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A fire ant inspired multi-agent system: a useful contribution to the ocean cleanup problem

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Abstract

The pollution of our environment is currently an issue that requires our immediate attention. One part of this problem is the plastic pollution of the oceans. An upcoming area of research in solving this problem is the application of robotics. In this paper the behaviour of fire ants is used as an inspiration in a model that simulates the cleaning of ocean trash. In order to determine if the addition of the fire ant behaviour to this ocean cleanup model is useful, the model is compared to a verification model. A comparison of the two models showed that the model with the additional fire ant behaviour performs better significantly. These results indicate that further research in this area is worth the effort.

Contents

Figure 1: An illustration of ocean pollution.

1 Introduction

In the past decades environmental pollution has become a big problem that is now larger than ever. It is currently the largest environmental cause of disease. In 2015 an estimated 9 million premature deaths occurred due to diseases caused by pollution, as stated by the The Lancet Commission [15]. Therefore it is not surprising that solutions to this problem are being proposed by many different research fields.

Environmental cleanup with the use of robotics is an upcoming area of research right now. An example of an environmental cleaning robot is the dustcart, created by Gabrielle Ferri et. al. [6]. The dustcart is a two wheeled garbage collecting robot that can also monitor air pollution. However, while this dustcart operates on land, the segment of environmental pollution this paper will be focussing on is the plastic pollution of the oceans.

The plastic pollution of the oceans forms a big environmental problem of its own right now. An estimated amount of over 5 trillion particles of plastics, together weighing over 250.000 tons, currently contaminate our seas [5] (see Figure 1). The problems that arise from this enormous amount of trash include beach pollution, the death of animals by entrapment and poisoning, population decline because of lowered reproductive and survival abilities [4], disruption of ecosystems by the introduction of new species that hitch a ride on a piece of trash [2] and even possible health risks for humans because of polluted water and contaminated seafood [25]. The combination of all these consequences makes ocean cleanup currently an important and interesting topic.

In order to handle ocean cleanup a combination of source reduction and actual ocean cleanup is necessary [18]. Source reduction, preventing trash from

Figure 2: Fire ants in raft formation.

ending up in the ocean at all, is obviously the best way to keep the ocean clean [21]. But even if no trash whatsoever would end up in the ocean from this point on, there would still be an enormous amount of plastics and other trash contaminating the ocean. Multiple different solutions to this problem have been investigated. A plan that is currently being carried out is 'The Ocean Cleanup'. This project plans to clean the oceans by using a passive, drifting, solid barrier that catches and gathers trash. The drifting barrier is driven by ocean currents. By using an anchor it is made to travel just a bit slower than the surrounding water, which causes the trash to be pushed into the barrier. A disadvantage of this method is that it could potentially be harmful to migrating marine life [22]. Another project that, just like the dustcarts mentioned above, makes use of robotics is the Waste Shark by Richard Hardiman [3]. These aqua-drones inspired by whale sharks are currently being tested in multiple harbours. The purpose of the drones is to gather trash before it gets to the ocean. This project however is restricted to harbours, marinas and canals.

An area of robotics that has - to my knowledge - been left largely unexplored in combination with ocean cleanup is swarm robotics. Swarm robotics is all about using relatively simple robots to display a collective behaviour by interacting with their environment and each other. They are highly useful in tasks that need to cover a region, that require scalability and redundancy or exposure to hazardous situations. These characteristics correspond to features necessary in organizing environmental cleanup [20]. A source of inspiration that has been successful before in the field of swarm robotics is ant behaviour, namely the foraging behaviour used in the Ant Colony Optimization (ACO) algorithm. A different kind of ant behaviour could possibly be useful in providing new insights into dealing with the ocean cleanup problem. Fire ants, also known as Solenopsis Invicta [24], are able to link together their bodies and form rafts when confronted with an obstacle, for example a flood (see Figure 2). In working together and reacting to their environment as a group the ants display a behaviour that could possibly be used in swarm robotics. From this point on this behaviour will be indicated with 'the fire ant factor/algorithm'. This paper will focus on dealing with the ocean cleanup problem by using a multi-agent system where the agents implement a fire ant factor. The research question of this paper is: Is the addition of a fire ant factor to the ocean cleanup model useful?

