Shape Formation using Self Assembly & Self Healing Intelligence for Swarm Robots

S. Sunil Anantha Kumar[1], G. Muralidharan, Dr. S. Gajendran
Department of Production Technology
Madras Institute of Technology
Anna University, Chennai-600044

Abstract—**The proposed work is inspired and evolved from nature's way of solving problems in a collective fashion. The objective is to design, fabricate and analyse a swarm of mobile robots and to develop an algorithm which can make them move and form a particular shape in shortest possible time.**

Keywords—Swarm robotics; robotic collectives; multi agent robots; shape-formation; self-healing

I. INTRODUCTION

A classic example, in the animal kingdom there exist animals such as elephants which can carry out bulky tasks single handed but whereas when it comes to ants it is difficult for them to carry few grains of rice or food in the same manner. This problem is overcome by a cluster of multiple ants which interact by sending and sensing information with the help of chemicals produced called pheromones. This technique helps the ants in accomplishing many tasks even to the level of building themselves huge ant hills and other complex structures as cited in the work (Ying T.et al.,2013) in [16].

The work is primarily focused on developing a method for controlling a robot collective swarm in which a group of identical robots with limited intelligence and knowledge of the surroundings to form a shape through individual localization, hold its position by keeping the robot in the same position through feedback systems, and be able to repair itself by determining the robot that is damaged and to replace its position with a next eligible robot in the collective. More features that are to be concentrated in the scale is at which the robot needs to create the shape .This enables the control algorithm to work with any size and any scale of operation. The robots are made to assume different roles based on their location in order to form the shape and make necessary corrections if needed. When compared to real biological systems the devised system will have less number of sensors and be cost effective and will work in a controlled environment, making the system robust to the trained environment .assumptions are made such that the robots do not have any prior knowledge of its location and its orientation. However, the robots will be associated with a unique ID for ease of access.

The project will be completed by solving the problem divided into 4 parts. The first problem solved is to self-align the robots into a given coordinate system. The second problem to be addressed is the formation of the shape which is predefined in terms of the points in coordinate space. The issue in this problem is to avoid any ongoing robot in its path (Oscar C. et a. 2012) in [11]. Make trajectory planning and be able to move in the shortest path possible .third task to be addressed is the scalability of the robot group .the robots must understand the new scale if presented and must accommodate the new coordinate from the old coordinate .The fourth problem is to enable multi-level communication amongst the robot disregard to the leader or follower system all the robots must know all the current locations .This is required in order to quantitatively know if any robot is misaligned, lost, damaged for replacement by other robots.

The first step is to create a common coordinate system for all the robots in the controlled environment and make the robots to respond to the given coordinate system .The robot must be able to trace its location against the total world coordinate of the environment .It must be able to localize itself from the origin of the system. This is done in two stages: One is to find the global origin coordinate and to create a reference point for all the robots. Next to go to the specified target position by using trigonometric relations and point to point distance formulae to reach the point as described in the work of (Chien C., 2009) in [1]. The ultrasonic range sensors give a definitive estimate of the distance as the feedback for the system enabling the closed loop control. All this done keeping the basic obstacle avoidance programs enforced to avoid direct contact amongst the robots.

The second step involves the robots to hold the shape that is to maintain the coordinates even in an event where the coordinates are slightly been disturbed. Now if the disturbance is higher than that of sensors reach, example if the robot is damaged or the robot sensors malfunction or motor damage .then the robot is disengaged from the mission of shape formation and the roles are interchanged amongst the robots which is discussed in details in the algorithm chapter ,allowing the new robot to capture a new position and the integrity if the shape is preserved .the importance is explained in (Dandan Z., et al.,2007)[2],(Haghighi .R, et al., 2012)[3], (John H., et al., 1999) in [5],(Teddy M. et al., 2011)in [14] ,(Paola F.,et al., 2008) in[12].

The third step involves scalability .this enables the user to set the scale at which the robots may arrange themselves. This is not a major work in the project but is important since it forms the crucial part swarm robotics itself as described in (Manuel M., et al., 2012) [7] and (Masao K .,et al,2014) in [8] . When working in larger groups the size of the shape is essential .this is because the individual robot size and minimum clearance robots can offer amongst themselves and the ability to accommodate themselves in the given controlled environment.

