Statement of Purpose

Alexander J. Wallar
B.Sc in Computer Science, University of St Andrews, UK
`http://aw204.host.cs.st-andrews.ac.uk`

November 28, 2014

1 Experience

Since I graduated from high school, I have been participating in research. I participated in the FIRST Tech Challenge and FIRST Robotics Competition during high school. I was accepted as a high school research assistant at the Computational Robotics Laboratory at the Catholic University of America (CUA) following my high school graduation in June 2012. At CUA, I developed interfaces for controlling the iRobot Create that included moving the robot using hand gestures interpreted using the Microsoft Kinect, and with an Android application that could interpret natural spoken language. After my first year of university in 2013, I participated in a National Science Foundation Research Experience for Undergraduates (REU) site at the University of Notre Dame. At Notre Dame, I developed a computer vision library for JavaScript that can be used to determine where a user is looking on the screen. For this project, I received the Best Poster Prize for the REU site.

Once I returned to university after the summer, I became a research assistant in the School of Psychology where I configured a novel experiment that involved three active-shutter 3D displays of different sizes that can be viewed simultaneously through beam splitters. The goal of this set-up was to determine how people can perceive 3D imagery. In parallel with working for the School of Psychology, I worked as a research assistant for the School of Computer Science developing computer vision algorithms that can translate monocular images into series of impulses that can be relayed to a haptic interface. The goal of this software was to allow people with sight impairments to perceive the real-world using haptic feedback.

During the summer of 2014, I was part of the Naval Research Enterprise Internship Program at the Naval Center for Applied Research in Artificial Intelligence at the Naval Research Laboratory in Washington DC. I worked in the Distributed Autonomous Systems group developing motion planning algorithms that enable a group of unmanned aerial vehicles to provide persistent surveillance of a given area. Each robot maximizes the quality of the sensory information being collected whilst minimizing the risk of damage to the vehicle and the risk of being detected by a hostile target on the ground. Most recently, whilst at university I have been affiliated with the Computational Robotics Laboratory at the Catholic University of America as an undergraduate research assistant developing path planning algorithms that enable swarms of robots to go from an initial configuration to a goal configuration in highly dense dynamic environments. The experience I have gained through my participation in research as an undergraduate prepares me well for a PhD because it has taught me how to solve difficult problems with little supervision, to be independent and self motivated, and how to present my work to the scientific community.

2 Areas of Research

The goal of my research is to develop algorithms that enable groups of robots to become more autonomous. My research is focused on path planning and navigation for swarm robotics centered around surveillance and collaborative source localization for homogeneous and heterogeneous systems. The main objective is to design simple local rules for individual robots that lead to emergent behaviors that solve the given task.

2.1 Path Planning for Swarms [1, 2]

The objective of swarm path planning is to develop algorithms that enable a group of robots to efficiently plan their motion from an initial configuration to a goal configuration. The algorithms that are developed need to be able to deal with dynamic environments and must generate trajectories that do not lead to collisions with any obstacle or other robot. During my affiliation with the Computational Robotics Laboratory at the Catholic University of America, I developed a path planning algorithm that combines potential fields and probabilistic road-maps that enable a swarm to manoeuvre around static and dynamic obstacles [1, 2]. By using the probabilistic road-map as a global planner, local rules are encoded using potential fields as cost functions for the individual members of the swarm. Repulsive potential fields exist around obstacles and around other robots. The repulsive field around other robots is weaker than the one around obstacles that allows for the swarm to become dense if needed. The swarm is also able to branch into multiple sub-swarms when there is a blockage in the current path. This is done by dynamically adjusting the edge weights on the road-map for areas the swarm senses are congested.

