Swarm driving with Deep Learning

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***Abstract*—This document is a model and instructions for LaTeX. This and the IEEEtran.cls file define the components of your paper [title, text, heads, etc.]. *CRITICAL: Do Not Use Symbols, Special Characters, Footnotes, or Math in Paper Title or Abstract.**

***Index Terms*—Deep Learning, Deep Reinforcement Learning, Robot Swarms, Q-Function**

I. Motivation

In recent years there has been an unprecedented evolution of communication technologies which introduced engineers to new horizons, which a couple of decades ago were not even imaginable. These advancements brought us a new field, namely the Internet of Things, and now every device has the possibilities to communicate with one another, hence augment exponentially their possibilities, since they are not limited by their on-board resources anymore. In other words, these devices can now fulfill requirements which would normally require to have a lot of memory and computational power.

Being able to communicate with others reliably and fast allows also to create situations where devices can cooperate with others to reach a common goal.

Cooperation has been proven in nature to exceed the capabilities of one individual and already provides a plethora of examples for it. [1]

The most shining example of teamwork in the animal kingdom are bees. A hive of honey bees consists of almost 60,000 different bees, each one having a very specific job and they contribute to the overall success of the hive the same amount. [2]

Cooperation, however, does not bring benefits to complex tasks exclusively. As a matter of fact, ants benefit from cooperation by transporting in groups a weight, which would otherwise impossible to lift by a single ant.

What complex and non-complex situations have in common is that each individual has at its own disposal only its basic and limited sensing of the environment and communication possibilities. [1]

From these biological process the field of robotic has been trying to take inspiration in order to solve very complex tasks with the use of rather simple agents. In most cases, those agents have very basic movement and communication capabilities and are only able to sense parts of the environment; yet, by cooperating, they are able to solve delicate real-time tasks in a fast and reliably way. What this translate to is systems which can solve very complex tasks with a relatively low cost of production, since they do not require expensive resources or cutting-edge technologies to operate.

As M.Hüttenrauch et al. pointed out in [1], usually to implement such cooperative systems a common approach of extracting rules from the environment is used. Such approach, however, if done manually, is not only tedious, but can also become in some case so complex that some tasks become unsolvable. The use of Deep Learning can obviate to this problem and at the same time augment the possibility of the system at the same time, making it more flexible to changes and therefore scalable.

Deep Learning techniques can bring a lot of benefit, however there are nuances which should be known and techniques like Neural Network can be fiddly sometimes. In this paper, we will explore the use of Deep Learning techniques in swarm systems and how they can be used to create fast, efficient, reliable system to tackle very complex problems. In order to achieve this, in the first section, we will introduce what swarm systems are and where they are applied. Subsequently, in the second and third section, we will introduce deep learning and we will define the difference between Deep Learning and Deep Reinforcement Learning. In the last section we will discuss the application Deep Learning in swarm systems with some proposed solutions. Finally, we will discuss an implementation of said techniques in a simulation of a swarm system.

II. Swarm robotics

Swarm robotics, as the name implies, is a branch of robotics which deals with the coordination of multiple, usually simple, robots in order to achieve a common goal, creating structures and behaviors inspired by the ones observed in natural systems. [3] Swarm Robotics usually refers to the application of swarm principles to robotics, while *Swarm intelligence* refers to the general set of algorithms which make swarm robotics possible.

Beni in [4] points out various properties that a swarm of robots must have in order to realize the idea of natural swarming efficiently.

Amongst all of the properties, the more important ones are:

Flexibility
Usually, in order to achieve the proposed goals, robots in a swarm need to solve a variety of tasks, therefore the system needs to be flexible. Robots should be able to find solutions for each task by working together and be able to act simultaneously and change their role according to the environment

Scalability
The system must be able to work independently from the number of robots in the swarm. Different task may require a different number of robots, hence the number of group members should not influence the overall performance of the system. The system, finally, should be effective when the swarm is small and should be able to support the cooperation amongs the member of a large swarm

Robustness
The swarm must be capable of cope with environmental disturbances or any fault that each single robot might encounter, or even if any of the robot fails. The robots in a swarm tend to be simple, therefore more error-prone and more subjected to environmental disturbances, and the errors which might be generated should not influence the performance of the whole system.

There are also other properties which should be taken as a to-do list when designing swarm systems. [3]
Each robot should be autonomous, hence able to act on their own, without a central entity commanding them.
The robots in a swarm should be self organized, hence able to cope with the environment and reorganize themselves accordingly. This is also a very important aspect for swarm robotics, as the main goal is to accomplish tasks in coordination.
Swarms are finally also decentralized, so there's no central leader, as it might be a single point of failure and hinder flexibility, scalability and robustness.
If these properties are respected, swarm robotic applications offer many advantages. Not only each robot has the possibility to autonomously cope with environmental changes, but they can combine their resources to provide unlimited features and possibilities in flexible and scalable systems. This creates very powerful and fast systems at a relatively low cost, since robots have very simple design and swarms are inherently parallel, since each task can be divided into sub-tasks assigned to each robot. [3]
Swarm robotic systems, however, bring not only advantages, but also disadvantages, mainly in real world applications.According to Matarić in [5], the main drawbacks are:

- Their decentralized nature does not make them suitable nor optimal for many applications and makes a the notion of global knowledge, which is required in real-life application, not trivial to implement.
- Due to their autonomy, the robots tend to act spontaneously to their surroundings and this might result in robots acting differently than the other.

