Electrical Engineering: Master's Thesis Proposal

Development of the KΩ Optimization for Autonomous Mobile Robots

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Abstract

The KΩ-search optimization provides the power and versatility or various search algorithms that can be used to provide optimal solutions at the cheapest cost to robots that are bounded by their resources (e.g. time and computational power). The objective of this research thesis is to explore the use of kΩ-search algorithms for autonomous mobile agents.

Introduction

The KΩ search [1] is the generalization of the Evolutionary Search Algorithms that consist of most of the typical search algorithms. Autonomous agents often use evolutionary computing [3] methods to perform its tasks at optimal costs. Classical robots that are purely reactive with no feedback of its environment cannot always conform to newer environments. This gives rise to a need for evolutionary computing methods that allow agents to interact with its environment rather than just react. As robots become an essential part of human life, it will be even more important that they perform tasks that minimize costs every time.

Inspiration

The motivation for this thesis comes from vision of the future where autonomous mobile robots play a key role in society. Autonomous intelligent agents will perform many of the important tasks that compliment human life. With the technological developments of the last two centuries, the robots have already replaced humans in tasks that provide no intellectual stimulation or have a high cost of human employment. Control and navigation of vehicles is one of those aspects which has developed to the extent where computers manage the primary controls of the vehicle while humans provide references and perform other more valuable tasks. With the advent of technologies like fly-by-wire, GPS, Inertial Navigation, Laser, Imaging devices and extremely powerful processors it is now possible to develop autonomous vehicles such as cars, UAV's and autonomous underwater vehicles. Examples of these technologies can be found in research institutes [2] such as NavLabs, US Navy Research centers as well as corporations such as Northup Grumman & Lockheed Martin.

As these autonomous vehicles become common in the next few decades, there is a need for the development of the intelligent algorithms that control these agents and provide them with evolutionary computing methods. Currently some of the latest agents use Anytime Algorithms [5] that provide them with a basic approach to problem solving.

Deficiencies in Current Technology of Autonomous Mobile Robots

There are two major deficiencies that most autonomous mobile robots face: (1) Detecting a problem (2) reacting to a problem; by computing new solutions. The first deficiency is an inherent deficiency that comes from the agent, either not having enough sensors or not having the knowledge of the problem. There is not general algorithm that allows an agent to detect universal obstacles. This thesis will not research the issue of problem detection; instead will assume that agents can detect the problem and then need to react to the problem. This thesis will focus on 'reaction' to detected and known obstacles.

Once a problem or obstacle is detected by the robot, it needs to react to the problem by generically re-computing the new solution. This new solution should not only be optimal but should also use the best computing algorithm. This is the basic goal of the KΩ optimization and the anytime algorithms. This research thesis will explore if the KΩ search algorithm, which is a generic algorithm, can be used to solve this problem. This research will be specific to autonomous mobile agents and will focus the implementation of anytime algorithm, with respect to such agents.

KΩ Optimization for Autonomous Agents
If applicable KΩ search will provide autonomous agents with an Evolutionary Computational methods that allow a generic problem solving approach. The agents will not only be able to find the optimal solution, but also the optimal algorithms to solve those problems. When autonomous agents come across a problem they will determine the best algorithm that can be used and then minimize cost to the solution while also minimizing resources used by the robot.

Research Objectives

This research will primarily be based on understanding the KΩ search method for Autonomous mobile robots and also implementation of the algorithm in a controlled environment. Research will be conducted based on the preliminary work done by Dr. Eugene Eberbach and his previous students. An in-depth analysis will be performed on some of the Evolutionary Computation and Anytime Algorithms that have a potential for implementation. Also, algorithms used of bounded rational agents will be studied in detail. The conclusion of the research will be determined by implementation of a usable algorithm on a simple robotic platform in a controlled environment.

This research will have the following major milestones:
1. Research & Development of the KΩ Optimization
2. Development of a controlled environment
3. Implementation of the Algorithms
4. Thesis & Defense

Research & Develop KΩ Optimization
The base of Evolutionary Computing is that the best solution is preserved from generation to generation, hence evolving the quality of the solution. This underlines the importance of not only computing the optimal outcome but also of preserving the method used to reach the outcome. The KΩ optimization or search method is very generic, which allows the agent to use several other searches such as A*, Minimax, dynamic programming, tabu search and evolutionary algorithms.