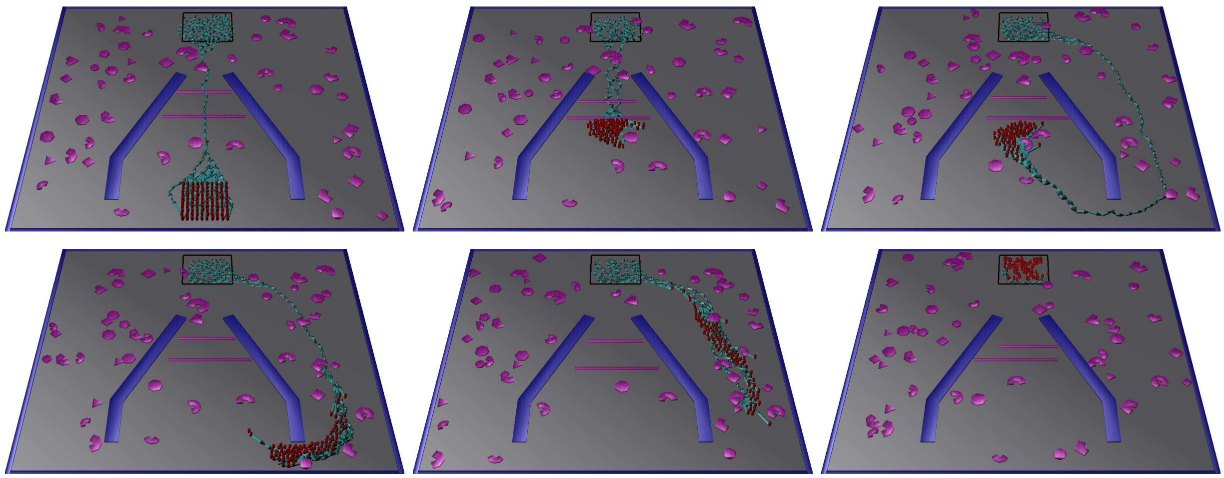

Figure 1: Planning the movements of a swarm by using a probabilistic roadmap as a global planner and potential fields as a local planner. Notice how the swarm is able to re-plan the global path when a blockage formed by dynamic obstacles is present.

2.2 Multi-Agent Risk-Sensitive Aerial Surveillance [3, 4]

Autonomous teams of unmanned aerial vehicles have been used by the military to provide high quality, persistent surveillance of a given area. These robots often are subject to external risk (i.e. detection by hostile agents, fire, wind). Amidst this risk, these teams have to provide persistent high quality sensory information of the area. The key motivation for my interest in multi-agent surveillance is that multi-agent systems have fault tolerance built into the architecture. A single robot or multiple robots may no longer be functional, but the persistent coverage may still be possible. Having a swarm of robots collaborating to provide surveillance speeds up the process, but techniques have been designed that allow for agents to leave the swarm and still allow the swarm to provide the necessary coverage. During my internship in the summer of 2014 at the Naval Research Laboratory, I created an algorithm that is based on simple local rules that is able to plan the motions of a swarm to continuously provide this information whilst minimizing the potential risk and maximizing the quality of the sensory information captured [3, 4]. Planning the motions of the robots in three-dimensional space was broken into two parts, planning in the xy plane and planning for altitude. Planning in the xy plane was accomplished by giving the robots a simple rule, move towards the area along the edge of the robot's sensor footprint that has the best combination of the lowest risk and highest uncertainty. For determining the altitude, the robot moves in the direction that would best maximize the sensor quality whilst minimizing the risk. Tests have been run using AscTec Pelican quadrotors that show the viability of the approach.

