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Swarm Bots: System Design for Echolocation

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Abstract—**This paper presents the study and implementation of a form of communication used by bats-ECHOLOCATION. Echolocation is a form of communication that animals such as bats use in order to navigate and locate their prey. Here, we base our results and inferences on an experiment carried out in which multiple swarm bots arrange themselves in a pattern using the principle of echolocation. By sending out ultrasonic pulses, the bots reassemble forming the required pattern. This experimentation forms the basis of working on advanced multi-agent swarm systems. These concepts of navigation and ranging along with swarm intelligence can be further extended to terrain mapping, security systems and even surveillance.**

Keywords-echolocation; bots; SONAR; swarm

I. INTRODUCTION

Robotics is an applied engineering science that involves a strong combination of mechanical technologies and computer science. Since the past, development of robots has taken a huge leap forward. Now with the development of robots with high computational, processing and multitasking abilities, a lot of universities and research institutions have started research and development in terms of how a group of bots could communicate with each other. This was the original inspiration behind *swarm robotics.*

Swarm robotics is a recently developed approach to developing systems with a large number of inter-communicating robots. This field has been derived from the collective study of swarm intelligence and swarm behavior of animals.

Animals, insects and birds - all have ways of communicating with each other. The forms of communication vary – but the objective is the same - to establish a method to interact and perform tasks collectively. In this paper, we try to study the form of communication used by a colony of bats, namely, *echolocation.* Echolocation involves using sound pulses to map the environment as well as objects in it.

II. LITERATURE REVIEW

Over the past decade, the amount of research done in the field of swarm robotics is staggering. Researchers, students and teachers are not only understanding the nature of swarms in particular, but are also coming up with new communication algorithms in order to fine tune their processes.

Swarm robotics is an emerging field with a large number of projects being undertaken by universities and research institutions. The I-SWARM project [1] and the Swarm bots project [2] are examples of self-organizing, environment mapping and task performing swarms. The Swarmanoid project [3] was another project that dealt with creating a swarm of bots capable of handling tasks in three dimensions.

With the inception of this branch of robotics, not only did similar projects develop, but platforms that enable faster and more efficient research have also been developed. The Player Project [4] is an example of one such 2D platform. Gazebo [5] is another 3D simulating platform developed. UberSim [6] and USARSim [7] are other similar platforms for swarm robotic research.

III. ECHOLOCATION

Animal Echolocation, also known as Biosonar, is a location technique that is used by animals in order to navigate and visualize the world around them. Animals use naturally produced *SONAR* waves to do help them echolocate objects, prey and also navigate with ease.

Along with bats, animals such as dolphins, whales, shrews and even some birds use echolocation to find their food and navigate. Animals produce sounds or sonar clicks which gets reflected back when it strikes any object. By bouncing these clicks off distant objects, animals get a sense of how far the object they are trying to locate might be. Some animals increase the frequency of these clicks as they approach the object. Doing this not only improves the accuracy of their hunt but also helps them estimate the shape, size, distance, orientation, speed and direction of the object in question.

This concept of echolocation has been studied and modelled to be used for research and development of practical applications. The scientifically modelled equivalent of echolocation is called SONAR, which stands for **So**und **N**avigation **AN**d **R**anging. The concept of SONAR is quite similar to echolocation - high frequency pulses are sent at an object. The time from then till the echoes of the pulses return to the sender is used to calculate the distance of the object from the sender. SONAR is especially used by ships to estimate the depth of the water. It is also a widely used concept in the defense industry. The original idea of using echolocation for this experiment was inspired by bats. The same concept was then extended to swarm bots. Figure 1 below gives a pictorial idea of how echolocation takes place. The black lines represent the sonar signals sent by the bat, and the grey lines represent the sound waves that are bounced back from the object.

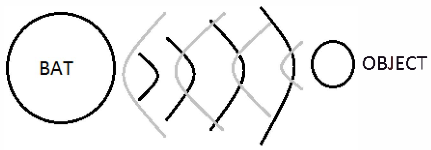

Figure 1. Concept of echolocation.

IV. Project Design

A. *Bots and Setup*

The arena was set up in a closed room which was cleared of obstacles for smooth execution of the project. The multi-agent arrangement consisted of a total of three bots. Each of the bot had dimensions of 12.7 x 10.5 x 4.7 cm and weighed approximately 2.5 kg. Each of the bots were fit with multiple data acquisition modules such as magnetometers, ultrasonic sensors as well as XBEEs for wireless data transfer.

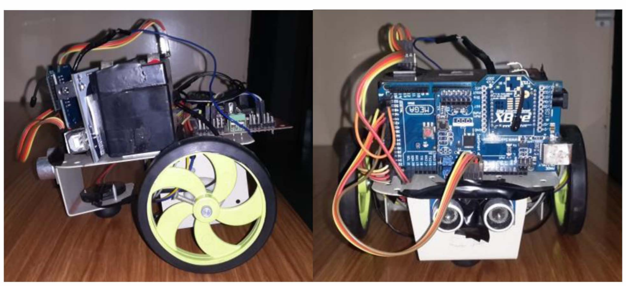

Figure 2. Front and side views of the swarm bot.

