *patrolling* entities are able to detect and encircle an enemy unit. They use an asynchronous LCM-based model where all oblivious entities knew the position of the intruder and the other entities. However before a group of entity begins to patrol on a dedicated area, they have to spread out from their gathering or starting point. A good solution for a distributed dispersion can be found in [5]. As we mentioned before, we would like to create a relatively complex behaviour. In order to approach this we will use a very simple but also imaginative solution which was created by Mataric [6]. At first she defined five easily adoptable rules which are the following.

1) *Safe-Wandering:* The ability of a group of agents to move about while avoiding collisions with obstacles and each other.
2) *Following:* The ability of an agent to move behind another retracing its path and maintaining a line or queue.
3) *Dispersion:* The ability of a group of agents to spread out in order to establish and maintain some minimum inter-agent distance.
4) *Aggregation:* The ability of a group of agents to gather in order to establish and maintain some maximum inter-agent distance.
5) *Homing:* The ability to find a particular region or location.

By using these five basic rules (like building blocks) it is possible to generate more dynamic and complex behaviours. As the computational capacity of embedded systems emerges it became possible to add communicational capabilities to them in order to share their information. As it was depicted in the work of Baranyi et al. [7], the cognitive infocommunication is a necessary part of the inter-cognitive information sharing if they want to enhance the *performance* of such systems. Therefore a proper communication layer is able to make a more effective distributed system. However the above introduced algorithms and solutions are illustrious, without a real collective knowledge, the entities will not get information about the swarm itself. Therefore they are unable get information about the status of the collective behaviour i.e.: They cannot determine whether the common goal is reached or not. In order to solve this issue we made the possibility for the entities to establish an inter-cognitive communication channel between the swarm and themselves. Fortunately there are already working approaches where the swarms are using the benefits of communication. In the works of Daniel et al. [8] [9] mobile sensor deployment and dispersion concepts were presented where the nodes were using communication channels to make the performance of the coverage and the detection better. However they did not use all benefits of cognitive communication. In this article we will use the idea of the basic behaviours with the combination of Cognitive Infocommunication in order to create a complex behaviour which demonstrate the benefits of the cognitive swarm. This higher level entity will be able to establish intra cognitive communication channel to other cognitive entities while it will also provide inter cognitive channels for its members too. We will present our result by solving the intruder problem with and without cognitive infocommunication.

III. Proposed Method: Area surveillance

In this section we will introduce our area surveillance concept by which a swarm is not only able to monitor the given area but it became also available to detect and capture an intruder. We use basic behaviours like building blocks in order to design the proper distributed algorithm. We will present two solutions, one will use local information only while the other will allow inter-agent communication as an addition. Both concept are using the same behavioural rules and sensing methods. The only difference is the availability of inter-agent or information sharing. The robots are fully decentralised and have limited memory. Only short range sensors and mid range communication interfaces[1] required. Before the presentation of the main algorithm we introduce our terminology and assumptions:

1) We handle the robots as circle shaped objects.
2) For each robot we distinguish: physical radius, r_b, sensing radius, r_s, communication radius, r_c

[1]only in the second case

3) The minimum and maximum distance between two robots $d(u, v)$ should be d_{min} and d_{max} where $d_{min} < d_{max}$.
4) In order to keep the system realistic, we define the following relations $r_b < d_{min}$, $d_{max} < r_s$, $r_s \leq r_c$. This guaranties that the entities are able to sense neighboring entities and it also enables them to communicate with each other.
5) The size of the guarded area is fix and finite.
6) The target is intercepted if the robots are forming a complete, hole-free circle around it.
7) The robots able to cover the whole area by their local sensors without sensing holes. This enables them to detect the intruder.

A. Dispersion

We divide the algorithm into two separated parts. The first one is the dispersion. As it can be seen in the basic behaviour set of Mataric [6], the dispersion is a simple behaviour which is already implemented in their work. In our concept two robots, u and v, are dispersing from each other until the distance $d(u, v)$ will be greater than d_{max}. This will enable the robots to stay in their neighbours sensing and communication range. If the deployment area is bounded by borders and the number of the robots is sufficient at the end of the dispersion the whole area will be covered by the robots without sensing holes. Of course if the number of the robot is less than the optimal, the end state of the dispersion will always contain sensing holes. In those cases when the area is greater than what the robots are able to cover by their sensors, the basic dispersion behaviour should be combined with the self-wandering behaviour in order to synthesise a complex *patrolling* behaviour. Unfortunately in this case the target will be able to get through unawares the guarded area by exploiting the sensing holes. In this article we are dealing only with the hole-free scenario.