The final step is actually the requirements of communications require by the system on the whole (HuiKeng L., et al.2011) in [4]. This is mostly needed just in case one of the robot fails to cooperate in the group but also to keep all the robots aware of the other robots position in relation to one another .this is still in study and Bluetooth is used as a technique with pairing and raster or polling techniques can be used to send and receive data. The evaluation of the system is crucial to the real time scenarios as suggested in (Micael S. et al. ,2013)[9]

II. PROBLEM STATEMENT

The work is focused on solving two problems of robot control. For both the problems the robot is given a desired shape. The first problem is to create make the robots to understand the environment and to reach the location of preference as per the algorithm given to it .The second problem is to hold the position and resist any damage by giving in self-healing algorithms as shown in (Ye-Hwa C. 2010) in [15].

This involves the robots that are displaced in the group to realign to its original space by the following steps (Michael R. ,2009) in [10]. Firstly analysing the location where is now placed. If the location formed is too far off or if the sensors failed then a new robot is placed in the location by applying the previous technique .the robots are to follow the spatial role based on the coordinate it is present . The problem can be graphically be shown below

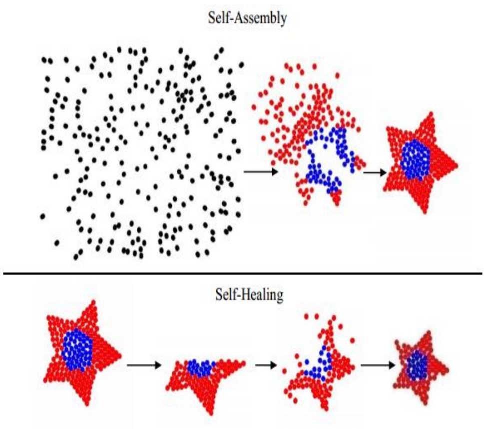

Fig. 2.1. Demonstration of self-assembly and self-healing algorithms. (Michael R, 2009)

III. IMPORTANCE OF SHAPE

The general of swarm is analogous to the term swarm in animals. As cited in work (Yong Z. et al., 2013) [17] where in many of the works done by various authors. For example, the shape of a bird helps give it the capability to fly, while flight is obviously not a capability of its individual cells. Similarly, the shape of a robotic collective plays a role in the collective's own capabilities, so it may be desired that the collective also be able to form and hold the property of shape, in order to maintain its capabilities. For example, a simple cube shaped robot (Fig. 3.1(A)) is not capable of holding water; however, if it is part of a collective that forms a water tight shape (Fig. 3.1(B)), such as a cup, then the collective of these robots gains the capability of holding water from its collective shape. In a second example, imagine a single SWARM-BOT (Chien C, et al. 2002) in [1] reaches a canyon like obstacle with a goal on the other side (Fig. 3.2(A)). By itself, a single SWARMBOT is not capable of crossing the canyon to reach the goal on the other side. However, if the SWARM-BOT joins a collective of other SWARM-BOTs, and forms a collective shaped like a bridge, the collective's shape enables it to cross the canyon and reach the goal (Fig. 3.2(B)).

In a third example, a single Superbot robot (Samuel R.2009)[13] needs to locomode as far as it can until its battery pack empties. As a solitary Superbot (Fig. 3.3(A)), it can only travel 200 meters until the battery is empty. If this single Superbot can form a collective with five other Superbot robots in the shape of a wheel (Fig. 3.3(B)), then it can move over 1000 meters until its battery pack depletes. In this case, the shape of the Superbot collective enables the collective to travel at least five times as far as any single Superbot can travel.

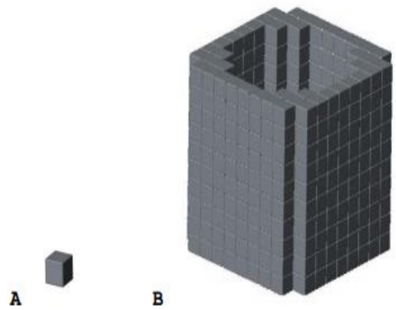

Fig. 3.1 A.Cube shaped robot.

A. Multi cube shaped robot forming a cup

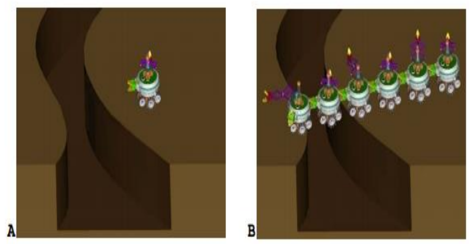

Fig. 3.2. A.Swarm bot inefficient crossing canyons B swarm collective crossing canyon successfully.

