SWARM ROBOTICS AND THEIR POTENTIAL TO BE APPLIED IN REAL LIFE PROBLEMS

Mr Sachin Jadhav[1], Mr Aakib Shaikh[2], Mr Kashif Zafar[3], Mr Rajas Patil[4], Mr Injmamul Shaikh[5]

[1]Professor, Dept. of Mechanical Engineering, Dr D Y Patil School of Engineering
[2,3,4,5]Student, Dept. of Mechanical Engineering, Dr D Y Patil School of Engineering

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ABSTRACT: *Swarm robotics is a relatively new research area inspired from biological systems such as ant or bee colonies. It composes a system consisting of many small robots with simple control mechanisms capable of achieving complex collective behaviours on the swarm level such as aggregation, pattern formation and collective transportation to name a few. However, more research is still required to apply swarm robotics in practice. Within the scope of our knowledge at the moment there are no swarm robotics applications for real-life problems. The current research tends to solve specific tasks in controlled laboratory environments. In this paper we survey the existing works on swarm robotics and their applications. We describe a mechanism by which the robot will travel long a direction. We analyse the possible ways of working algorithms of swarm robots and also potential of their applicability to solve real-life problems*

***Keywords**: Klanns mechanism, Swarm Robotics, Robotics, Swarm*

1. INTRODUCTION:

Swarm robotics is a branch of multi-robot systems that embrace the ideas of biological swarms such as insect colonies, flocks of birds and schools of fish. The term “swarm” is used to refer “a large group of locally interacting individuals with common goals” [1]. Swarm robotics systems as well as their biological counterparts consist of many individuals exhibiting simple behaviour’s. While executing these simple behaviour’s, individuals are capable of producing complex collective behaviour’s on the swarm level that no individual is able to achieve alone. Ant colony can be viewed as an example – a single ant has limited sensing capabilities and relies only on local information, but by working together the colony is able to perform rather complex foraging, construction and transportation tasks.

Swarm robotics systems are characterized by simplicity of individuals, local sensing and communication capabilities, parallelism in task execution, robustness, scalability, heterogeneousness, flexibility and decentralized control [2]. Some researchers (e.g., in [3]) conclude that even simple passive entities (such as rice) are able to produce interesting behaviour's (i.e., form patterns) if stimulated by external force. Practical experiments were conducted by Aleksis Liekna, Janis Grundspenkis to analyse characteristic behaviours in a static environment. Swarm robotics was studied in the context of producing different collective behaviour's to solve tasks such as: aggregation, pattern formation, self-assembly and morphogenesis, object clustering, assembling and construction, collective search and exploration, coordinated motion [10], collective transportation, self-deployment, foraging and others.

The analysis of the results of these studies shows that robot swarms are capable to solve these tasks satisfactory in controlled laboratory environments, at the same time there is no evidence of applying swarm robotics to solve real-life problems. **The purpose of this paper is to take a step closer to bridging the gap between research in swarm robotics and their practical applications**. We analyse the existing approaches in the field of swarm robotics and discuss their result applicability for solving real-life problems by outlining tasks that have been studied in the context of swarm robotics systems and analysing their potential practical applications. We also discuss how the tasks could be combined to achieve desirable practical results.

1.1. LITERATURE REVIEW

Simon X. Yang [1] has discussed that an improved SOM based approach is proposed for task assignment of multi robot systems in arbitrarily non-stationary environments in this paper. Current directions of robots are considered and a path tracker is applied in it. Because of the self-organizing feature, the improved approach treats the tasks, the robots, and the around environment as a self-organizing system, which can be automatically changed while the tasks are moving and the robots are tracing tasks. The improved approach can deal with arbitrary number of robots and tasks in dynamic environments subject to tasks being movable. The considering of the robot directions made the approach more reasonable and widely application in real world. The addition of a path tracker guarantees the tracking paths of the robots being smooth and easily applied in real robots.