The research will focus on developing this general algorithm defining an implementable fitness function allowing for developing qualitative solutions while minimizing the cost of the solutions. Semantics and metrics for the cost function will be developed allowing for study and understanding of the quality of solutions and cost minimizations. The intelligence [1] of the agents will be measured in various aspects including the following

- Completeness
- Optimality
- Search Cost
- Total Optimality

Some of the work concerning thresholds for cost functions will also be conducted under this research. The project will try to investigate various generic methods of adapting acceptable performance thresholds. In theory, optimality is achieved when the cost function is minimized completely and a solution is achieved. However, for practical implementation, there is a need for developing algorithms & analysis that define optimality.

Development of Controlled Environment

Once the preliminary research is completed, a controlled environment will be developed for the implementation of the algorithm. A controlled environment is an experimental setup that provides a foundation for a research oriented implementation. This particular controlled environment will be designed for a robot with a locomotion system that allows it to freely move within the environment. The mobile robot will also require a sensory system which will help it understand the environment and provide feedback control for locomotion. The controlled environment will consist of a setting where the robot can detect obstacles and also have the ability to differentiate between goals, obstacles and nodes. The ideal sensor may be to use binocular vision but a simpler approach may also be possible. Instead of using binocular vision, a combination of ultrasonic sensor and a couple of light sensors maybe used.

Since the inspiration of this research comes from autonomous mobile robots, the setup will be such that it mimics a grid with obstacles that are unpredictable. The grid will consist of the paths that have a cost associated with it (for example it may be a speed limit on a road), a destination node as well as moving and stationary obstacles. The robots objective will be to find the cost optimal path to either a known or an unknown destination while minimizing the resources used to reach the optimal goal. In other words, the robot will find the shortest as well as the fastest path to its goal, recalculating the path when it comes across a moving obstacle.

Although the details of the grid will be developed throughout the research, a basic example of a grid may be designed as follows:

1. Grid will consist of nodes (intersections) and paths
2. Grid will consist of horizontal and vertical paths defining a rectangular grid such that the distance from any one node to the adjacent one will be equal.
3. The grid will be defined in a Manhattan like street structure such that each horizontal and vertical path is unique.

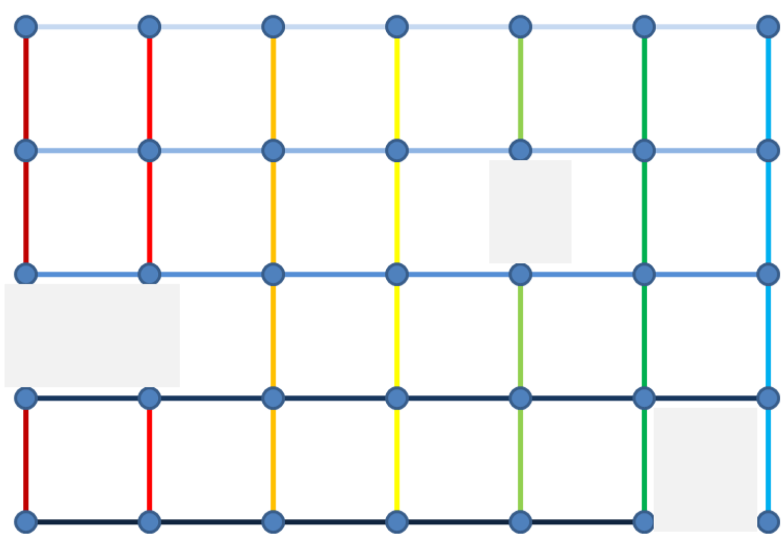

Figure 1. Example Manhattan Grid

In the figure above (Figure 1), an example of a grid is given where, all paths are unique, and all nodes are equidistant. The stationary obstacles are defined b y the grid structure with the absence of a path. This grid is designed for a mobile robot that can differentiate between colors to identify its location on the grid. The goal is not identified in the figure because it may or may not be stationary. This means that initially the robot may, or may not know the location of its goal before hand.

Developmental work will be required to adapt the KΩ algorithm to this controlled environment. Also a control system with be required to controlled the robot's locomotion through this path plane. The robot will have a basic map built into it and if time allows the robot's functionality may be improved by allowing the robot to learn new paths.

Implementation of the Algorithm

The Lego mindstorms NXT (Figure 2) robot is one of the simplest adaptable agents that can be programmed using with Java or Not Exactly C (NXC). The robot can be integrated by using ordinary LEGO pieces which are provided with the product. NXC is a C style programming language that can be used for this particular agent. The NXT provides a bounded controlled platform for the KΩ optimization. The NXT comes with a number of basic sensors as well as three actuators. Although the included sensors & actuators may be sufficient, it is possible to utilize other sensors that are commercially available.

Figure 2. The LEGO Mindstorms NXT Robot with all included Sensors & Actuators

For the purpose of this research the robot will require at least two actuators for locomotion along with a sensory system that consists of light sensors, allowing it to detect distinct paths. The robot will also utilize the ultrasonic sensor to detect moving obstacles.