B. *Algorithm*

The experiment involves using a three agent system which is initially randomly placed and oriented. Each bot uses the concept of echo-location to map itself one behind another. The algorithm followed by the bots is represented Figure 3.

The Master bot works in the broadcast mode, sending signals to both the slaves. The slaves receive the messages, but respond to only those meant for them. The randomly placed bots first align to a certain angle with respect to Earth's magnetic field. Following this, both the slaves move left and right reading and storing ultrasonic values till they find the other bots. Once the bots encounter another bot, the distance picked up by its ultrasonic sensor drops drastically, and the bot stops. By this technique of echolocation all the three bots align themselves one behind the other.

C. *Design Constraints*

In order to meet realistic working expectations, certain constraints were set up while designing the experiment. The constraints that were set up are as follows:

1) Closed Space: The project heavily relies on ultrasonic sensors for the desired outcome. Ultrasonic sensors work on the concept of SONAR. Without a closed space, the ultrasonic sensors would not be able to work to the required level of accuracy, and thereby echolocation would not be possible. The execution of our project requires a closed space with walls and no obstacles for proper data acquisition.

2) Accuracy: The project involves real time data-acquisition to perform its task. Real time data acquisition can result in partial erroneous results. Moreover, since average grade sensors are being used errors may creep into the results. Multiple readings must be taken at higher resolutions for better accuracy.

3) Terrain: Robots are designed to self-assemble in smooth and plain terrain. Since the robots use ultrasonic sensor to guide them and the design of robots include a heavy battery, navigation through rough and uneven surface would make the experiment biased in results.

4) Delay: For the purpose of communication amongst the robots, ZigBee, which has lower data rate than WIFI and Bluetooth, is used. To avoid information overlap during transmission and reception, a delay of minimum 2 seconds is required during wireless communication. By decreasing the delay, the amount of error in the experiment may increase as it causes signals to overlap.

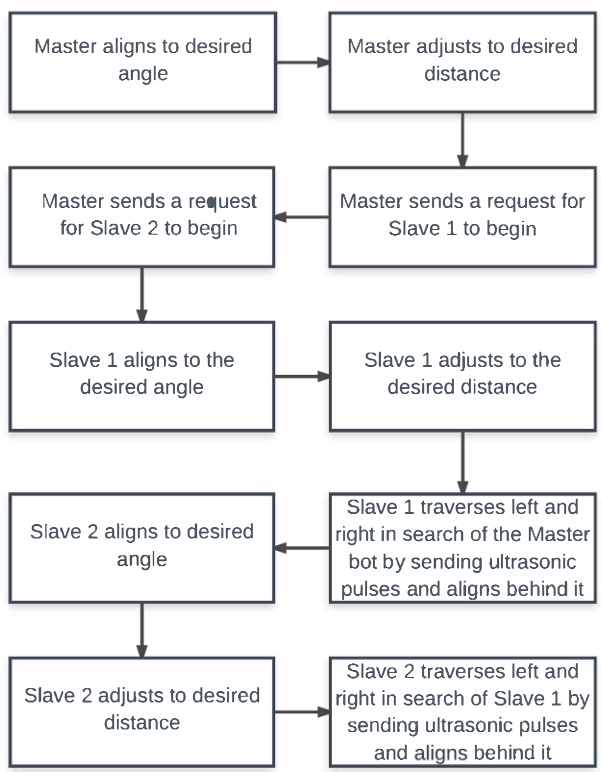

Figure 3. Algorithm.

D. *Trade-Offs*

In order to achieve the required results, a few trade-offs or sacrifices had to be made in terms of the equipment used. The trade-offs involved were:

1) Accuracy versus Cost: The accuracy of any experiment ties proportionally with the precision of components used. High precision components will lead to more accurate and less erroneous result in exchange for a higher cost. Keeping the setup low cost has introduced some errors making the experiment close to accurate. Also real time data acquisition requires multiple readings at higher resolutions which solves the precision issue of the experiment making it accurate to a plausible extent.

2) WIFI versus ZigBee: WIFI is a better wireless medium that was initially chosen for inter-bot communication, however using WIFI would not only increase the cost of the experiment, but also increase the battery consumption, which is a critical component of this experiment. Although WIFI provides with high data rate, it consumes more power. Keeping these things in mind, we settled for ZigBee, a low power consuming, low data rate Personal Area Network (PAN) which is preferred for devices smaller in size.

E. *Improvements*

The execution of the project can be made much more robust and error-free by working on diminishing the number of constraints that restrict the current execution of the project. By developing a solid prototype with a well-balanced structure, we can to a great extent minimize the impact of the 'Terrain' constraint.

