A study of swarm robotics

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ABSTRACT
Swarm robotics is the branch of robotics that deals with large number of robots acting in a group performing different action for the same application with no centralized control but with collective behavior. This paper helps for the addressing of swarm robotics for new learners. Swarm robotics has been evolved from multi-robot to swarm intelligence. This paper deals with the survey of the taxonomy and applications of the swarm robotics. The problems faced while designing swarm robotics is also considered. The simulation platforms for the basic designers in swarm robotics are elaborated

KEYWORDS: swarm robotics, taxonomy, problems-faced, multi-robot

INTRODUCTION
Swarm robotics is a combination of collective behavior and co-operation of robots. These are the low cost robots and their size is negligible hence can be used widely. The collective behaviors are held from the design of swarm robotics and the co-operation achieved as the characteristics of swarm robotics. The characteristics of real nature swarms are being used to define and design swarm robotics.

Swarm Robotics:
Swarm robotics has been defined as “a novel approach to the co-ordination of large number of robots” and as “The study of how large numbers of relatively simple physically embodied agents can be designed such that a desired collective behavior emerges from the local interactions among agents and between the agents and the environment in [4]. The term swarm robotics was coined by Gerardo Beni [5]. Swarm robotics is a field of multi-robot systems with simple robots with respect to the complexity of swarm robotics. Swarm robotics has been evolved from the multi-robot systems to swarm intelligence.

History:
Evolution of swarm robotics is from robotics to multi-robotics system. The swarm intelligence is from multi-robots systems that has induced itself into swarm robotics. The researchers had done many researches and reduced the size, cost, energy and increased the number of robots and tasks allocated for the robots. The natural colonies like bacteria, fish, ants, bees, locusts, birds, primates and human beings constitute swarm robotics. The cooperation and collective behaviors are the main concepts from natural beings and these became inspiration for swarm robotics.

Taxonomy:
Taxonomy was coined in early researches. Taxonomy is the method of classifying swarm robotics based on the concepts and topics related to design swarm robots.
In the paper [1] Levent classified the swarm robotics taxonomy based on modeling, behavior design, communication, analytical studies and problems axes. Modelling is based on sensor-based, microscopic, macroscopic and cellular automata. Behavior design classification is done based on non-adaptive, learning and evolution axis. Learning includes reinforcement learning. Communication is done as interaction via sensing, environment, communication. Problems axes discussed are as pattern formation, aggregation, chain formation, self-assembly, coordinated movement, hole-avoidance, foraging and self-deployment problems.

[2] Brambilla classified swarm robotics taxonomy as methods and collective behavior. Methods coordinate with design and analysis methods. Design method goes on with behavior based and automatic design methods. Analysis methods are divided based on microscopic, macroscopic and real-robot analysis. Collective behavior is presented along with spatially organizing, navigation, collective decision-making and other collective behavior. Spatially organizing behavior classified in [2] are aggregation, pattern formation, chain formation, self-assembly and morphogenesis & object clustering and assembling, navigation behavior are as collective exploration, coordinated motion & collective transport. Collective decision-making conceals of consus achievement and task allocation. Other collective behaviors included are collective fault detection, group size regulation and human-swarm interaction.

Our taxonomy includes all topics needed for the study and design of swarm robotics as the combination of all other researches performed for swarm robotics. Our taxonomy includes methods, behaviors, communication and problems.

**Methods:**

Methods constitute the internal understanding of the swarm robotics. Methods are divided into 2 divisions as design methods and analysis methods. These are both practical and mathematical basis. Analysis methods go for the fulfillment of the requirements and specification of the robots. Design methods are the method for designing the swarm robots.

Design is based on behavior and automatic design methods. The collective behavior is obtained from each single robot hence each robot is tuned and iterated till collective behavior is succeeded [2]. Adaptive design deals with the change in group to survive in the new environment. Non-adaptive design is when there is no change in the group to complete the task. The design concepts are discussed in [1]. Learning is designing swarm robots from the past algorithms, methods and techniques [1]. Reinforcement learning in [1] is determining cumulative value by comparing the action and the state of the robot. Evolution is techniques from the genetic
algorithms to escape from the local optimums [1]. Automatic design is the behavior of the robot without the control or intervention of the human. Many researchers have kept learning and evolution under automatic design.