B. Target interception

In contrast with the patrolling, the second part of the main algorithm, *the target interception*, is a complex behaviour. Therefore in order to keep it easily understandable, we not just mixed the basic behaviours of Mataric [6] but we also used an additional basic behaviour, the *Circulation*, which was introduced in [10] and can be seen on Algorithm 1. This behaviour enables the robots to circulate around a given target on a predefined circular orbit. This circular motion is ideal for target interception as it can be seen in [10] and in [4].

Algorithm 1 Circulating

```
loop
  face to the target
  move to a desired tangential direction of the curve around
  the target {this is uniform for all of the entities}
end loop
```

However there are many dedicated methods for target interception like [11], we will rather use a simple solution. This is because the goal of this article is to demonstrate the benefits of cognitive infocommunication in the filed of swarm robotics. Therefore we have choose the concept of Li et al. [12]. Although their algorithm is designed for sensor self deployment, the simplicity and effectiveness of the basic Greedy-Rotation-Greedy manoeuvres are also suitable for target interception. If a robot is able to detect the target it will automatically switch from dispersion state to interception mode. During the interception the robot should move as close to the target as it can. This is the greedy advance which is similar to the homing basic behaviour. In this case the robot u is fowling this behaviour until there is no other robot in front of it or until the distance between the target T and itself is greater than d_{min}. If greedy advance is not possible the robot should circulate around the target on a dedicated orbit. This is the circulating behaviour. In order to avoid collision situations, circulation is only allowed on dedicated orbits around the target. The distances between the neighboring orbits should be greater than d_{min}. The radius of first orbit should be d_{min}. After translating this into the language of basic behaviours we get the desired behaviour of target interception which can be seen on Algorithm 2.

Algorithm 2 Target interception

```
loop
  if current position is on the first orbit or a neighbor
  prohibits to move towards the target then
    Circulating
  else
    Homing
  end if
end loop
```

We should note that if we stuck to the original basic behaviour set of Mataric[6], the interception behaviour would be much more complex.

C. Cognitive Swarm

In order to acquire and use the knowledge of the other members of the swarm, communication capabilities should be added to system. Although simple communication capabilities will be also sufficient in this case, we add more sophisticated cognitive infocommunication capabilities to the swarm. If this communication layer has established, the swarm will emerge from a group of individual members, who are able sense each other, into a higher level entity. This entity will be able to communicate through intra-cognitive channels with other such cognitive entities and it will also be able to communicate with its members via inter-cognitive communication. In this surveillance case by the addition of such capabilities the robots will able to share and propagate the position of the target and they will be able to collectively determine whether the target is successfully intercepted or not. In the usual case it should be determined by an external observer. This information sharing potential is go beyond of the benefits of the area surveillance problem, however it is a good example to demonstrate the benefits.

