**Swarms of Oil Sensing Robots in a Simulated Environment**

**By Dave Cavaletto**

**Introduction**

This paper is to present my work on creating a simulation of a swarm of robots that can be dispatched in a decentralized way to detect oil in an ocean environment.  I hope to show that using a swarm is an effective and inexpensive way to monitor and identify oil slicks in the ocean.

Swarm behavior implies that each member of the swarm operates independently. Each robot moves, communicates, and coordinates only with the robots within its communication field. Those outside its field are ignored. With the limited radius of communication (ignoring a "base station" at the shore line or buoy in the water, or a satellite), the complexity of the robot is allowed to remain minimal and they can be a less powerful (read expensive) tool.

The paper follows a fairly standard format.  Starting with background information including the problem I am working to solve including statistics on oil pollution in the ocean.  Related work including work done by the Heraclea lab and by UC San Diego on this and similar problems and solutions.  Design of my project describing the algorithm for the robots and how the swarm operates.  Results of my work and what I have found out about this problem and its possible solutions. Conclusions I have come to about the feasibility of a project like this and what I have learned due to my research.  Future work including items not able to be implemented at this time.  And finally acknowledgements for those who have helped me in this project and paper.

**Background**

It is widely believed by the populace that marine oil spills are one of the most devastating disasters to water quality and marine life. This, however, is really only a misconception.  Ship and oil platform accidents account for only 5% and 2% (respectively) of the total marine oil pollution.  Operational tanker oil discharges accounting for 45% of the total pollution (3).  This comparison isn't to trivialize the effect that oil spills have.  But, it clearly does not contribute as much oil to the total dumped in the ocean each year.  What does have great impacts on the amount of oil deposited is tankers.  If their high traffic shipping lanes were monitored for spills, response times could shorten and the effects on the water quality and marine life could be minimized.  This tracking can also allow the collection of real time data so that the offending ship(s) could be identified. The robots ability to track the edges of the oil and its movement means that those monitoring the data could discern if oil was dumped or was leaked. Tracking a spill requires finding the spill's origin, what direction the ocean is carrying the oil, how deep the oil has settled, and the rate that the oil is expanding toward sensitive ecosystems and shore lines. Currently there are many ways to identify and track marine oil spills, some better than others.

Current technology tracks oil spills using satellite imagery, aerial photographs, and aircraft onsite of the oil spill. Aircraft cover limited areas and come with high overhead operational costs (7).  Space-borne Synthetic Aperture Radar (SAR) detection, which is available through a number of satellites owned by various countries, produces images that are not available daily and are affected by cloud cover and wind speed.  While these methods cover large areas of ocean, they cannot always discriminate between oil slicks and naturally occurring phenomenon such as algae blooms and other surface anomalies (3).  All of these methods require a technician to inspect data to determine size, location, direction and size of a spill.  The methods using images from satellites only provide a static image of the spill, no information about where it is moving is given.

These methods work well as deployable monitoring for known oil spills. They may not be the best solution for continuous monitoring of a "clean" site.

**Related Work**

Christopher McMurrough’s work on swarm behaviors in the Heracliea lab was the jumping off point of my work. Chris’s projects involved swarm behavior using potential fields and trust consensus algorithms.  They involved a swarm of robots following a single leader in the group while avoiding other robots in the swarm and obstacles in the environment (1).  I examined the code he had written in Matlab and determined that an object oriented approach was needed to make the project easily expandable and portable.  While I did not use his algorithms for movement of robots, I believe that future versions of the programs could benefit from adapting his algorithms to this simulation.

UC San Diego Jacobs School of Engineering won a nearly $1.5 million grant from the National Science Foundation in 2009 for the building of autonomous underwater explorers (AUEs).  The AUEs will map and track ocean mechanisms that can be used to determine ocean currents.  These ocean currents will give insight to the path of contaminants dumped in the ocean.  Jorge Cortes, a principal investigator working on the project says “The information that each robot in the underwater flock has is pretty limited…and this information is very local. From this, we want to induce some sort of global behavior so the whole group moves in one direction—to follows the spill, for example. This is part of the algorithm design. Out of very local information, we need to induce global behavior of the flock of underwater robots (2).”

Autonomous robots continuously monitoring the ocean would have widespread effect on the knowledge of how the ocean works.  Jules Jaffe, a co-principal investigator with the UCSD grant, explains how using a combination of mini AUEs and larger AUEs (containing more sensors) would help create a detailed account of how life in the ocean works.  The mini AUEs would be passive sensors in the ocean used to track ocean currents while the larger AUEs could contain sensors to measure light and fluorescence in the water. They could also have cameras to capture images of coral reefs (8).

**Design**

The goal is to build a simulation of a variable sized swarm of oil detecting robots.  The swarm is designed to operate not as a single entity, but with each robot updating its own position based on the positions of those within its immediate vicinity.  In this way each robot can work independently of the rest of swarm.  This keeps overhead on the system down and keeps the design of the individual robot simpler because there doesn't need to be a central control unit.  This methodology mimics the reality of having robots in an ocean, where each robot may not be able to communicate with every other robot in the swarm due to technological or physical restrictions.