It will be determined if the usage of the fire ant algorithm is advantageous by comparing a 'normal' ocean cleanup model with an ocean cleanup model combined with a fire ant feature. The comparison of the two models showed that letting the cleaning agents make use of fire ant behaviour improves their abilities to clean trash. The model that implements the fire ant algorithm consistently scores higher than the model without this extra feature.

This paper is structured in the following manner: Section 2 clarifies the exact behaviour of the fire ants that is used as inspiration for this paper, section 3 describes the models based on this behaviour: a fire ant model, an ocean cleanup model and a combination of these two. Section 4 explains the methods that were used to get the results that are displayed in section 5. In section 6 the research related to this subject is reviewed. The results of this paper are further discussed in section 7 after which this paper is concluded in section 8.

2 Background

Ants are already known as an inspiration for algorithms that use a swarm of agents. The ACO algorithm, for example, is inspired by the foraging behaviour of ants. This paper is focussed on a different kind of ant behaviour, namely the rafting behaviour of fire ants. The fire ant is native to South America and has evolved to survive swampy terrains. If the colony is surprised by a flood the group can survive by grabbing onto each other and forming a raft. The papers that have been written on this subject mainly focus on the biological aspects of this behaviour. One of these papers was written by Mlot, Tovey and Hu [13]. Their main goal is to model the rafting behaviour of the ants as accurately as possible. Together they published multiple papers on this subject and made improvements to their previously designed models. In the paper cited above they made efforts to predict the growth of large ant rafts more accurately. In larger rafts the behaviour of the ants comes closer to behaviours like foraging and scouting. In this paper they describe an algorithm that simulates the rafting behaviour of the ants based on their observations. The algorithm consists of the following three rules quoted from Mlot, Tovey and Hu:

1. An ant only moves if there are no ants atop it.
2. When an ant moves, it travels straight in a random direction (...) for a distance s, changes direction randomly, and repeats this pattern until it reaches an edge.

3. Upon reaching an edge, an ant gets stuck with probability $p \approx 0.3$, measured experimentally. With complementary probability $1-p$, the ant bounces off the edge and begins traveling straight in a random direction away from the edge ..., continuing with behaviour 2.

Mlot, Tovey and Hu

In my paper these three rules were used as inspiration to make a fire ant model. The model section describes how these rules were implemented and how the model is combined with an ocean cleanup model.

3 Model

For the purpose of finding out if it is useful to add a fire ant factor to an ocean cleanup model three different models were created. First, a fire ant model based on the three fire ant rules as they were proposed by Mlot, Tovey and Hu [13]. Second, a model for ocean cleanup. And third, a combination of the first two models. A comparison of the results of the last two models will give an answer to the research question. This section will describe the implementation of the three models one by one. As the parameters are introduced their fixed values will be given as well. These are the values that will be used in the tests. All the values were chosen in a way that optimizes the end results. The grid for each of the three models is formed by a 2D environment of 34×34 patches (where each patch is made up by 13 pixels).

3.1 The fire ant model

For the first model (the fire ant model) the implementation of the fire ant rules, the parameter values that were chosen for this model and the behaviour the modelled ants display will be described.

All three fire ant rules involve either moving or not moving. To incorporate these rules in the fire ant model all ants are given a variable called 'freedom'. This variable determines if the ant in question is free to move or not. In the latter case the ant is part of a raft and therefore cannot change its location on the grid. At initiation the ants are generated at a random location. No rafts have been formed yet so all ants are still free to move. From this point on the ants that can move will be called 'free ants', the ants that have become part of a raft will be called 'raft ants'.

The first fire ant rule stops an ant from moving if there is another ant on top of it. This behaviour is implemented by asking all free ants to take the freedom of the ants close to it, they fixate the positions of the nearby ants. These fixated ants are not allowed to change their location on the grid any more and are now essentially part of a little raft. According to the second rule the free ants that are on top of a raft should move in a random direction. In the model an ant is on an ant raft if it is on the same patch as one or more raft ants. If a free ant finds itself on an ant raft this ant should also execute the third ant rule. This

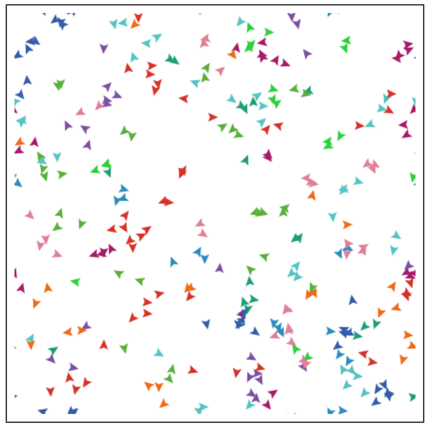

Figure 3: The converged outcome of a model implementing the fire ant rules. Ants that are close to each other and share one colour belong to one raft.