Aleksander Jevtic[2] has discussed that, the detailed overview of current swarm intelligence research and its applications in swarm robotics. Swarm robotics is an interesting alternative to classical approaches to robotics because of some properties of problem solving by social insects, which is flexible, robust, decentralized and self-organized. Advantages of swarm-based robotics are numerous. Some tasks may be too complex for a single robot to perform. The speed is increased when using several robots and it is easier to design a robot due to its simplicity. Rapid progress of hardware brings innovations in robot design allowing further minimization. The communication between robots is reduced, because of the interactions through the environment. We are reaching a stage in technology where it is no longer possible to use traditional, centralized, hierarchical command and control techniques to deal with systems that have thousands or even millions of dynamically changing, communicating, and heterogeneous entities. The type of solution swarm robotics offers, and swarm intelligence in general, is the only way of moving forward when it comes to control of complex distributed systems.

S. G. Ponnambalam[3] concluded that the research conducted was based on the biological inspirations adopted from the behaviour's of ants, bees and birds. Implicit communication seems to give more robustness in the communication architecture of swarm robotics. Distributed control architecture was preferred compared to centralized architecture to prevent single point failures. As far as mapping and localization is concerned, work is still being carried out to fine tune the problems faced in this domain. In object transportation and manipulation, caging is preferred over the available methods as the constraints in the domain can be reduced and kept simple. In last two decades, research in reconfigurable robotics has taken a good progress. Even so, this domain is still at its infant stage. Path-planning and formation generation is one of the main domains that received a lot of attention from the authors. A lot of new heuristics and algorithms were introduced to solve the problems in this domain. In the learning domain, reinforcement learning (RL) was given much interest by the researchers. In task allocation domain, heterogeneous and homogenous systems are widely discussed. This domain has contributed in development of various techniques as listed in the paper.

Janis Grundspenkis[4] discussed the basic characteristic behaviours of swarm robotics by which we can define a task and algorithm. For example, by combining the ideas of coordinated motion, obstacle avoidance and cooperative hole avoidance might be possible to produce "safe motion" behaviour. Combining mapping and localization and swarm guided navigation would produce "safe navigation" behaviour. Combing safe navigation with safe motion would produce a swarm capable of safely travelling through environment while being aware of the position of individual robots.

R.Arjunraj[5] discussed that he constructed a sex legged robot. It is used to step over curbs, climb stairs, or travel into areas that are currently not accessible with wheels without microprocessor control and other actuator mechanisms. It would be difficult to compete with the efficiency of a wheel on a smooth hard surface but as the roughness of the path increases this linkage becomes more viable and wheels of similar size cannot handle obstacles that this linkage is capable of. Further, pivoting arms could be used to optimize

- The height of the legs for the waterline.
- Increase the platform height.
- Reduce the vehicle width.
- It allows the legs to fold up compactly for storage.

1.2. Tasks of the swarm:

The potential applications of swarm robotics range from surveillance operations to mine disarming in hostile environments. We believe it is essential to identify the tasks that can be solved using swarm robotics. According to recent literature reviews [1; 2; 17-19], swarm robotics has been studied in the context of the following tasks:

Aggregation deals with spatially grouping all robots together in a region of the environment. Aggregation is used to get robots in a swarm sufficiently close together and can be used as a starting point for performing some additional tasks, such as communication with limited range. Aggregation near points of interest can be viewed as the first step of more complex tasks, such as collective transportation where objects of interest need to be transported by several robots. Research in aggregation includes.

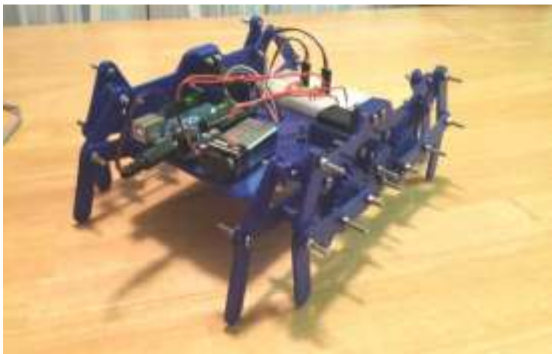

Figure:- A typical Swarm robot working on klann mechanism

Aleksis Liekna, Janis Grundspenkis summarised characteristic behaviour of swarm robots in following points:-

Pattern formation considers robot deployment into environment forming some sort of geometric pattern such as a circle, a square, a line, a star, a lattice, etc. Pattern formation is useful in preserving communication range and helping to overcome environment limitations (e.g., forming a chain to pass a narrow passage). Pattern formation is studied in [5; 22].