Fig. 3.3 A. super single link. B .Superbot module swarmbot.

Besides shape, another way a swarms achieve capabilities beyond that of the individual robot is when all robots take a specific role. This differentiation does not only causes the collective to lose its homogeneity just as a group of homogenous state machines remain homogenous even if they are not all in the same state at a given time (Michael .R. ,2009). Differentiation is common in games, such as when team captain differentiate to team players, depending on their location within the play field.

This arrangement makes it efficient to from invaders (Yong Z .et al.). If, instead of arranging themselves on the surface, skin cells were just randomly distributed throughout the body without any regard to location, then they would lose their effectiveness. In a second example of differentiation, consider an ancient military formation called the “testudo” or tortoise shell (fig 3.4). In this example, a collective of soldiers differentiate into two location-dependent roles. The spatial-temporal role map for the testudo formation dictates that the soldiers in the front row hold their shields in front of themselves, protecting against frontal projectile attacks, and that the soldiers in the back rows hold their shields on top of themselves to protect themselves.

Fig. 3.4. Special temporal role played by testudo.

IV. METHODOLOGY FOLLOWED

The following algorithm is to be implemented as per the requirement of the given designed robot:

Step 1: START

Step 2: Accept the value for shape under the 5 predefined shapes available

Step 3: Determine the bot according to IP address and send the data over wireless network to all the bots.

This is common to all bots

Step 4: Receive the data for the coordinates to reach in the constrained environment.

Step 5: Using the functions for distance calculate distancecheck enc and motor, navigate to the target position.

Step 6: Make one final distance check and broadcast the value of the current coordinate to all the fellow bots

Step 7: If any bot does not confirm to its location or out of range values are read by sensors, then the following steps are taken

Step 7a: The bot affected is renamed bot last

Step 7b: All the other bots are renames to bot-1 till last bot occurs.

Step 8: Shape and inter bot distance is maintained by distancecheck function.

Step 9: STOP

The algorithm is self-explanatory for the self-healing and self-assembly of the robots to form the shape .mainly the algorithm focusses on the following functions .they are illustrated in the pseudo code.

Formations explaining the shape forming without healing

Fig 4.1 Various steps in formation of shape with SAHAS OFF.

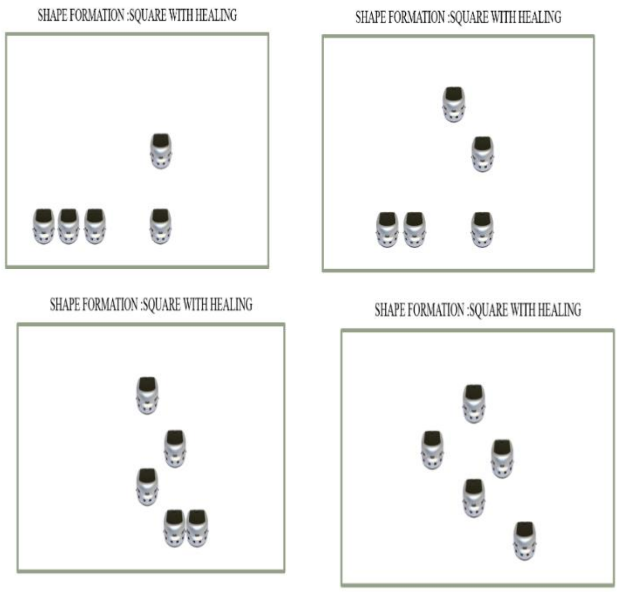

Fig. 4.2. Various steps in formation of shape with SAHAS ON.

V. CONCLUSIONS AND FUTURE WORK

The initial attempts were initiated and the following defects were observed and suitable corrections have been made such that the robot is compact, compatible to any algorithm changes initially the design had considerations to include a holonomic kiwi drive .since the encoder value cannot be quantified and methods are being studied to get the holonomic wheel in order to compact the size even more further. This would enable even sharper turns and pivoting actions.

The second trials were made using Matlab to send data to the data serially to the host robot .the issue is that the command fopen takes considerable time to establish connections. Alternatives to this is use of VB or normal Rterm software's to establish connection amongst the robots.