rule states that if the ant is close to the edge of the raft it should either attach itself to the edge or walk the other way. The ant checks if it has reached an edge by scanning the patch in front of itself. If there are no ants on this patch, an edge has been reached. Three out of ten times the ant attaches itself to the edge of the raft (this probability will be called P from now on). This means the ant loses its freedom and becomes part of the raft. In the model the ant takes a final step forward (to step over the edge of the raft) and fixates its position next to the other raft ants. The other seven out of ten times the ant makes a random turn of 90 to 270 degrees and moves on in this direction. All three rules were implemented by using the most general interpretation of the rules provided by Mlot, Tovey and Hu. With these three rules the model is able to imitate the fire ant rafting behaviour.

The only parameters that can be varied in this model are the number of ants N and the probability P of an ant attaching itself to the edge of the raft. N is initialised at 300. As the grid is made up of about 1200 patches (34×34) the density of the ants will be about one ant per four patches. This density makes for a good midway point between an overly crowded model and a density to small to show any results. Probability P is set to 0.3. This value was proposed by Mlot, Tovey and Hu after taking measurements as described in their article [13]. The model converges quickly to a state where multiple little rafts are formed and none of the ants move. This is because once the ants come close to each other at least one and likely multiple ants will no longer be allowed to move. By giving the ants that are part of the same raft the same colour, the rafting behaviour is made visible. Figure 3 shows that the ants converge into little rafts.

Table 1 gives an overview of the parameter settings of the verification model and the combined model that were used in the tests. The values that were chosen optimize the results of the final tests. The verification and combined model section will explain the function of the mentioned parameters.

Name	Fixed Value	Symbol
Nr. of ants/cleaning agents	300	N
Probability of attachment	0.3	P
Amount of trash continuously deposited	10	T
Drift-distance of trash	0.2	δ
Ant-radius	3	r
Amount of cleaning agents sufficient to clean trash	5	C
Trash-radius	4	q
Grow-rate search-radius of ants/cleaning agents	1.02	ρ
Trash-threshold	4	θ

Table 1: The fixed parameter values fo the verification model and the combined model that were used in the final tests.

3.2 The ocean cleanup model (the verification model)

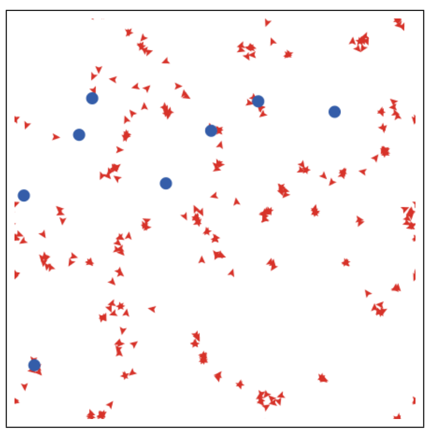

Figure 4: A view from the ocean cleanup model, the red and the blue agents respectively represent the cleaning agents and the trash.

The ocean cleanup model makes use of two kinds of agents: the trash particles and the cleaning agents. The trash particles, indicated by the little blue circles, are initialized at a random position in the model (see Figure 4) and

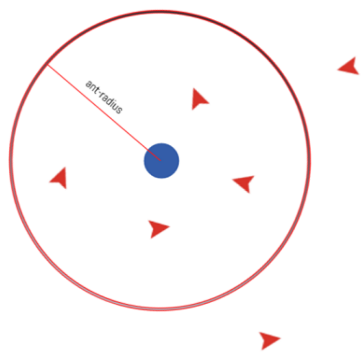

Figure 5: A visualization of the area-search the trash particles use. The particle now senses four ants in its search area.

the amount of particles T that is deposited is variable. In the final tests this value was chosen to be $T = 10$ to optimize the outcome variables. The particles themselves do nothing except drift around - with a maximal distance of $\delta = 0.2$ per time step - and check how many cleaning agents are nearby. If enough cleaning agents gather around a trash particle the trash can be cleaned up and the particle will disappear. The amount of cleaning agents necessary to clean one particle C is variable, during the testing this value will be set to $C = 5$. By scanning the surface of a circle with a variable radius, with itself as its centre, a trash particle can measure the amount of cleaning agents in that area. During the tests the trash particles will search in a circle with a radius of $r = 3$, r will be called the ant-radius. If the amount of ants within the radius is sufficiently large, larger than or equal to C, the trash particle can be cleaned up. Figure 5 displays the area a trash particle can search.

