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Abstract

SWARM ROBOTICS

Researchers have always been inspired by nature to find elegant solutions for modern problems. One of the most astounding behaviours observed in nature are swarms. Swarms of simple-minded species work together to solve complex issues that cannot even be perceived by an individual belonging to that group. It is nature's way of combining intelligence to build a next level of intelligence. This trait of swarming is observed in many species, from simple celled bacteria to insects like ants, bees to aerial birds (starlings) and even in aquatic life in fish(herring) and krill.

Swarm robotics deals with the idea of working together to solve problems with relatively simple robots that could never accomplish the task given infinite time but with the help of a swarm, the ability to solve complex problem increases exponentially. It is an evolutionary approach to emergent intelligence in the field of science and engineering. It does not require high computational power or a very good neural network, it just needs simple robots but a lot of them which results in an unexpected super intelligence or swarm intelligence.

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1 INTRODUCTION

Evolution is a process of invariably selecting most efficient systems, where various systems with different capabilities are tried and tested for billions of years. the complex behaviours we see in various life forms is the result of this relentless process. One of the fascinating complex behaviours observed in nature is swarms. A Swarm is defined as large group of entities which exhibit collective behaviour that coalesce in order to accomplish a task. This trait of swarming is observed in many species, from simple celled bacteria to insects like ants, bees to aerial birds (starlings) and even in aquatic life in fish(herring) and krill.

Swarm robotics (SR) is a field where a group of agents try to mimic the behaviour patterns observed in swarms in nature. Autonomous multi robot systems that exhibit these set of behavioural principles form a collective intelligence or also known as swarm intelligence. The term swarm intelligence was introduced by Gerardo Beni and Jing Wang in 1989, in the context of cellular robotic systems, which defines swarm intelligence as a group of non-intelligent robots able to perform a complex task which cannot be achieved by a single agent individually that belongs to that group. (Beni, 1993).

On top of swarm intelligence, Swarm robotics also deals with the physical embodiment of the agents and their interaction with each other and also with the environment. The goal is to create an end to end physical system that can function abiding by the rules of swarm intelligence and also have a physical manifestation to execute ideas.

Inspired from nature, relatively simple agents can perform fascinating tasks when they work together. Ants colonies search through huge territories to find food work together to move it to their shelters in a coordinated way. School of herring shifts in direction instantaneously to fool their predator. Same properties are displayed by termites, bees, birds and many more. (Ying TAN, 2013). An individual entity in these swarms, it seems so small compared to the sheer size of the swarm. It is mind boggling that this group can coordinate at all. When one individual at one end cannot understand what's going on with another individual at the other end. It is mesmerizing how efficiently they work together without any centralized leader. Who is in charge?

This sheds light on the fact how intelligence emerges from individuals with very limited computational power when they work together.

"A brain is a system of neurons so deeply connected that an intelligence is formed. A swarm is a system of brains so deeply connected that a super intelligence is formed."

- Dr. Louis Rosenberg

This is the general idea behind swarm robotics. We need not create exceptional artificial intelligence models or exceptionally efficient individuals. We can make relatively simple agent but make lots of them, with this we can make them do things we want. Not only things that are found in nature but align them with the pressing issues of mankind.

2 SELECTION

Robots have clearly proved efficient in the industrial era dealing with heavy materials or to speeded up repetitive tasks in assembly lines. Various applications of robotics are now being directed towards solving much more pressing concerns, like the use of drones in search and rescue operations or use of robots in agriculture. (Fernando Alfredo Auat Cheein, 2013)

The reason robotics is not used widely in areas like this is due to budget constraints. The real world is still very unpredictable and even small reparations to the robot can end up in large sums in maintenance. The cost of sensors and actuators is very high, hence reducing the cost of robots is still one of the major challenges of robotics.

These principles promote the realization of systems that are fault tolerant, scalable and flexible. A work around for this is the main advantage of swarm robotics. Swarm robotics are not fully connected systems they cope well with loss or failure of one or more agents, as loss of an individual robot does not cause the swarm to malfunction. (Justin Werfel, 2005)

Therefore, swarm robotics is a promising approach that can be pursued as individual agents are fairly cheaper compared to robots in other fields of robotics. So, areas of interest could be harsh territories where the probability of damage is high. Swarm robots are also highly efficient in accomplishing mountainous tasks, as it is scalable the work can be divided and coordinated with high robustness: other individuals can take over work previously worked in by an agent that is now damaged. (Justin Werfel, 2005)

Examples of tasks that could be profitably tackled using swarm robotics are building, demining, search and rescue (Ross D. Arnold, 2018), planetary or underwater exploration, and surveillance.

3 EVALUATION

This section will evaluate various aspects of swarm robotics namely from technical, social to industrial impacts.

3.1 TECHNOLOGY

The main challenge in swarm robotics is the miniaturization, and this also leads to cost as the number of agents is large. Therefore, there is a huge emphasis on making agents as simple as possible but they keeping in mind they have to be equipped enough as the entire swarm has to accomplish a particular task.

