Bio-Inspired Correlation in a Multi-Robot System

Alice Abraham, Jeson Kamalnath R., Naresh T., Ashutosh Tripathy, Samarth Bharani, and Narendra Kumar G.

***Abstract*—Swarm Robotics is an emerging field which focuses on controlling the behavior of groups of Robots which allows a group to perform seemingly complex tasks while having simple individual behaviors. Group behavior among animals have evolved over the course of time influenced by the environment and the need for survival. Due to the simplicity of the nervoussystem in social animals like ants, fish, etc., the individuals in a group perform basic tasks and follow elementary rules which give rise to a group behavior. Aligning the direction of motion along which a preceding animal is heading can give rise to correlation and hence ordered behavior in a group. This is implemented in a group of Robots which are easy to design and construct having few sensors and run small controller programs. The individual Robots follow straightforward rules and perform simple actions giving rise to a correlated behavior as a group which finds application in fire-fighting. The multi-Robot system is simulated in Webots and the results are promising and can be adopted in real time environment.**

***Index Terms*—Swarm robotics, correlation, ad-hoc Networks, we bots.**

I. Introduction

Swarm robotics deals with the behaviour of groups of robots, inspired by the behavior of social animals like ants, birds and bees. A group of simple robots, which are otherwise incapable of complex tasks as individuals can achieve them as a group[3]. Unlike conventional multiple robot systems which employ a centralized control system, swarm robot systems do not have a centralized control mechanism, instead, they are influenced by the environment and communicate with nearby peers through ad-hoc networks. Swarm robots can be highly modular as they need not perform the same task at a particular location. i.e., different groups of robots can perform different tasks as required, depending on the environment[4]. The size of the swarm can be increased or decreased according to the necessity with little to no reprogramming. They are more tolerant to component or individual robot failures than conventional robotic systems and they have very little to no impact on the behavior of the swarm.

The simplicity of the individual Robots command certain advantages as it is easier to accomplish certain tasks with a group of simple Robots than with a single complex Robot. It is also easy and cost effective to design small Robots which perform simple tasks. As an example, a group of Robots will head towards a fire as a group, extinguish it and then move on to other fire fighting tasks immediately.

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II. Behavior of Self-Organizing Groups In Nature

Bird flocks, fish schools, bacterial colonies, respond to disturbances as a group. In many cases, global ordering airses as a result of alignment of individual directions of motions in the group. Origins of the order can be different in different groups. There can be a top-down centralized control mechanism, a leader can be picked by assessing the conditions and the others can synchronize their behaviors with that of the leaders. There can also be bottom-up self-organizing behavior emerging from local behavioral rules[5].

The behavior of the group is dependent on behavioral correlations between the various individuals. Correlation is formed when there is an information transfer due to interaction between individuals[5]. Two individuals who are not directly in interaction can still be correlated due to information transfer through the intermediate individuals. Correlation is a measure of how the change in behavior of an individual affects the behavior in other individuals and is responsible for the groups ability to respond collectively to its environment. Individuals who are nearer to events or disturbances can sense them directly and the other individuals who cannot sense the disturbance (as they may be farther away from the disturbance or blocked due to the presence of other individuals ahead of them) can get information due to behavioral correlation.

Interaction happens between two individuals in the vicinity of each other. Behavioral correlations are the product of inter-individual interaction and research has shown that in birds, the interaction range is in the order of around seven individuals. The spatial span of correlation can be significantly larger than that of interaction. Although correlation length is larger than the interaction range, in most cases it is significantly smaller than the size of the group. It creates localized sub-groups within the group which act independently to environmental disturbances[7]. The individuals in each subgroup are correlated and those individuals who fall outside the correlation range of a sub-group are independent of the sub-group. Hence, the correlation range limits the collective response of a group but at the same time makes the group more robust in some scenarios by making sub-groups of a group react independently to different disturbances simultaneously.

Behavioral correlations have been observed in bacteriaswarms and it has been found that correlation range decays with length and remains shorter than the swarm

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size[6], which creates sub-swarms. In starling flocks however, the correlation is scale free and the range scales with the size of the swarm[5].

The correlation range is as big as the group and all the birds in the flock are correlated. This implies that the whole flock responds to a disturbance as one and there are no sub-groups. Correlation requires inter-individual co-ordination mechanisms, which are not complex. Simple behavioral rules based on imitation can give rise to correlation. One such rule would be to make the individuals change their alignments along with the other correlated individuals[8]. As an individual (a temporary leader), senses a disturbance and heads in a new direction, the other individuals in direct interaction with the leader can change their alignments accordingly and another set of individuals can follow the previous set of individuals hopping the information during which time, there is a decay in the magnitude of information due to noise[5]. The information propagates to a few individuals who are correlated and there is no propagation beyond the correlation range due to loss of information.