It may seem counter-intuitive to let the trash particles search their surroundings, as they would not be able to do this in real life. This is, however, only a simplified and convenient way of implementing the cleaning of the trash in the model. In the real world each cleaning agent could, for example, take a little piece of the trash particle away. As the cleaning agents would decrease the size of the particle by each taking a piece until the trash is gone, there would be no need to keep track of the amount of cleaning agents and no need for an explicit removal of the trash particle. The area-search that the trash particles use is just a simplified and improvable way to check if enough cleaning agents have gathered around a particular trash particle. Ultimately, the main focus of this paper is the fire ant algorithm and not the actual removal process of the trash.

The cleaning agents have a way of finding trash that is similar to the area-search the trash particles use. They scan the area around themselves just like the trash (see Figure 6), but instead of measuring the amount, they choose one

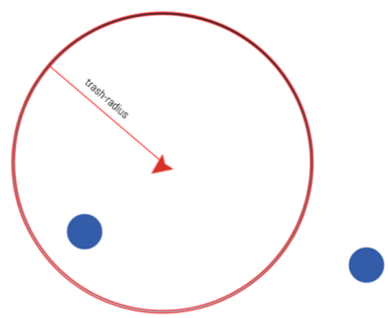

Figure 6: A visualization of the area-search the cleaning agents use. The displayed ant senses one trash particle and turns toward it.

particle and move towards it. The radius of the search area of the cleaning agents (the trash-radius) q will be fixed at $q = 4$ during the tests. If they don't find any trash they expand their searching area exponentially by a variable amount. This grow-rate ρ was chosen to be $\rho = 0.02$ in the tests. Each time an agent does not find any trash, the length of the trash-radius will increase by 2%. Once they have found a trash particle their search area returns to its original size.

The outcome variable that is acquired from the model is the amount of trash the cleaning agents can clean in a fixed amount of time steps. To prevent the trash from running out - and the model from converging to a non-moving state like the fire ant model - new particles are deposited once the total amount of trash gets below a trash-threshold θ. This way the amount of trash in the model remains low and constant. As opposed to depositing a large amount of trash at the initialization of the model and measuring how long the cleaning takes. The trash-threshold will be fixed at $\theta = 4$ and the amount of newly deposited trash particles will be 10, the same as the initial amount of trash T added to the model.

In the following sections the ocean cleanup model will be referred to as the verification model (see the combined model section for further explanation).

3.3 The combined model

The final and most interesting model is the combined model. This model is a combination of the fire ant model and the ocean cleanup model. It works largely the same way as the ocean cleanup model, but here the cleaning agents are replaced by fire ants. The fire ants will be taking up the cleaning task, but when they don't sense any trash in their search area they will behave like fire ants and try to form rafts. By cleaning up the drifting trash and forming the ant rafts the ants display a collective behaviour. The ants are working towards a common goal that is achieved by interacting with their environment and each other. The competence of the combined model will also be measured by counting the trash particles that the ants can clean in a fixed amount of time steps. To accurately measure the difference between the two models, the parameter settings were chosen to be identical.

To avoid confusion the ocean cleanup model will be referred to as the verification model, because technically both of the models are ocean cleanup models. This name was chosen because the model can be used to verify if the fire ant factor is a useful addition to the combined model, as this factor is the only difference between the two models. The way this will be tested is described in the method section below.

4 Methods

As was mentioned before the purpose of this paper is to find out if the addition of a fire ant factor to an ocean cleanup model can make a useful difference. To reach an answer to this question the combined model will be compared with the verification model. Both of these models were described in more detail in the model section. The parameter settings that are described in the model section and displayed in Table 1 are fixed in both the combined and the verification model. The only difference between the two models is the addition of the fire ant factor in the combined model.