Analysis methods [2] are to check whether the collective behaviors are succeeded or not. This is normally done by modeling. The models used in analysis methods are microscopic, macroscopic, real-robot, sensor-based, cellular automata and hybrid model. In microscopic modeling only the simulation part is done and the interaction from robot to robot and the robot to environment is analyzed. A single robot is modeled in microscopic model. Macroscopic modeling holds the analysis of the whole system not the individual. In a controlled environment a real robot is tested, this analyzing is called real-robot analysis. Sensor-based modeling is an old method of analysis where the obstacle, sensors and actuators are modeled and tested. Cellular automata is a modeling of the complex system with discrete lattice cells and the cell interaction [1].

**Behaviors:**

Behavior of swarm robots are collective behaviors, navigation behaviors and cooperation behavior. Collective behavior is the description of typical characteristics of the swarm robotics. The behavior at the axis of the robot comes under collective behavior and the behavior of the swarm robots to travel comes under the topic of navigation behavior. Swarm intelligence has been inspired from the cooperation nature of social animals, how they interact with each other. The cooperation is required for the completion of task and to improve performance.

The collective behavior has 2 types as collective decision making and other collective behavior. the collective decision making is how choices of decision are made. The consensus achievement and task allocation also takes the topic of the collective decision making. The best-decision is followed by all other robots chosen from the possibilities of other decisions. The task is allocated by the members itself for the betterment of the performance and to achieve the task. Other collective behaviors include collective fault detection, group size regulation and human interaction [2]. The robots are programmed in such a manner to detect fault by the population itself which is mainly caused by hardware failures. The group size regulation is the capability of determining the size of each group by the group itself, by addition or deletion of robots from the group. Human–swarm interaction [2] is how human controls the swarm robots and how feedback is received from the systems.

3 types of navigation behaviors are discussed by researchers as collective exploration, coordinated motion and collective transport, dealing with the movement of the robots. The collective exploration is achieved from the environment by area coverage and swarm-guided navigation [2]. The area coverage is to create communication between robots by deploying robots from environment. Swarm-guided navigation is of guiding the movement of other robots in the group. Coordinated motion behavior is to avoid collisions while navigation. The cooperation and coordination by each robot to transport an object is said to be collective transports.

**Communications:**

Communication is required for each robot to communicate with other robots or from group to another group in the population or to the environment. The types of communication discussed in [1] and [2] are interaction via sensing, interaction via communication and direct communication. Interaction via sensing is the communication between the robots and its ability to differentiate between robot and the environment. A robot senses the pair robot to do a specific task. Interaction via communication is the communication between the robot and the environment. Direct communication is one to one communication which is not possible in swarm robotics hence it reduces the scalability and flexibility of the system [1].

**Problems:**

Problems are the specifications that hinder for the design of the swarm robotic system. These are the obstacles faced by the researchers while in simulation as well as hardware design. Pattern formation is the complex problem for the researchers because it deals with the avoidance of complexity and chaos. In order to get the global pattern, deployment of the robot is done and the distance between the robots also considered. Aggregation is the method of bringing all robots within a single environment thereby increasing the communication of the robots. Chain formation is bringing the robots in the series to complete a task. For doing this researchers [16] have competed the explorer timeout and the speed and found that when timeout is less speed is more. Self-assembly is the acute property of swarm robots since these arrange themselves into a pattern by the influence of local environment.

Coordinated movement between the robots is also an issue since the distance between each robot should be maintained to avoid collision. Hole-avoidance means how the robot reacts when it faces a hole bigger than the size of the robot. By using the ground sensor, it detects the hole and forces itself to the opposite direction of the hole disturbing the whole system. Other robots detect the force by traction sensors. The problem is to find how to react for this disturbance in the system [1]. The aim of robots in a foraging task is to find the prey and bring them to the nest. This task is also known as prey retrieval task [1]. Self-deployment is done to get the global
pattern. Each robot of the population has the capability of deploying itself to help the population sustain in the environment. Morphogenesis is the method of self-assembling of the robots to complete the allocated job. Object clustering is grouping the objects which are not connected. Physical connections are the hardware connections and the hardware failures within the population.