III. Implementation

The above discussed group behavior is implemented in a group of Robots following elementary rules with a light source as an external stimulus. The group heads towards the light source and the mechanism is explained in the following sections.

A. Robot Structure

All robots in the group are identical both in terms of hardware as well as software. Each Robot consists of light sensors, SONAR based obstacle detection sensors, Digital Compass for path finding, Differential wheels for steering and movement and Accelerometer to assist in collision avoidance.

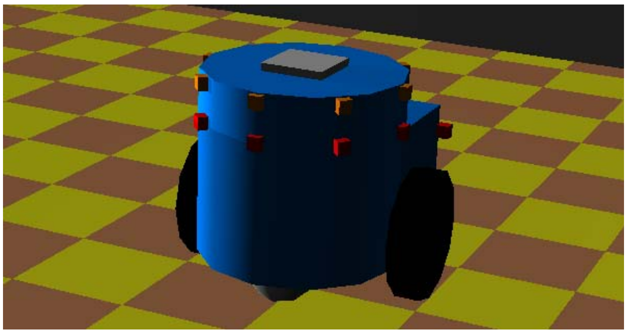

Fig. 1. A Front view of the robot, modeled in Webots.

The orange protrusions at the top of the surface of the robot are the light sensors distributed horizontally around the robot surface at steps of 45 degrees. The SONAR obstacle detection sensors are distributed at the front of the robot at -45, 0 and 45 degrees. Two additional sensors are placed at the rear of the robot at +90 and -90 degrees, which help collision avoidance between individual robots, as found by simulation in Webots.

The Robots use Ad-Hoc wireless networks over Wi-Fi for communication adopting AODV for routing data in the Ad-Hoc network.

B. Group Formation

As in the case of well-informed individuals in natural swarms who lead the group, the group of Robots have a temporary leader. The Robot closest to the light-source is analogous to the well informed individual in a natural swarmand becomes the leader. Other Robots which are fartheraway from the light source or are obstructed by other Robots become followers. Taking the example of a bird swarm, the birds in the front of a group have a clearer view of the environment and views of the birds that follow are obstructed by the birds which precede them. Birds which are at the front of the swarm, i.e. the well informed individuals will move towards a saferdirection upon sensing a predator and the birds behind them will just change their alignments accordingly and follow the leader recursively behind them. There are multiple sub-groupsin a group, similar to bacterial swarms, where the correlation or coherence does not span the entire group but smaller subgroups. There will be a leadership contention process, after which leaders and followers of the various sub-groups will be defined.

C. Communication

The Robots use Wi-Fi and the transmission range of each Robot is around 5 metres. During the contention process, a Robot will form links with only those Robots which are closest to it. Once the sub-groups are formed, the leader will send a message to the Robots closest to it, which will be propagated to the following Robots. In the natural swarms, the correlation range is limited by noise. The information hops only for a certain number of times and the individuals ufficiently far from the source of information will not receive the information. A similar mechanism is used here wherein message from the leader will have a hop limit so that it can be forwarded only a certain number of times. After forwarding a message, the value in the hop-limit field of the message is decremented by 1. Upon the hop-limit reaching 0, the message will be dropped. A follower, Robot A which receives a message directly from the leader can forward it to many other Robots nearer to it. Another Robot B, which also receives the message from the leader can also forward it to other Robots near it. When Robots A and B are near each other, then other Robots which are near both the Robots, will receive the same message from both. In that case, Robot C which is near both Robot A and B can drop the duplicate message. The size of the group is thus determined by the transmission range of each Robot as well as the hop limit.

D. Leaders

The Robot which is closest to the light source becomes the leader. If there are many independent sub-groups, there can be multiple leaders for the sub-groups. Before the Robots can start heading towards the light source, there is a contention process after which leaders and sub-groups are formed. During this process Robots exchange light sensor information using which, the Robots find out if they should become a leader or a follower. The sub-groups acquire a unique group ID number which is the ID number of the leader. As the ID number of each Robot is unique, the group ID number of the various groups are also unique. The sub-group is defined by the limitations in the range of communication of the Robots.

A leader will turn all its sensors ON and search for light. At the same time, it sends its compass reading as well as the maximum light sensor value to the followers.