Both of the models will be run 120 times with a limit of 2000 time steps (see Table 2). Each test returns the amount of trash the cleaning agents/fire ants were able to clean in the set amount of time steps. By comparing the means of the gathered data of the two models it can be determined if there is a difference in cleaning speed. There are two possible outcomes of these results. Either the average amount of cleaned trash of the combined model and the average of the verification model are significantly different, or they are not. If there is no significant difference between the two models the answer to the research question would be a clear negative, as the fire ant factor does not change anything about the results. However, if they do differ significantly the degree of usefulness of this difference can be determined by observing which model has the higher average. If the verification model scores higher it can be assumed that the fire ant factor slows the algorithm down (which is not very useful). If the combined model scores higher it can be assumed the fire ant factor contributes to the model in a positive way, it increases the cleaning speed of the model. The results section will display which of these possible outcomes was obtained.

Model	Number of Tests	Time steps
Verification Model	120	2000
Combined Model	120	2000

Table 2: Specific testing values used to gather data.

5 Results

After explaining the models and methods that were used to perform the tests the research question can be answered. This section will display the results of the performed tests and analyse these results with an unpaired two-sided t-test. The outcome of this t-test will indicate whether the means of the combined model and the verification model are significantly different or not. In other words, is there a significant difference between the combined model and the verification model?

The unpaired two-sided t-test will determine whether there is a significant difference between the means of the two models. The null hypothesis of the two-sided t-test will be: The means of the combined model and the verification model are not significantly different. This means the alternative hypothesis should be: The means of the combined model and the verification model are significantly different. The t-test was chosen not to be paired because for each performed test (all 240 of them) new cleaning agents and trash particles were randomly and independently initialized.

Three assumptions are made when doing an unpaired t-test. Namely:

1. The data of each category is normally distributed.
2. Both of the datasets have a common variance (homogeneity of variance).
3. The observations have been obtained independently.

The third assumption has already been satisfied. For each individual test completely new ants and trash particles have been used to get the data. This is also the reason for an unpaired test instead of a paired one. The first and the second assumption can be verified with the help of the Shapiro Wilk test and an F-test. To check if the data is normally distributed the Shapiro Wilk test has been performed. It returned a p-value of 0.7988 which is higher than the significance level of 0.05. This means that the distribution of the data is not significantly different from the standard normal distribution. It can thus be assumed that the data is normally distributed. The variances are compared using a two-sided F-test. This test is commonly used to check the equality of the variances of the two samples that are compared in a two-sided t-test. The returned p-value of the F-test, 0.7513, is greater than the significance level of 0.05. This means it can be assumed that there is no significant difference between the two variances.

After performing the necessary checks the results of the unpaired two-sided t-test can be assumed to be valid. The result of the test (see Table 4) shows that there is a significant difference between the means of the verification model and the combined model, t-value = 8.36, p-value = $5.2e - 15$, as the p-value is smaller than the significance value of 0.05. Figure 7 displays the means and the error bars of the results returned by the final tests. The left bar represents the combined model, the combination of the ocean cleanup model with the fire

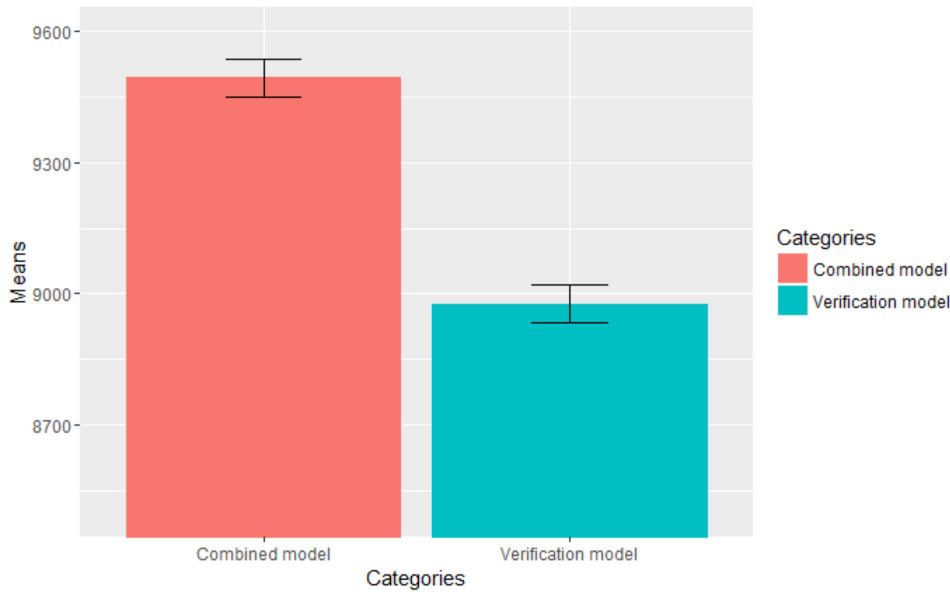

Figure 7: The means and error bars of the final tests, from left to right, the combined model and the verification model.