**Properties:**

The properties and characteristics are derived from the natural swarms. The researchers had said about the different characteristics of the swarm robotics:

- Scalability is the basic property of the swarm robots.
- High redundancy of tasks is upheld in swarms.
- Flexibility in number of robots.
- Most of the swarm robots are autonomous.
- Interaction is by local sensing & communication.
- No centralized control in swarm robotics.
- Cooperation is the unique property of swarm robots.
- Robustness is minded since the system can manage with failure of robots also.
- Parallel tasks are done.
- The system remains stable.
- Swarm robotics are very economical.
- Not much energy is used in swarm robots forming energy efficient systems.
- Group of swarms are homogenous.

Swarm robotics contributes both homogenous and heterogenous [6]. Swarm robotics is said to be heterogenous only when a group of robots assigned a task and other groups are assigned with some other task. The opposite of heterogenous is homogenous.

  - The system can cope up for the failure of one or more robots. Hence creating a high robustness.
  - The swarm robots are of high redundancy. The task allocated to swarm robot will all for sure completed.
  - Scalability has been achieved by local sensing and communication [6]. Scalability and stability is contributed by re-allocating the task when there is a change in size of population without any external intervention. The performance is not affected by the change of size of group. The swarm robotics by itself task allocate causing flexibility.
  - Multi-tasking concept is titled and parallel many tasks are done at the same time. The swarm robotics are very small and are very low in cost hence economical. If the loss or damage for robots, will not affect the financial affairs of the research and applications.
  - Each individual robot must be capable of sensing and interacting i.e. said to be autonomous.
  - Swarm robotic co-operate as following the nature of swarms, ants and flocks to tackle a given task.
  - Only decentralization is performed in swarm robotics i.e. no centralized control is present. No robot is controlled by any other robot.
  - Only local sensing and communication is availed in swarm robotics.
  - As the energy cost for the swarm robotics is very much lesser than a single robot which takes large amount of space and time. Swarm robotics are energy efficient and also reduces the problem of fueling.

**Simulators:**

  - The software packages for robotics are very economical not affordable by new learners hence here are few open source packages which are readily available.

**Virtual Robot:**

Virtual robot is a freeware software [8]. It is composed of VRM (virtual robot modeller), VRT (virtual robot translator) and VRS (virtual robot simulator). VRS can be used to simulate industrial robots [7].

**Player/Stage:**

Player/stage is a 2D simulator which allows the simulation of large number of groups with the combination of both robot and sensors. A series of tasks can be done using player software [9]. Player is the robot control interface and stage is the multi-robot simulation platform along with player.

**Gazebo:**

Gazebo is a general-purpose open source robotics simulation platform [10] extended with user-defined plug-ins and capable of rigid-body dynamics simulation.
Usarsim:

Webots:
Webots has a file as ‘controller’ in C language for simulation. The 2 types of controller files are caterpillar-type webots controller file and snake-type webots controller file [12].

V-Rep:
V-rep has advanced to 3D simulator which is versatile and scalable. V-rep has an integrated development environment [13] based on distributed and script-driven architecture. V-rep has many robotic models, sensors, cameras and actuators.

Argos:

Matlab:
Matlab with robotics toolbox, Simulink provides hardware support packages supporting low-cost hardware such as arduino, raspberry, lego[15].

Applications:
Swarm robotics are mainly used where human intervention is dangerous i.e. where human cannot enter. The main applications of swarm robots are military applications, in reserved forests and also in mines. Many research are done in these decades using swarm robots.

Summary:
This paper conveys the new learners about the basic topics relating to the design. The idea of swarm robotics is discussed deeply in this paper. The taxonomy problems faced and simulators for the swarm robotics are undergone in this paper. The future work goes on to include the future problems and studies relating to swarm robotics as the advancement continues in the field of robotics.

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