In self-assembly robots physically connect to each other to form a particular structure. Self-assembly is used to increase the pulling power of the robots, provide stability to the robot swarm while moving on rough terrains, form a connected structure to guide other swarm robots, assemble structures used to overcome holes that a single robot would fall into and to combine capabilities of heterogeneous robots. Self-assembly is studied in several large-scale research projects such as SWARM-BOTS [4; 5], Symbrion [6], Swarmanoid [23] and Replicator [24].

Object clustering and assembling involves picking up objects that are spread across the environment and clustering or assembling them in specific regions. There is no connection among objects in a cluster while objects are physically linked together in assembling tasks. The techniques of clustering and assembling are used in collective construction to produce 2D and 3D structures (such as walls) [25-27].

In swarm-guided navigation robots of the swarm are navigated by other members of the swarm. Robots are not aware of their actual location or the location of the target. Instead, the swarm is guided by directions supplied by previously deployed robots forming a communication relay. Examples include robots forming a chain from a pray to the nest and indicating directions to other robots in a foraging task [28], navigation via exchanging navigation messages [29] and flying robots navigating wheeled robots [30].

Mapping is the process of obtaining a map of the environment using a robot swarm. Determining the position of robots or targets in the environment is called localization. Mapping and localization is usually addressed together since it is essential to know the positions of robots to obtain a map. Mapping has dual purpose. First, it is used to map previously unknown (or even hazardous) environments; second, it assists the navigation of robots reducing the need for beacons and swarm-guided navigation techniques. Mapping and localization is studied in [31-33].

Self-deployment addresses the problem of deploying robots (disperse them) in the environment by covering as much space as possible. This task is also known as area coverage task. The self-deployment problem is known to indirectly solve the mapping problem [18]. Potential applications of self-deployment include surveillance and security. Self-deployment is discussed in [34] and [35].

Coordinated motion task represents moving while preserving formation and is also referred to as flocking. This is useful in applications involving movement groups of robots since preserving formation allows avoiding collisions among robots and serves as a navigation mechanism. Coordinated motion is investigated in [10; 36; 37].

The aim of obstacle avoidance is to prevent robot collisions with environment and with each other. Path planning is used to navigate robots in the environment while avoiding obstacles. The research results dealing with path planning and obstacle avoidance are included in articles [38-41]. Obstacle avoidance is also coupled with coordinated motion in [42; 43].

Collective transportation task involves robot cooperation to collectively transport an object, given that the transportation of single object requires more than one robot. Research in collective transport is divided into pushing [44], grasping [45] and caging [46].

In Consensus achievement and collective decision making robots must agree on a common decision such as which path to take or which target to follow. Agreement is achieved by either direct communication via exchanging messages (e.g., voting) or indirect communication using local sensor information (e.g., follow nearest robot). Consensus achievement is examined in [47-49]. Potential applications include scenarios where a collective decision is necessary to successfully accomplish the task at hand.

In cooperative hole avoidance tasks robots must travel through environment while avoiding holes. The hole avoidance for a single robot is viewed as a variant of obstacle avoidance task with holes representing the obstacles. However, robots in a swarm can be connected together while moving in formation, making this problem more difficult to solve. Robots may not only avoid the hole but also assemble into a larger structure and overcome the hole that a single robot would fall into hole avoidance is investigated [53; 54].

Robot soccer is an experimental test-bed for multi-agent and multi-robot algorithms. To be successful in robot soccer, a team of robots must possess various skills and capabilities, combining existing research and introducing novel algorithms. Examples of studies in robot soccer are [58] and [59]. From a practical application point of view robot soccer is interesting in terms of collaboration in competitive scenario. Ideas from robot football could be transferred to other applications such as military defence operations.

The above mentioned tasks are studied together or separately depending on the research conducted. We consider these tasks as basic building blocks to produce a swarm applicable in real-world scenarios. We agree with the authors of [19] in terms that new research should focus more on applications of previous work. The authors of [1] also mention that future swarm research should focus on addressing multiple issues, not just one. Considering the above mentioned we introduce an example of swarm application and analyse how the abovementioned tasks can be used to solve it.