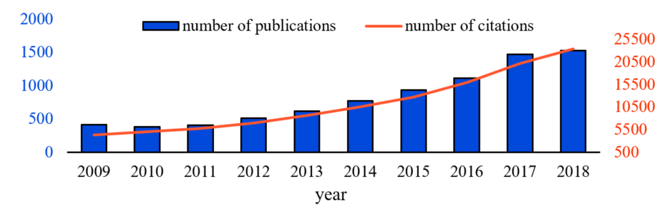

Fig. 1. Numbers of publications and citations in autonomous driving research over the past decade. [6]

- The simple design of the robots makes the implementations of systems with a hundred percent guaranteed goals achievement particularly tough

These drawbacks, as challenging as might seem, are not hindering the work both the industry and academia are putting on this approach, as the trade off between those and the benefits is considered highly valuable.

III. Application of Swarm Robotics

As mentioned in the previous section, one of the properties which defines swarm systems is their great flexibility and this is reflected in the amount of fields in which swarm systems are recognized to be of great use.
Autonomous cars are highly considered the future of the car industry and this is shown in the fact that the number of papers about the topic is rapidly increasing as years go by, as shown in Fig. n. 1. [6] Although the technology is advancing at an

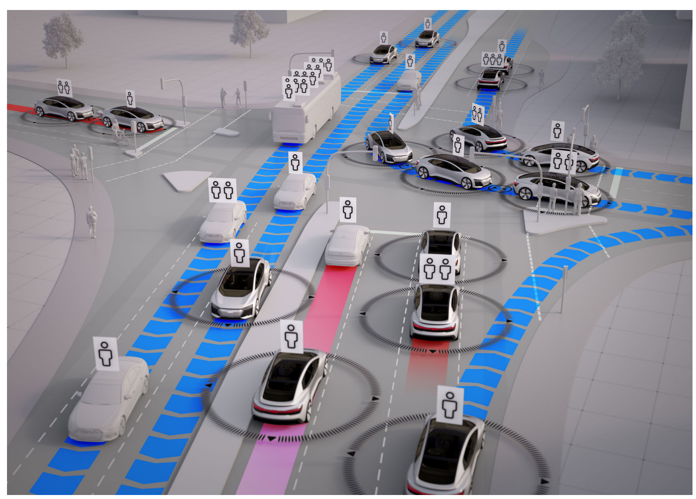

Fig. 2. Audi study "25th Hour – Flow": No Congestion in the City of the Future (Example City Ingolstadt) [7]

unprecedentedly fast pace, so fast in face that technologies become obsolete within years [6], many still questions the safety of this new way of conceiving road mobility ([8], [9]). To increase safety for passengers in autonomous vehicles, German car manufacturers Audi and Daimler consider swarm robotics as the main solution. ([7], [10]).
Both visions share a particular term: "Car-to-X" principle. The Car-to-x principle can be thought as an augmentation of both

the Vehicle-to-infrastructure (V2I) and the Vehicle-to-Vehicle (V2V) principles. Basically, according to this principle, every car exploits the properties of 5G to communicate not only with other cars, but also with every other entity in the environment to receive information about traffic, parking spots, various dangerous like icy roads or bikers, etc. (Fig n. 3). The information are then dealt with using swarm intelligence techniques to achieve the most stable, flexible and robust system possible.
As Audi claims ”The car-to-x technologies developed by Audi open up numerous new possibilities for making driving safer, more relaxed, and more intelligent”.
Where swarm robotics technologies really shine, however, is in the farming field. According to some, farming is now undergoing a revolution thanks to swarm robotics. [11]
One of the most notable example is the Swarm Robotics for Agricultural Applications (SAGA) project. [12] [13]
The main goal of this project is to demonstrate the advantages of multi-robot systems, guided by swarm intelligence principles, working in farms over the current state of the art within the context of monitor/mapping. [12]
Unmanned Aerial Vehicles (UAVs) are programmed to work collectively in order to build a map of the field,in which the plantation is divided in different areas with different semantic tags in such a way that the spatio-temporal planning of weeding operations is facilitate, also with the use of autonomous precision weed removal robots.

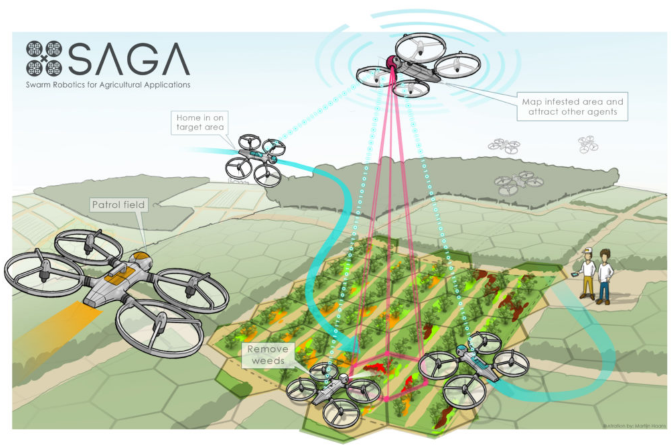

Fig. 3. Vision of the Saga project (https://echord.eu/saga.html)

The application of swarm robotics in Agriculture, however, is not limited to the monitor scenario or for inspection tasks, like the solution proposed by Carbone et al. in [14], but rather applicable to every other scenario. As a matter of fact, Fichtl et al. in [15] proposes a concept consisting of tractors with an intelligent and modular (tillage) unit using swarm intelligence to cooperate with each other.

IV. Deep Learning

- What is deep learning
- positives
- Negatives
- Application in robotics

V. Deep Learning and Deep Reinforcement Learning

- What Deep reinforcement learning is
- Main positives
- main drawbacks relative to deep learning

VI. Deep Reinforcement Learning in Swarm Driving

- Machine learning in swarm driving in general
- Q functions
- Example where normal learning is used in swarm driving
- how deep learning can benefit, especially in terms of q functions
- Examples of implementations where they use deep learning in swarms

[16]

VII. Implementation

VIII. Conclusion

[1] [17] [18] [19] [20]

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