ant factor. The right bar represents the verification model, the ocean cleanup model without the addition of the fire ant factor. The statistics visible in the barplot are also displayed in Table 3.

Model	Mean	Standard Deviation	N
Verification Model	8977.4	484.7	120
Combined Model	9493.3	470.8	120

Table 3: The descriptive statistics of the test results.

As is visible in Figure 7 and Table 3 the results of the tests suggest that the combined model performed better than the verification model. The two-sided t-test indicated that the difference between the two models is significant. As the two-sided t-test only looks for a significant difference and does not actually indicate which mean is higher or lower, there is the possibility that the difference that was found by the t-test actually means that the verification model was faster than the combined model. However, as the barplot indicates the mean of the combined model is higher the probability of this being the case is negligible. Based on these results the assumption can be made that the combined model performs faster than the verification model. This means that the addition of the fire ant factor to the ocean cleanup model does, in fact, make a significant difference.

T-value	8.36
Df	238
p-value	$5.2e - 15$
95% confint	$394.3 - 637.4$

Table 4: The results of the unpaired two-sided t-test

6 Related Work

In this section I will describe the work that has been done in the area of environmental cleanup in general and ocean cleanup specifically using robotics. These projects were briefly mentioned in the introduction, namely the Waste Sharks of Richard Hardiman [3] and the dustcart of Gabriele Ferri [6]. The Ocean Cleanup project of Boyan Slat [22] and the robotic fish of Maarja Kruusma [17] will also be briefly mentioned.

The dustcart is a two-wheeled robot that goes from door to door to collect garbage. Apart from collecting garbage the robots also take measurements of air pollution while collecting the garbage. The measurements taken by different robots in different places can be combined into a map that displays the levels of air quality in different areas. This project could be useful in providing a solution to the ocean cleanup problem by mapping the state of pollution in different areas. By implementing this mapping algorithm in combination with the fire ant algorithm aquatic bots could possibly be used to map ocean pollution.

The Waste Shark project uses unmanned aqua drones, modelled after the whale shark, that clean harbours, marinas and canals by 'eating' waste. They have been or are currently being tested in Dordrecht, Rotterdam, Gotland (Sweden) and Dubai. A scale up of this project could potentially prevent the problem from getting any bigger by keeping marinas and harbours clean and preventing waste from reaching the ocean at all. This project demonstrates the possibility of using aquatic drones for cleanup purposes. A scaled up version of this project could potentially implement a form of swarm robotics or even a fire ant algorithm.

Figure 8: The robotic fish made by Maarja Kruusma and her team.

Unlike the Waste Sharks the Ocean Cleanup project of Boyan Slat is not meant for cleaning harbours and canals. It is an initiative of which the first goal is to clean the Great Pacific Garbage Patch (GPGP). They plan to clean 50% of the GPGP in 5 years time, potentially starting this summer. The system of the Ocean Cleanup project consists of large, passive barriers that make use of ocean currents to catch trash. Although it has a harder time catching smaller particles, it is eco-friendly in that it is driven by ocean current alone.

Finally, the robotic fish developed by Maarja Kruusma should be mentioned. She and her team focus on bio-inspired robotics and developed a robot that can be used to sense things a fish can feel, like water flow, velocity and pressure. These robotic fish can be used to gather data without subjecting actual fish to harmful tests. Figure 8 is an image of the robotic fish in question. While this project does not relate to ocean cleanup itself these small aqua-robots do show the possibility of using robotics in the ocean. The shape and the technique used to let the robotic fish float to the surface could inspire a design for fire ant cleaning robots. Also, the sensors that are used to measure water flow etc. might serve as an inspiration in designing a sensor to search for trash.

7 Discussion

This section contains a short account of what the final result of this paper is, my expectations, some possible explanations for the obtained results, the limitations of my research and some potential paths for further research.