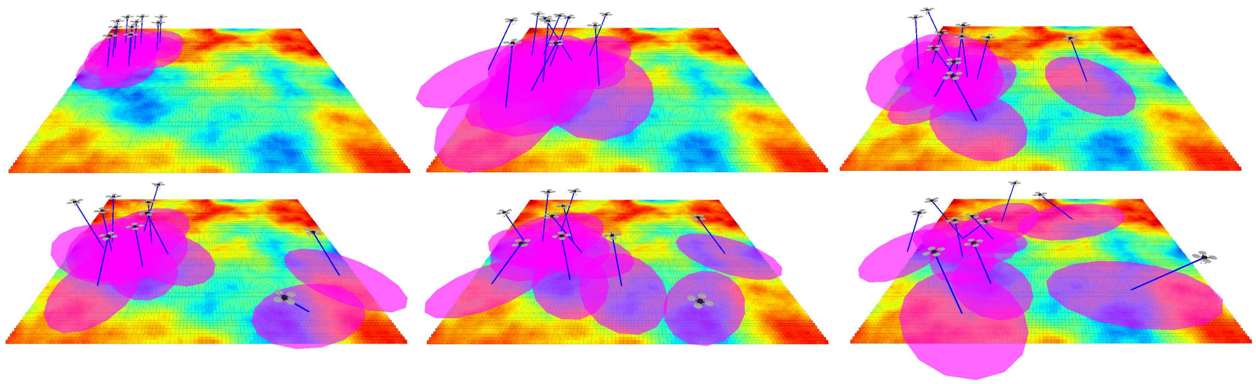

Figure 2: Using simple local rules to plan the trajectories of a swarm to provide persistent high quality sensory information of a given area whilst minimizing the risk of gathering the information.

2.3 Multi-agent Source Localization [5]

There many occasions when localization of a particular stimulus source is not possible with only one sensor node in the general case (i.e. heat, sound, vibration, etc). Each of the sensor nodes receives non-directional information about the intensity of the stimulus at their position. By combining the knowledge from each of the nodes, we are able to determine the position of the source. However, this case is only possible when there is no associated noise with a given position in the search area. In real world scenarios there will be noisy sensor readings and these could be caused either external or internal perturbations. Averaging sensor intensities over time, removing outliers, can account for noise caused by internal factors, but constant Gaussian noise based on the location of the node must be accounted for by moving the node out of the noisy area (i.e. for sound source localization, by moving out of locations with high background noise). However in some cases it is not possible to determine whether a node is in a noisy area (i.e. constant noise being applied to the node) and therefore, consensus filtering is needed to determine how much noise each node has and how to move the node out of the noisy area. As a undergraduate research assistant at the Computational Robotics Group at the Catholic University of America, I developed an algorithm that is able to incrementally reduce the error in the location prediction for a source by a group of mobile sensor nodes [5]. This is accomplished by moving the sensor nodes at a speed inversely proportional to the amount they contributed to the source localization during consensus filtering stage. The nodes move towards the closest neighbour node that contributed the most to the localization (i.e. the node that had the least agreed upon error during the consensus filtering stage). This simple homogeneous rule for the swarm of sensor nodes allows the global localization error to be reduced over time.

3 Future Work

Ultimately, my research aims to enable homogeneous or heterogeneous teams of robots to accomplish high level objectives using very simple local rules. The creation of simple rules for emergent behavior has the possibility of addressing problems not only within my research domain, but also to further the progress of amorphous computing and nanomedicine.

I plan to continue research in swarm robotics by developing algorithms using simple local rules that create emergent behaviors that can complete several higher level objectives such as search and rescue, autonomous surveillance, and source localization. I would like to not only provide validation through simulated environments, but to also test the developed algorithms on physical robots in real-world situations. Furthermore, I would like to use tools such as UPPAAL, SPIN, and PRISM to formally verify that the developed algorithms function as expected.

For future research, I would like to extend the work I have done in multi-agent autonomous surveillance to deal gracefully with heterogeneous teams of robots capable of efficiently gathering different types of high