E. Followers

The followers turn their sensors OFF and follow the leader by aligning along the same direction as the leader. However, their obstacle detection sensors stay ON. The followers use the compass reading of the leader and use it to align themselves to follow the leader. The followers also monitor the maximum light sensor value of the leader. The light sensor value on crossing a certain threshold, indicates that the leader is close to the light source and implies that the leader cannot guide the group anymore as the leader has already reached the goal. The followers then turn ON their sensors and move towards the light source, using sensor information and surround the light source.

IV. Operation of A Robot Group

Each Robot has a unique identification number associated with it. All Robots run the same controller program which has two flags, the leader flag and follower flag indicating the state of the Robot. Each Robot also has a group identification number which specifies to which group the Robot belongs. The message format used by the Robots has five fields: Robot ID number field, which is unique to the Robot; Hop limit field, which controls the number of times a message can be forwarded; Sequence number field, which is used to discard duplicate messages; Maximum sensor value field, which contains the maximum light sensor value of the sending Robot and Direction field, which contains the compass readingof the sending Robot.

A. Leadership Contention

Each Robot checks its light sensor values and finds the maximum value among them. This maximum value along with the ID number is sent to other Robots which are in the vicinity of the sending Robot with each Robot initially assuming leadership and the leader flag is set to 1.

A Robot receives many such contention messages and checks its own maximum value. If the value in the received message is greater, it discards its own value, sets the leader flag to 0 and becomes a follower by setting the follow flag to 1. At the same time it forwards the message to the other surrounding Robots. A forwarded message has its hop limit decremented by 1 and is forwarded till the hop limit reaches 0.

If the maximum value in a received contention message is smaller, the message is discarded and there is no alteration of its state. The Robot will create new packets and sends them to other surrounding Robots. The Robots which have the same leader will form a group and a number is associated with the group which is the ID number of the leader Robot.

After a sufficient number of iterations, the leader and the corresponding group are formed and depending on the number of Robots and Hop limit, many such groups can be formed. In a situation where two leaders are formed and a Robot receives message from both the groups, it can decide which group to follow at random and associate itself.

B. Movement Towards the Light Source

The leader has all its sensors ON, whereas the followershave their sensors OFF. The leader uses its light sensors and turns towards the direction of maximum light and moves towards the light source, avoiding obstacles. The leader sends messages at regular time intervals that contains the direction along which the leader is heading and the maximum light sensor value. The followers use the direction value to go along and at the same time, monitor the maximum light sensor value from the leader. The leader will send the message to nearby Robots and upon receiving the message they forward the message to the other nearby robots, reducing the value of the hop limit till it reaches 0. Robots might receive messages from other groups as well, but the Robots check for the ID of the leader Robot, which also happens to be the group ID number. If the message does not belong to the group, the message is discarded. The Robots will also check the sequence number and discard duplicate messages.

C. Avoiding Obstacles

Each Robot has a collision avoidance system with corresponding functions in code, which has higher priority overother systems and ensures that collisions are automatically avoided. There can be situations where a leader heads in a direction whereas the followers are left behind due to obstacles. On encoutering obstacles, there is a possibility of a sharp turn at the end of an obstacle which makes the leader turn sharply and continue moving, whereas the followers avoiding obstacles are left behind.

There can be a loss of communication within the group, if a follower is left too far behind. If a Robot does not get messages from other Robots in the group for certain amount of time, it assumes that it has lost communication and falls out of the group. The Robot turns ON all its sensors and becomes independent while listening to messages from other groups.

It becomes a part of another group whose direction messages have some correlation with the sensor readings. Another complication that arises due to obstacles is in the case of a light source being present just after an obstacle such that the leader has to turn in a direction drastically different from the direction along which it had arrived at that point. Since the followers are far away from the leader, the followers will get the new direction and will turn towards the new direction and run into an obstacle.

To counter these complications, two simple rules are followed by the Robots. When a leader Robot takes a sharp turn, it immediately reduces its velocity for a small amount of time, which gives time for the other Robots to catch up and stay in contact. When a follower senses a sharp turn in the leader, it will ignore the new direction for a certain amount of time and head along the old direction. After a certain period of time, the followers will update their direction, matching it with that of the leader's. These rules make the Robots stay near each other and with the leader in the presence of obstacles while allowing for smoother transitions in directions while encountering obstacles.

D. Behaviour in the Vicinity of the Light Source

The followers will monitor the maximum sensor value of the leader Robot from the messages. After the maximum sensor value of the leader crosses a certain threshold, it is implied that the leader is very close to the light source and cannot guide the followers henceforth. The followers set the follower flag to 0, turn ON all their sensors and using the sensor information, converge towards the light source.