This paper shows that the addition of the fire ant algorithm can have a positive influence on the speed with which a swarm of agents can clean trash from an ocean like surface. If developed more and applied to other problems the fire ant algorithm might provide solutions and/or new insights in the field of swarm robotics and ocean cleanup.

Because of extensive research that has been done in other ant based algorithms like the ACO algorithm and the successful results this multi-agent system delivers I expected this particular ant behaviour, namely the fire ant rafting behaviour, to have similar positive results. I think mimicking nature is one of the best ways to solve problems and develop new technology and that the rafting behaviour of fire ants can inspire innovations in swarm robotics, ocean cleanup and other areas.

What could be a possible explanation as to why the combined model - where the agents use the fire ant feature - is more successful than than the verification model - where the agents don't use this feature? Where the verification model lets the agents communicate with their environment to search for trash, the combined model also allows the ants to communicate with each other. This way they can clean trash in a more organized way and increase their speed collectively. This could possibly explain why the addition of the fire ant factor is beneficial.

One on the limitations of this research project is the lack of real data. Testing the algorithm in real life would require a large amount of bots. Acquiring such a large amount of bots and programming them all separately is not feasible feat within the boundaries of this paper. One of the cheapest and fastest ways to get a swarm of robots is described by M. Rubenstein et al. in their paper about the kilobot [19]. A bot specifically designed for use in water by M. Kruusma and her team [17] was mentioned in the related work section. But here no mention is made of the price of manufacturing the bots.

A drawback of a solution that uses bots in general is that it requires energy to work. No matter how much you might be able to minimize the necessary amount, energy will always be needed to a certain extent. As ocean cleanup itself is an effort to improve the environment it would be great to do it in the most eco-friendly way possible. One such eco-friendly ocean cleanup project is, in fact, planned to start mid-2018 in the Pacific Ocean as mentioned earlier in the related work section. Boyan Slat found a way to use ocean currents to gather and remove trash [22].

Another limitation of the proposed model is that the cleaning agents can only reach the surface of the ocean. However, not all trash drifts on the surface of the ocean. Many particles are at the bottom of the a water column [10]. This complicates many proposed solutions to the problem. Cleaning this subsurface trash would require vast nets or blockades or submarine cleaning agents.

There a many possibilities for further research in this area. By adjusting the fire ant algorithm, adding features to make the model more realistic or applying the model in different problem areas new insights might be obtained. For example, instead of just letting the ants raft together they could be made to pass on information to the other ants. They could use a flocking algorithm [16] to slightly turn the other raft ants in the right direction or give the other ants the location of trash particles.

The removal of the trash particles could also be improved. As stated in section 3.2 the way the trash is cleaned right now is simplified and could be made more realistic. More features that simulate ocean-like circumstances could be added, like a drift factor for the ants and not only for the trash particles.

The algorithm and bots could also simply be used to locate the trash instead of actually having them gather it, this alone would be a huge help in solving the problem. It could also possibly be applied in different areas that are suitable for swarm robotics like solving the traffic jam problem [23] and providing help in rescue missions after natural disasters [20].

A problem of a lot of current solutions is that they are harmful to marine life. Fish and other sea animals are caught in the systems that gather the trash. Finding a way to repel marine life to prevent catching fish instead of trash would be a huge help in designing a good solution.

Another area that needs more research is the specialization in cleaning macro plastics, these plastics are hard to gather as they are too small to be very buoyant and thus often sink too deep or slip under nets [10]. They are still harmful to sea life, because they can be eaten easily.

And finally, an important part of the way to a clean ocean is to prevent the trash from reaching the ocean at all by educating on the importance of disposing of trash in a responsible way.

8 Conclusion

In this paper I showed that an implementation of the rafting behaviour of the fire ants in a multi-agent model that cleans trash makes the agents clean faster than the agents in a model without this implementation. While there isn't a massive contrast, there is a definite difference between the two models. This paper makes a useful contribution to the ocean cleanup problem by showing that the fire ant factor can make a significant difference and providing a promising new area of focus. In other words, it gives an indication that further investigation in this direction is worth the effort. In the end the specific sub-area of the fire ants algorithm applied to ocean cleanup forms only a small aspect of an enormous subject. However, because of the importance of the matter, the future of our oceans, all aspects should be investigated.

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