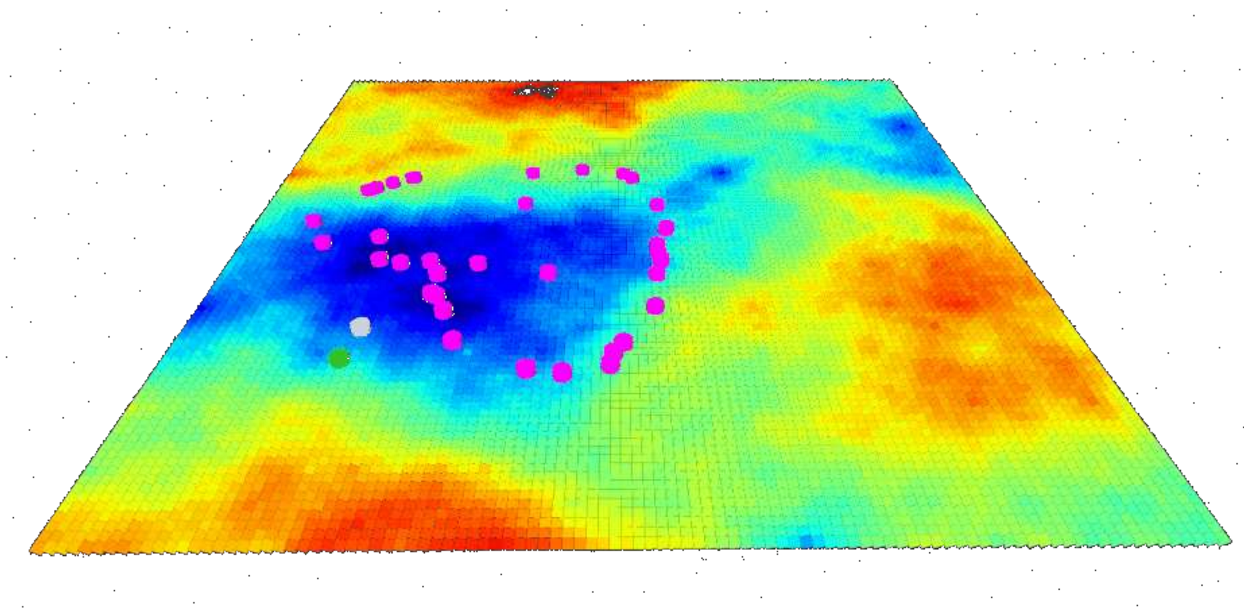

Figure 3: By moving nodes towards the neighbours with the smallest relative error, the predicted location of the source gets closer to the location of the actual source. The red areas are areas of high noise whereas blue areas have little noise.

quality sensory information whilst minimizing risk (i.e. UAVs providing aerial imagery whilst ground robots use this imagery to gather soil samples). I would also like to create algorithms that optimize the number of robots needed in the field to provide persistent coverage. For instance, a robot will eventually to to return to a base station to recharge. At this time another robot can leave the base station and take its place. Developing methods that determine the total number of robots needed to survey an area 100% of the time given the resources of a base station (i.e. number of recharge stations) can lead to fully autonomous persistent surveillance solutions that can be deployed with minimal oversight in the field.

Figure 4: An AscTec Pelican. The physical UAV that was used to test the risk-sensitive surveillance algorithms that were developed.

Furthermore, I am interested in expanding the multi-agent source localization tool-kit I created to be more accurate by using genetic algorithms to automatically generate neural controllers that are able to deal with the lack of information provided by the system.

For my PhD, I would like to develop a set of algorithms that will allow a group of robots to complete high level objectives with minimal human oversight or intervention. These algorithms would allow the robots to return to base stations to automatically recharge and dump gathered information and would automatically optimize how many robots are in the field at any given time to ensure persistent operation.

References

[1] A. Wallar and E. Plaku, "Path Planning for Swarms by Combining Probabilistic Roadmaps and Potential Fields," *Towards Autonomous Robotic Systems*, vol. 8069, pp. 417–428, 2014.

[2] A. Wallar and E. Plaku, "Path Planning for Swarms in Dynamic Environments by Combining Probabilistic Roadmaps and Potential Fields," *IEEE Symposium on Swarm Intelligence*, 2014.

[3] A. Wallar, E. Plaku, and D. A. Sofge, "A Planner for Autonomous Risk-Sensitive Coverage (PARCOV) by a Team of Unmanned Aerial Vehicles," *IEEE Symposium on Swarm Intelligence*, 2014.

[4] A. Wallar, E. Plaku, and D. A. Sofge, "Motion Planning for Surveillance of Risk-Sensitive Areas by a Team of Unmanned Aerial Vehicles (under review)," *IEEE Transactions on Automation Science and Engineering*, 2015.

[5] A. Wallar, "MALT: A Multi-agent Source Localization Toolkit." `https://github.com/wallarelvo/malt`. Accessed: 2014-11-22.