2. Working:-

In Swarm robotics as there are many robots working for a given task assignment. The robots faces numbers of problems at single time in a dynamic environment. The microprocessor has to produce best solution for different problems supplied from many different robots at a single time. The main concept of working of swarm robotics is simple, first sensors are positioned to sense surrounding problems. Then the signals are processed by microprocessor. And then a best possible action is taken by microprocessor according to the problems and the given tasks. There are many methods used by microprocessor to solve many bots problems in one shot according to given tasks.

Some methods are proposed to efficiently control a group of robots moving to task locations. Most of the early methods are proposed for static environments, such as the graph matching algorithm [61], network simplex algorithm, agent based algorithm [63], pattern formation algorithm [64], and dynamic Tabu search algorithm, Voronoi diagram approach. These algorithms mainly focus on the task assignment problem without considering the current situation and motion planning of robots, and without considering the movable task locations. Other studies focused on priority control of a small group of robots, which normally break a task into several subtasks and then complete the task by competing with little cooperation among the robots. Miyata et al. proposed a method to solve the problem of transporting an object from one to another place using a group of robots in unknown static environments. This method focuses on dividing the transport task into sub tasks with priorities and then assigning the subtasks to different robots. The method is fitted to a small group of robots and a static environment. Uchibe proposed a method for task assignment of a group of robots by pre-designing of subtask models. This method focuses on solving conflict among model selections. It is suitable for a small group of robots with a task which can be divided into several subtasks.

Recently improved approaches are proposed. For example, inspired by the self-organization phenomena of biological systems, Shen et al. [69] proposed a "Digital Hormone Model" for multi-robot self-organization to form a global pattern. However, this algorithm didn't consider negotiation and cooperation among robots. It also cannot deal with multiple tasks and dynamic location situations. Passino [70] proposed a method by modifying a static method to fit dynamic environments. It is available to deal with a dynamic environment, but additional computational costs arise in this method. Michael et al. [71] proposed a distribution algorithm using market-based coordination protocols to assign tasks to multiple robots. This algorithm focuses on dynamically assigning robots to desired task locations by bidding among robots. This method can be applied in applications such as distributed formation control, and merging and splitting of robot groups, but without considering sudden changes of situations in terms of the task or robot changes. Frew and Elston [72] proposed an algorithm for task assignment of multi robots. It integrated area search and target tracking to maintain a coordinated coverage map by all robots. Each robot can reach an unsensed target by this algorithm. However, this algorithm didn't consider complex situations such as a robot reach more than one targets or more than one robot reach one target. Zhang and Wang [73] proposed an improved Hungarian algorithm by adding genetic algorithm for task assignment of multiple robots. By using this method, the robots have temporal cooperation, and can reach targets with improving the survival capability of the team. However this method didn't consider the robot situations, such as some of them are destroyed or added.

A self organizing map (SOM)-based approach is proposed for multi-robot systems to tackle the task assignment problem which focuses on the self organization issue with a large number of robots and a large number of task locations in varied environments. It combines the target assignment and motion planning for a multi-robot system, allowing the robots to start moving before their destinations are finalized. It is capable of dynamically controlling a group of mobile robots to achieve different task locations in sudden changes in situations, such as the breakdown of some robots, the target being movable(60).

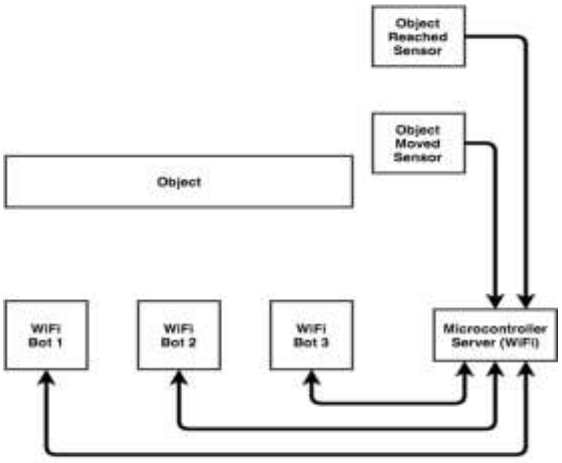

Fig:- Architecture

2.1. Klann Mechanism:

Klann mechanism was inspired by watching legged animals. The main objective here is to replace the rolling motion with legged motion. Klann mechanism provides the best way possible for a bot to render on a surface with legs attached to it. In this mechanism links are connected by pivot joints and convert the rotating motion of the crank into the movement of foot similar to that of animal walking. The proportions of each of the links in the mechanism are defined to optimize the linearity of the foot for one-half of the rotation of the crank. The remaining rotation of the crank allows the foot to be raised to a predetermined height before returning to the starting position and repeating the cycle. Two of these linkages coupled together at the crank and one-half cycle out of phase with each other will allow the frame of a vehicle to travel parallel to the ground. Klann Mechanism shows promising application due to its feasibility of working mechanism. Klann Mechanism can be used in military based applications and many more[74].