The design of a robot swarm is a difficult endeavour: requirements are usually expressed at the collective level, but the designer needs to define hardware and behaviour at the level of individual robots. The resulting robots should interact in such a way that the global behaviour of the swarm meets the desired requirements. Approaches to the design problem in swarm robotics can be divided into two categories: manual design and automatic design.

We can look at this problem in two ways. We either model the agent individually or model the entire swarm, there are two levels of scaling micro and macroscopic levels (Erol Şahin, 2008):

I. Microscopic level

   At microscopic level, modelling is carried out at an individual level. This is a tedious task each robot in the swarm has to be separately represented, and given the large numbers it’s a difficult task. Hence microscopic modelling usually relies on computer-based simulations.

II. Macroscopic level

Modelling is carried out at a swarm level; macroscopic modelling takes into account the collective behaviour of the swarm. This type of modelling has clear advantages over microscale, like complexity and scalability.

So, there has to be a decent balance between simplicity and capability of the agents. Researchers usually use hybrid of the two where both the agent and the entire swarm are modelled.

Another way to classify swarms is by system control. Heterogeneous/Homogeneous Swarms: - A heterogeneous swarm is a group of robots where agent consist of different/complementing capabilities. These types of swarms can be advantageous in some situations. Example, (Carlo Pinciroli, 2009) uses a group of aerial and grounded wheeled robots, where aerial robots can search vast regions and the wheeled robots can perform various tasks based on the information obtained by the aerial robots. Another example is the heterogeneous control of unmanned mother-daughter network system (Jack Elston, 2008) however this method is not as fault tolerant as any damage caused to an agent cannot be replaced by another agent which reduces the redundancy of the system.

Homogeneous swarm is a group of identical agents. (Vito Trianni, 2007). A research experiment conducted by Harvard shows coordination of a thousand miniature robots (kilobots) to form patterns. (Michael Rubenstein, 2012)

Hence researchers generally use homogeneous swarms as one of the main properties of swarm robotics there is no centralized control, hence agents follow very simple rules and make decisions only based on local knowledge, i.e. neighbours and surrounding environment. As there is no central control dictating on how an agent is supposed to behave the collective decision of all the local agents leads to an emergence of intelligent global behaviour which is termed as super intelligence. As the key is to device large number of groups, due to budget constraints the robots have very small capabilities. So, implement the hardware that can communicate with other individuals is a difficult task. It is tricky to device tiny sensors and actuators.

So, for the purpose of research people started using computer simulations to understand swarm/collective behaviours. Collective behaviours can be further classified into: - spatially organizing behaviours, navigation behaviours, decision-making behaviours, human interaction behaviours.

Spatially-organizing behaviours; - focus on how to organize and distribute robots and objects in space.

Navigation behaviours: - focus on how to coordinate the movement of a robot swarm.

Decision -making behaviours; - focus on how robots influence each other in making decisions (Jean-Marc Amé, 2006)

Human-swarm interaction behaviours focus on how a human operator can control a swarm and receive feedback information from it.

A lot of current research revolves around navigation behaviours. Ant colonies is a great example for this trait. Ant colony optimization (M. Dorigo, 1999) where each ant leaves a trail of pheromones to indicate the path taken to its followers. After this many optimization techniques have been invented namely Particle Swarm Optimization (PSO) (Eberhart, 1995), Differential Evolution (DE) (Rainer Storn, 1997), Artificial Bee Colony (ABC) (Basturk, 2007) and many more.

Simulations can never capture the unpredictability of the real world. Even being able to use hardware arises in electronic failures in sensors and actuators. So many researchers dwell into using hardware with simulations to encounter and resolve unpredictable issues and broaden the scope of swarm robotics. Therefore, one of the main necessities of swarm robotics is to use low cost individual robots to make the system more robust and allow room for scalability. (Emaad Mohamed H. Zahugi, 2012)

Communication in the system is key because a swarm relies on continuous feedbacks. Swarm robotics can be classified based on how they communicate and how the system is formed one way is self-assembling or self-reconfigurable robots. Self-assembling robots connect to each other to form patters like circles, stars, squares etc. The latter is where they can change shapes by altering their connections. This is very advantageous to recover from damage.

To sum up the technological aspect of swarm robotics, there are various ways in which they can be clubbed and divided based on hardware to software to the way we model or control them. Swarm robotics has a plethora of applications based on each method depending on the situation or problem we need to solve.

3.2 Social, Legal and Ethical Impact

Since the industrial age machines have been a part of the society and played a key role in the advancement of the human race. With advancements in science and engineering there has been a drastic increase in the use of machines, from pouring our first cup of coffee to exploring corners of the universe. The innovation of AI has had a huge social impact and use of AI and robotics has become a much more sensitive topic.

Social impact of swarm robotics is the impact of robotics in general. But social, legal and ethical impacts are much global of an issue with respect to robotics. Swarm robotics might not have as much of an impact as assistive robotics.

One area that could be sensitive is social impact on employability. As swarm robots work in large numbers, any current jobs that can be replaced by multi agent systems could be construction based on the work of a Harvard group that uses robots to build structures. (Justin Werfel, 2005). Other than this swarm robotics will not impact legal or ethical areas as there have been no situations where swarm robotics have been used to deal with sensitive personal data.