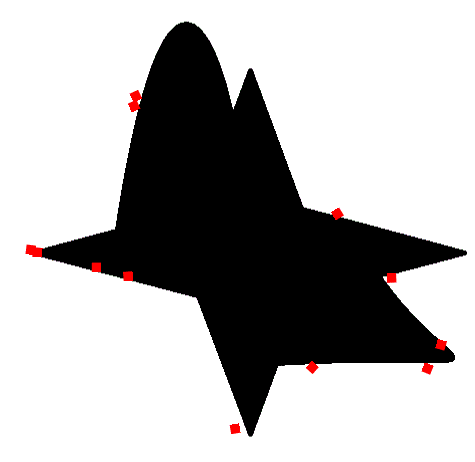
When creating my initial C# classes for this project I ran into much trouble getting individual robot icons to print to the screen and update with each click of a timer.  Research into similar systems led me to a blog post by John Wakefield showing his implementation of the popular simulation Boids (6).  It was from this project code I modeled my environment and icons.  This gave me the mechanics to get icons printing to the screen.  I was able to strip out all the movement code and replace it with my own algorithms to make the robots spread and maintain distances.

The overall program includes three main parts each containing the latter and implemented as a class using C#: the environment, the swarm, and the robots.  The environment is the space the robots live in, holds the background image of the oil spill, and defines the boundaries of space.  The swarm is the collective for the individual robot. Its content is dictated by the total number of robots within it.  The swarm works within the environment and organizes each robot. All entities within the swarm do not communicate with one another.  Last, is the robot.  Each robot, upon initial creation, is given a calculated value based on the overall size of the environment and the total number of robots within the swarm.  This value is used to mandate the distance each robot is to keep between its self and local robots.  As the system is currently implemented, the effective communication range between robots is linearly related to the previously calculated distance value between robots. In other words, the communication range is equal to the distance plus some constant.

As currently implemented the system loops through every robot in the swarm repeatedly.  Every iteration the current robot (this robot) polls every other robot (that robot) in the swarm to determine if that robot is within this robot’s communication range.  There are three general outcome possibilities for polling the distance from this robot to that robot, that robot is out of this robot’s communication range, that robot is in this robot’s communication range, and finally that robot is in this robot’s space.  The first two cases produce the same result, no change is made to this robot’s position.  The third case results in this robot changing its heading to move away from that robot.  This robot will not update its position until it has polled every other robot in the swarm.  The result is this robot moves away from every other robot within its space.

In the absence of an oil slick, the swarm should spread to cover the ecosystem evenly.  In the presence of an oil slick, if a robot comes upon its edge, 35-65% in oil, it will stop moving and hold its position.  These robots no longer communicate with robots that have not detected oil. This results in robots not within oil to ignore robots that have discovered oil. Because of this they will no longer use robots in oil to determine their heading, causing them to fill the "voided" space and spread out. This will greatly increase their chances of coming in contact with the oil slick.

**Results**



The product of my research and work is a program which simulates an environment and a swarm of robots that equilibrates within it.  The current version of the program allows the robots to spread in the environment and locate edges of ‘oil spills’.  Once on the edge of an oil spill the robot will stop moving on the edge.  This location information for each robot could be used to calculate the size of the spill or its location in the environment.

Robots Identifying the Edge of an Oddly Shaped Oil Slick

**Conclusion**

The implementation of a swarm of robots to track oil pollutants in the ocean could have far reaching affects.  Being able to monitor shipping lanes and areas around likely oil producing structures would allow for quick responses to such disasters.  I’ve shown that it is possible to distribute a group of robots without a central control and have them spread evenly over a given area.

Swarms of robots that can operate independently have other possibilities as well.  Robots that are designed to sample the ocean water and find oil spills could also be used to monitor and discover how the ocean and its inhabitants exist.  These robots would have far reaching implications on our knowledge of how the ocean and its inhabitants live (6).

**Future work**

This project does fall short of my initial projected goals.  In future versions of the simulation the oil slicks should not be static images, but should be a slideshow of oil images.  In this way the oil spill could evolve, forcing the robots to continue moving to identify the edges of the slick.  The ocean should not be a static environment either.  I would like to see currents in the ocean that the robots must fight against to hold position.  The robots could then provide information about the currents in the ocean.  One major improvement I would lie to see is the robots not hold their positions when the find the edge of the oil slick, but continue to spread and evenly cover the circumference of the slick.  This would allow for the implementation of surface area calculations.  Because oil slicks are hardly ever in nice neat shapes, sufficient coverage of the circumference is needed to be able to determine the surface are of the oil slick.  Only with enough points on the circumference can the irregular shape of the oil slick be split into regular shapes where surface area can be determined.  Algorithms to determine surface area by a number of points on the circumference of an object would need to implemented.  This may require that the robots not only find and surround the oil slick, but continue to move around the edge of it so that they can identify all of its edges.

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