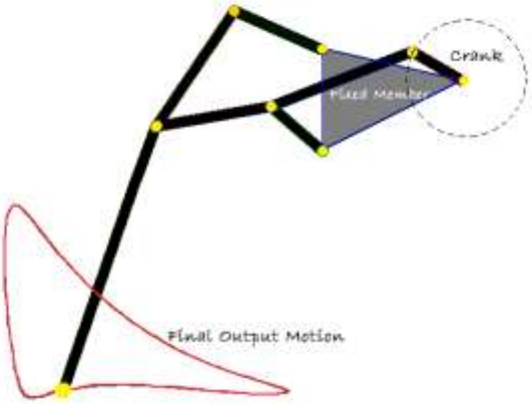

Fig:- Klann's Mechanism

2.2. Practical application of swarm tasks:

We introduce an example of practical application where swarm robotics could be used and analyze which tasks can be applied for the swarm to be successful. The aim is to show how the tasks identified in the previous section fit into solutions for real-world problems and how they can be combined to achieve the desirable result. Consider an example of agriculture – a field that needs to be cultivated. The task is to mow cereals and deposit them at the warehouse. A swarm of robots with the appropriate capabilities (e.g., harvesters and transporters) is sent to complete the task. This is how the tasks contribute to successful completion of the mission.

At the beginning of the mission robots aggregate on the field to achieve the starting point of the mission. To effectively cover the field while performing the mowing operation, robots form patterns, e.g. lines of harvesters. Harvesters self-assemble with transporters providing harvester-transporter combo. Ideas from object clustering and assembling are used in two phases of the mission. First, mowed cereals are clustered by harvesters in specific points of the field for them to be later picked up by transporters. Second, at the warehouse object clustering and assembling are used to store the goods in an effective way. To overcome drawbacks (or lack of) GPS signals, robots use moving beacons for navigation on the field. A precise map of the field is constructed during the mission and used to overcome environment limitations, e.g., large rocks in the field. After the initial aggregation at the beginning of the mission, robots use techniques from self-deployment to cover the field in the most effective way. While mowing, robots sustain a pattern of harvesters moving in lines to effectively cover the field. Robots avoid obstacles such as rocks and trees and use planning techniques to construct collision-free paths. Depending on a situation it might be beneficial for a group of transporters to collectively transport a large amount of goods at once instead of transporting smaller amounts several times. Harvesters and transporters collectively decide upon the most beneficial way to act upon a field. Harvesters either cluster goods at specific regions of the field where transporters pick them up later of self-assemble with transporters to provide harvester-transporter combo. The entire scenario can be abstracted as a foraging task where robots go into the field, forage for goods and then return to the warehouse.

3. Conclusions:

In this paper we have summarized tasks that have been studied in the context of swarm robotics and discussed the practical applicability of these tasks. To take a next step towards practical application of swarm robotics, a research on combining multiple task types should be conducted. The task types studied in the context of swarm robotics can be considered the basic building blocks to produce more complex behaviours with bigger potential of practical applications. One of the possible steps in this direction is to combine studies in the existing task types to obtain new ones aiming at specific practical applications. For example, by combining the ideas of coordinated motion, obstacle avoidance and cooperative hole avoidance might be possible to produce "safe motion" behaviour. Combing safe navigation with safe motion would produce a swarm capable of safely travelling through environment while being aware of the position of individual robots. Such swarm has direct application in surveillance and patrolling applications. The best possible methods to produce best algorithms were also discussed, out of which SOM seems to provide the best solution. The mechanism by which the robot will transverse along a surface is given by Klann mechanism which converts crank's rotatory motion into linear displacement of robot legs. Klann Mechanism seems preferable option while travelling along a rough surface, hence having promising military applications. We believe this research topic is of great potential.

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