V. Simulation

This section gives an overview of the simulator used. The unctionality of the Robot swarm is explained along with relevant figures from the simulation. The Robots are simulated on a plane of size 30mx30m with obstacles and Point lights as light sources using Webots.

A. Webots

Webots is a development environment used to model, program and simulate Robots, used for educational and research purposes. Users can design complex robotic set-ups with one or more robots in a virtual environment. The graphical properties of each object such as shape, colour, texture, etc and physical properties such as mass, density, etc. can be specified. Webots includes a set of sensors and actuators frequently used in Robotics. The controller programs for the Robots can be written in C, C++, Java, Python, MATLAB. The Robot behaviour can be tested in physically realistic worlds. Webots uses ODE(Open Dynamics engine), an open source physics engine, for detecting collisions and simulating rigid body dynamics. The ODE library allows accurate simulation of physical properties of objects such as velocity, friction, etc.

B. Screenshots of Simulation

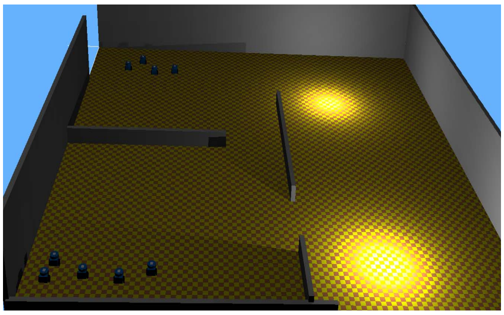

Fig. 2. At time=0s: The state of the simulation before the leadership contention process

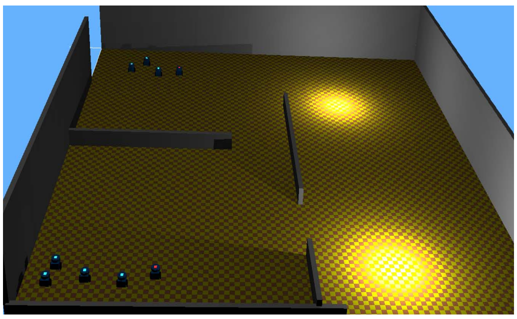

Fig. 3. At time=10s: The state of the simulation just after the leadership contention process. The Robot with the Red light on top is the leader and the Robots with blue lights are the followers

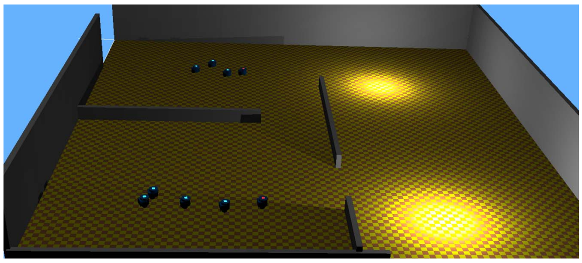

Fig. 4. At time=30s: The leader heading towards the light source, with followers behind. It can be observed that the direction of motion of the followers is parallel to the direction along which the leader is moving.

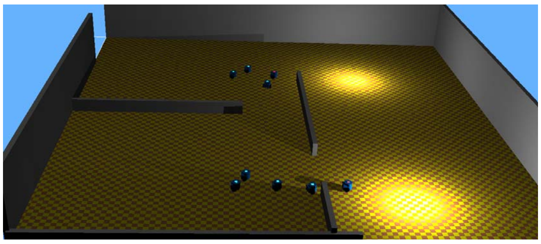

Fig. 5. At time=50s: The leader is very close to the light source and the maximum light sensor value has crossed the threshold. The followers now become independent of the leader.

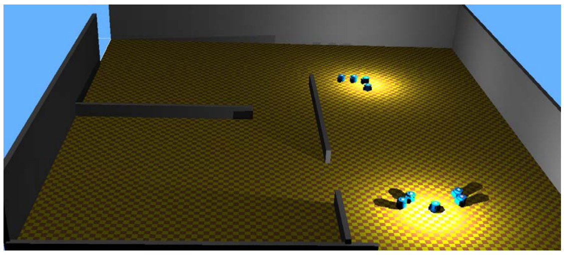

Fig. 6. At time=80s: The Robots converge towards the light source. This could also be a fire for example.

VI. Conclusion

Been Correlated behavior in natural swarms has implemented in a multi-Robot system. The Robots have simple hardware and software. Their task is straightforward: create groups with leaders and followers, head towards a source of light with the guidance of a well informed individual, i.e., the leader. Simulations have been done on Webots and the results are encouraging. These Robots can be used for fire-fighting wherein the Robots converge towards sources of fire and use small extinguishers mounted on them to fight fires.

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