Trials using Wi-Fi as a medium was carried out but the at commands couldn't be generated and be used with the esp8266 module .after facing several issues in connecting the module the usage of Wi-Fi was discontinued from the usage for communications.

Till date the robot designed is designated to follow simple Bluetooth commands and be able to locomode to various positions in the controlled environment. Programs have been devised to read encoder data and to align itself to a particular angle. The code for using ultrasonic sensor in conjunction to avoid any obstacles have been developed .this enables the robot to follow basic commands to go around the arena at the same time avoid obstacles in order to implement self-assemble and self-healing. The future work plan for the swarm collective is to implement the completed version of the SAHAS (Self Assembly and Healing Autonomous Swarm) and a method to arrive at evaluating the system using unity 3d engine. The software is capable to generating path using various shortest path planning algorithm. Since the work involves a lot of software's to run a simplified UI has to be devised to reduce the complexity of the user in terms of not showing the program and internal working and to create a package in order to install all the required packages for running the program

Finally the requirements to create a team 5 robots which can get the same program and send data amongst themselves in order to accomplish the task without the requirement of human operator .the updated distance values will help to visualise the various paths travelled by the robot using 3d rendering engines and artificial intelligence algorithms.

REFERENCES

[1] Chien C., Saing P., Jean Jacques E. (2009),'Region-based shape control for a swarm of robots', Automatica 45 , pp.2406-2411.

[2] Dandan Z., Guangming X., Junzhi Y., Long W. (2007) ,'Adaptive task assignment for multiple mobile robots via swarm intelligence approach', Robotics and Autonomous Systems 55 ,pp.572–588.

[3] Haghighi .R, Cheah C.C. (2012),'Multi-group coordination control for robot swarms', Automatica 48 ,pp.2526–2534

[4] HuiKeng L., Iain B., Paul C., Jon T. (2011) ,Adaptive data-driven error detection in swarm robotics with statistical classifiers', Robotics and Autonomous Systems 59 ,pp.1021–1035

[5] John H., Hongyan W. (1999) ,'A distributed behavioral control for autonomous robots' Robotics and Autonomous Systems 27 ,pp.171-194.

[6] Luis G., Antonio S., Fabricio G.(2014), 'Robot coordination using task-priority and sliding-mode techniques', Robotics and Computer-Integrated Manufacturing 30 ,pp.74–89

[7] Manuel M., Javier L., Félix P. (2012),'Auction based method for graphic-like maps inspection by multi-robot system in simulated and real environments', Robotics and Autonomous Systems 61, pp. 676–681

[8] Masao K., Hiroshi S., Tatsuro Y., Akihiro Y., Takahiro T. (2014),' Multiple targets enclosure by robotic swarm', Robotics and Autonomous Systems 62, pp.1294–1304.

[9] Micael S. , Patricia A. , Rui P. , Nuno M.F. (2013) ,'Benchmark of swarm robotics distributed techniques in a search task', Robotics and Autonomous Systems 62 ,pp. 200–213

[10] Michael R. (2009) ,'self-assembly and self-healing for robotic collectives' University Of Southern California.

[11] Oscar C., Ricardo M., Patricia Melin, Fevrier Valdez, José Soria (2012) , 'Comparative study of bio-inspired algorithms applied to the optimization of type-1 and type-2 fuzzy controllers for an autonomous mobile robot', Information Sciences 192 ,pp.19–38

[12] Paola F., Giuseppe P., Nicola S., Peter W. (2008),' Arbitrary pattern formation by asynchronous, anonymous, oblivious robots', Theoretical Computer Science 407, pp.412-447.

[13] Samuel R., Nikolaus C., Alcherio M.(2009),'Collaborative coverage using a swarm of networked miniature robots ',Robotics and Autonomous Systems 57 ,pp.517-525.

[14] Teddy M., Andrey V. (2011),'Decentralized control of multi-agent systems for swarming with a given geometric pattern', Computers and Mathematics with Applications 61, pp.731–744.

[15] Ye-Hwa C. (2010) ,Adaptive robust control of artificial swarm systems ',Applied Mathematics and Computation 217 ,pp.980–987

[16] Ying T., Zhong-yang Z.(2013),Research Advance in Swarm Robotics, Defence Technology 9 , pp.18-39

[17] Yong Z., Dun-wei G., Jian-hua Z. (2013),'Robot path planning in uncertain environment using multi-objective particle' ,Neurocomputing 103 ,pp.172–185.