Apart from this, the other constraints can be significantly reduced by using high grade sensors which minimize defects and improve accuracy. As the multi-bot system will increase in size in terms of the number of bots, the form of communication will also have to be changed to WIFI or any other alternative which supports a higher data transfer rate. The navigation of the bots can also be improved by changing the technique, namely echolocation, to a more robust form such as acoustic triangulation thereby removing the dependency of a closed environment.

V. RESULTS

The result of the experiment involves the analysis of the acquired data. The Electronic controls units on both slaves keep recording the ultrasonic distances as the bots progress. A graph of these readings shows how the alignment takes place. Once the distance reading in both control units falls to a minimum, it indicates alignment.

A graph of distance versus reading number is developed in MATLAB. Since the initial conditions of the experiment are random, the number of readings required may change with every trail. Table I. displays the readings of the most efficient trial, whereas, Figure 4 and Figure 5 display the graphs of the Slave 1 and Slave 2 bots respectively.

TABLE I. DISTANCE MAPPING-READINGS

Reading No.	Distance (in cm)	
	Slave 1	***Slave 2***
1.	58	88
2.	57	91
3.	57	90
4.	56	88
5.	55	89
6.	27	86
7.	-	87
8.	-	22

For Slave 1, it can be seen that, after the 5th reading the distance drops rapidly, indicating that it has found the master and aligned behind it. Slave 1 stops moving once it has successfully aligned behind the master bot.

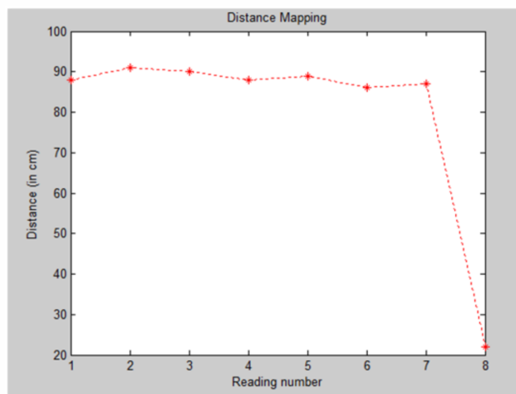

Figure 4. Distance mapping for Slave 1.

For Slave 2, it can be seen that, after the 7th reading the distance drops rapidly, indicating that it has found a bot and aligned behind it. Slave 2 stops moving once it has successfully aligned behind the Slave 1 bot.

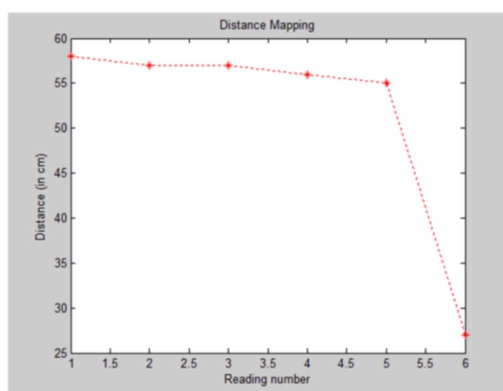

Figure 5. Distance mapping for Slave 2.

Figure 6. Bots before echolocation (initial position).

Figure 7. Bots after echolocation (final position).

Fig. 6 and Fig. 7 depict how the entire process of echolocation looks like. Fig. 6 shows the setup of the randomly oriented bots at the start of the experiment. The bots are placed randomly in the arena and are then powered up. The master bot controls the other two bots and distributes the intended algorithm amongst the bots. Fig. 7 shows how the bots arrange themselves post echolocation. The arrangement is in the form of a straight line with the master in front, slave 1 behind it and slave 2 at the end.

Although this experiment talks about the bots working towards arranging themselves in a straight line, they can be easily tweaked to perform a lot more than just find each other. While developing the algorithms and the code for the bots, the bots were also used to demonstrate other patterns like a march past and triangle formation as a part of testing. Though this concept is in its preliminary stages, further research and development in this technology can be used to make machines perform much more complicated and meaningful tasks.

Drones are one of the finest examples of such revolutionary developments in research. They are now not only being used by the armed forces for intelligent surveillance, but also by the common man in day to day activities. The scope to use such machines is limited by no boundaries – it ranges from photography and leisure to patrolling, spying and navigation.

VI. Conclusion

Humans have always been inspired by nature since the beginning of the time. Swarm robotics is one of those examples of inspiration. Swarm intelligence is an emerging area in the field of science and technology. This experiment is aimed at understanding and demonstrating swarm intelligence at a grass root level. In an era where our day-to-day activities are heavily dependent on machines and robots, swarm robotics is going to evolve rapidly in every field.

In this paper, we have tried to apply swarm intelligence on a small scale. A group of three swarm bots, which consist of one master and two slaves, perform the desired task of aligning with each other, from their random orientations, using the concept of Echolocation.

The mimicking of bats on a small scale using the concept of Echolocation was successfully tested and evaluated. This concept when developed further can be used for surveillance, other military applications and much more.

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