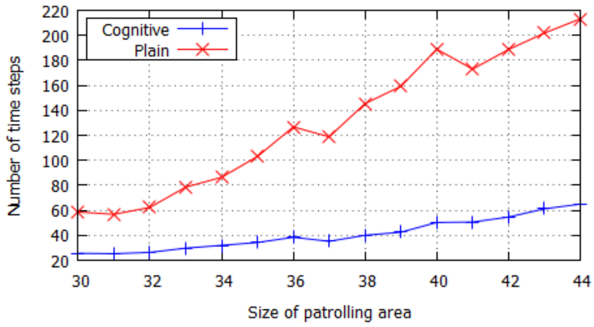
IV. Performance Evaluation

In order to evaluate the benefits of our cognitive infocommunication based solution we have implemented both algorithms in our discrete synchronous simulation environment. We performed discrete synchronous simulations where the robots were placed uniformly at random on the vertices on a square shaped Equilateral Triangle Tessellated (TT) graph. This means that the robots and the target were able to move only on the edges of the TT graph. The minimal and maximum distances between each robot pairs (d_{min}, d_{max}) was 1 and 5 hop. The sensing radius (r_s) was 6 hop and the communication radius (r_c) was 7 hop. In all scenarios the target had to cross the area while the robots were trying to intercepting. The speed of the robots were 4 times faster than the speed of the target. This means that the target were able to move only in every fourth time step. This limitation was designed because of the limitations the interception algorithm. In all simulations during the evaluation we kept the number of the robots fixed (90), while we varied the size of the guarded area from 30×30 to 44×44. We performed 40-40 simulations with each parameter. At the beginning the target was placed on the border of the TT graph and the robots were gathered in the centre of the area. This start up setup enabled to demonstrate both the dispersion and the target interception behaviour.

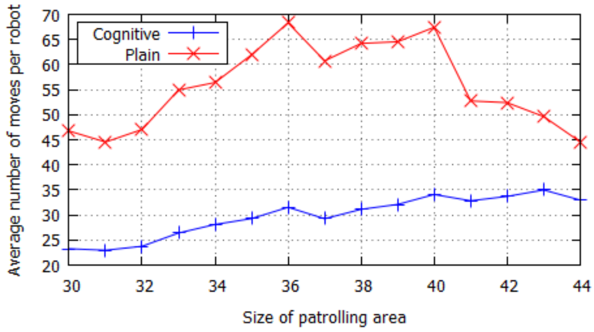
Fig.1(a). shows that the *cognitive* solution intercepts the target faster than the original and it depends less from the size of the guarded area. It can be also observed that both curves are increasing. This is because the number of the robots is fixed therefore the dispersion section takes more time in a larger area. Fig.1(b) requires more discussion. As it can be seen, when the guarded area is small the number of average steps are increasing in both cases. However as the area gets larger, the step count start to decrease in the usual case while it still emerges in the cognitive case. This is because, as the robots disperse in the usual case they won't get informed about the intruder. In contrast in the cognitive case sooner or later every robot will get informed about the intruder. However due to the faster interception the increase is not significant. Fig.1(c) shows the total steps taken by the robots during the simulations. The same trend can be observed as on the previous figure. In the usual case after a certain area size those robot who are not involved in the interception are stopped. However in the cognitive case each robot had participated in the interception of the target. This explains the increasing tendency of overall step count. As we predicated, during the simulations the cognitive infocommunication aided solution were always faster and therefore more effective than the *usual* communication-less solution. Thanks to the fact that it involved more robots, it was also more cooperative. And due to the availability of intra cognitive channels the swarm were able to detect an broadcast the end of the interception, which was unsolvable by the usual swarm.

V. Conclusions

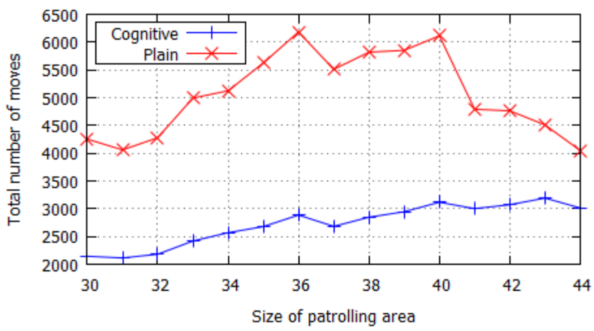
We have introduced the concept of *cognitive swarm* by which a group of individual robots will be able to became a real collective entity which is able to make inter cognitive communication channels with other high level cognitive entities like humans. In oder to evaluate the benefits of the cognitive swarm concept we presented a cognitive infocommunication based solution for a scenario in which a swarm of mobile robots had to guard a given area by intercepting eventual intruders. Therefore have formalised the area surveillance problem and we have presented a simple, *basic behaviour set*-based solution for that. We have extended that baseline solution with cognitive infocommuniation aided capabilities and we have showed that due to these capabilities it is more effective than a usual swarm.



(a) Interception time



(b) average moves per robot



(c) overall moves of robots

Fig. 1. Simulation results for cognitive infocommunication aided (blue) and usual (red) area surveillance solution in fixed size swarm, var. size guarded area, (a) Interception time (b) average moves per robot (c) overall moves of robots

We have evaluated our concept trough simulation results which were made in our discrete simulation environment. As we predicated the cognitive swarm based solution performed two times faster than the usual communication-less solution.

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