In a more general view, it is evident that robots have already started to replace workers where repetition is the task as they are far more efficient in terms of productivity and also in terms of cost if we look at the bigger picture. But the same technology is being used to save and rescue others in times of danger, like search and rescue bots or surgical robots (James Chi-Yong Ngu, 2017). Robots have already started accompanying the elderly as assistive robotics, performing intricate surgeries with the precision of few millimetres. Although one can argue the unfortunate outcomes of malfunction in self-driving cars or the privacy issues relating to assistive robotics.

After the data privacy act many new rules are being considered for the transparency of systems. (Academy, 2017) .Hence to answer if AI and Robotics will benefit or not is not a simple answer. Surely there are pros and cons to this argument but at the end of the day I think the pros outweigh the cons and It is our jobs as engineers that we have certain quality standard we abide by to ensure that social and ethical issues are addressed and laws are followed at all costs. (Committee, 2017)

3.3 Environmental impact

One of the major issues of the 21st century is global warming. One of the main advantages of using robots is that they do not use fossil fuels. Robots use electrical energy and consume less energy and produce no waste. Although many components of robots are usually not eco-friendly, as synthetic polymers are extensively used to reduce the cost and as they are easy to fabricate compared to metal.

Swarm robotics can be used extensively for monitor and maintain the environment. Use of swarms will enable the system to cover vast areas, where drones or grounded bots can clean or gather harmful substances to the environment like plastics and maintain the eco system. This can be applied to marine life as well. (Miguel Duarte, 2016) Humans have already polluted a fair bit of the ocean, use of aquatic swarm robots can make sure we not only rectify the damage but also make sure it is maintained.

So, in conclusion, with the use of eco friendly materials to fabricate the links or the body of robots, swarm robotics can surely help the sustainability of the environment and keep the eco system intact for better survival of not only humans but other wild like too.

3.4 Economic and Industrial Impact

The properties of swarm robotics are flexible, scalable and cost effective. These multiagent systems promising for various potential applications. As they are cost effective, they are ideal to tackle dangerous tasks, such as post disaster help and rescue, which need not put a human life in risk. The nature of these situations makes it ideal for swarm robotics, being fault tolerant losing a single agent will no be a devastating as losing an entire robot costing thousands of pounds. Using swarms also takes advantage of the fact that it can over large areas in short period of time.

Another example is sensing and cleaning toxic spills as mention in (Emaad Mohamed H. Zahugi, 2013). Scalability is also a key characteristic that can be used in this scenario, as these disasters are unpredictable, the need of how many robots is unclear or unpredictable. Being scalable it is easier to add or remove robots to change the size of the swarm entirely. Similar approach can be followed in post-earthquake scenarios. As swam robotic systems do not need any external control they can also be used in unknown environments, such as space or deep-sea exploration, the list goes on.

Swarm robotics is an emerging and promising filed of robotics that offers solutions to many real-world problems.

4 Discussion

Swarm robotics arrived from the study of swarms in a strictly biological sense. Early work on corelating biological research in swarms to robotics made remarkable strides in the science community. Since then swarm robotics is being drifted to becoming a completely engineering field where researchers are finding new and elegant solutions to modern-day problems.

Given the robustness of the systems swarm robotics are yet to be completely accepted by society. Researchers are still yet to figure out the hardware shortcomings and to be able to equip the human operator to control and interact with an entire swarm. They also face many challenges in the field of swarm intelligence (AI), scientists are still to find reliable models that can act as brains to such complex behaviours. Few problems may also arise in the communication front. Although theatrically it is fairly simple but as the numbers increase the loss in communication may be quite significant as mentioned by

Even after considering the drawbacks of swarm robotics the benefits outweigh the limitations by a mile, with endless applications from aquatic, space, nuclear weaponry, surveillance. Pollution and search and rescue.

5 CONCLUSION

Swarm robotics is a relatively new and fast-growing field of robotics. Inspired from nature it is an intriguing and very complex at the same time a very simple idea. After reading current research being carried out by the leading scientist in the field, the concept has clearly convinced me to pursue swarm robotics. It is the perfect amalgamation of mechanical, electronics and Artificial intelligence. Which gives me an opportunity to tackle problems in all these interesting fields. Given that each technology or scientific method has its flaws, swarm robotics clearly has plethora of benefits, and hence is going to be a significant area of focus in the coming era.

It is not only swarm robotics but the notion of swarms that is mind boggling. Consider bees for example, a swarm usually consists of a few thousand bees. In search of a new home, this sounds like a simple problem but this is a life or death decision for the entire colony. They canvas up to 30 square mile area to find a dozen of possible homes. They need to pick the bees possible one taking water heat sunlight pollen and various aspects into consideration and solve this complex multivariable problem before deciding on one viable solution. Studies show that bees pick the right home 85% of the time. Honey bees have less than a million neurons, humans have 85 billion neurons, which means hones bees are so tiny they can’t even perceive the problem but together they can rival a human brain. They do this by forming a swam intelligence. Of hone bees can accomplish so much it’s a wonder how much humans can, or how much swarm of intelligent robots can. Let’s work together in making a better world using swarm robotics.

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