The physical structure of the robot will be such that the NXT Brick (The central part shown in figure 2) will sit on top of a three wheeled platform, two of which will be actuated. The wheel that is not actuated will have two degree freedom of motion and will be used as a third point to hold the weight of the robot while maneuvering on the grid. A set of light sensors and an ultrasonic sensor will be placed along with the brick. The light sensors will be pointed in a direction such that it can read the various colors on the grid.

Thesis & Defense
All the research and experimentation done during this period will be documented in a thesis paper that will explain in-depth each step of the research. The thesis will be written in a professional manner such that in can be submitted for publishing at the end of the research period. The thesis will also accompany a defense presentation where the work accomplished during the research and experimentation will be shared with a committee of advisors and faculty members. The approval of the thesis and defense will define the closure of this master's thesis.

Research Plan & Timeline

In this section, the resources required for this research are discussed. The research is expected to commence in September 2007 at the beginning of the Fall 2007 semester and is expected to continue up until the end of the semester in December 2007. The initial committee members for this thesis consist of the research advisor Dr. Eugene Eberbach and the academic advisor Dr. Farooq Mesiya from the Renssellaer Hartford Campus. If either of the advisors inclines towards including other committee members they may do so. Regular meetings will be setup with the research advisor throughout the semester to asses and advise the progress of the research. The major resources required and their costs along with the research timeline are described below.

Resources Required
To accomplish this research project a number of resources are required; from the physical robot, to the advice of the research advisors. Most of these resources are readily available to the students or the advisors and shall only have a minimal cost impact.

The most important physical resource required for this research is the LEGO Mindstorms NXT kit. The NXT kit is already available to the research advisor. The other physical resource required will be access to utilities that will allow the development of the controlled environment as mentioned earlier.

Another resource needed will be access to research papers and journals through the University Libraries. This resource is also already available to the university. Along with the NXT block, the NXC software programming tool will be required. The NXC is a freeware available on the internet.

Cost & Budget
Since most of the resources required for the research are readily available, no costs have been identified for this research. During the research if any extra costs or resources are identified that cannot be covered, the advisors will be notified.

Timeline
The major tasks required for the research have been outline in the above objectives section. In this section, the detailed timelines for the semester of fall 2007 are described.

1. Submission of Thesis Proposal – September 4th, 2007
2. **Meet advisory committee** to discuss proposal(optional) – September 12th, 2007
3. Proposal acceptance Deadline for advisors – September 12th, 2007

4. **Meet research advisor** to initiate research – Week of September 17-21, 2007
5. **Meet advisor(s)** for Research Update – Weeks of October 8-26, 2007
6. Submit initial thesis to advisor(s) – October 26th, 2007
7. **Meet advisor(s)** for Research implementation – Week of October 29, 2007
8. Completion Controlled Environment – November 9th, 2007
9. Implementation deadline – November 13th, 2007
10. Final thesis Deadline – November 16th , 2007
11. **Demonstration to advisor(s)** – Week of November 26th, 2007
12. **Defense of thesis** – Week of December 3rd 2007
13. **Grades Due** – December 17th 2007

The RPI Academic calendar of fall 2007 [6] is as follows. The important dates for advisors and students are highlighted.

1. **July 2, Monday -**Fall 2007 registration begins
2. **August 3 - Friday** Application deadline for Fall 2007 new students
3. **August 20 - Monday** Registration deadline for Fall 2007 - tuition due
4. **August 29 - Wednesday** New Student Welcome Reception
5. **September 3 - Monday** Labor Day - no classes, facilities closed
6. **September 4 - Tuesday** Classes begin
7. **September 25 - Tuesday** Drop Deadline (Last day to drop a course without full financial penalty)
8. **October 5 - Friday** Degree Applications due in Office of the Registrar for December 2007 graduates
9. **October 26 - Friday** Last day to request Thesis or Project Defense and to submit copy to advisor
10. **November 12 - Monday** Spring 2008 registration begins
11. **November 16 - Friday** Last day to submit approved Thesis or Project
12. **November 22 - 23 - Thursday and Friday** Thanksgiving recess - no classes, facilities closed
13. **November 26 - Monday** Classes resume
14. **December 7 - Friday** Application deadline for Spring 2008 new students
15. **December 13 - Thursday** Classes and exams end
16. **December 17 - Monday** Grades due
17. **December 21 - Friday** Registration deadline for Spring 2008 - tuition due
18. **December 25 - Tuesday** Christmas Holiday - facilities closed
19. **December 28 - Friday** Official date of December degree award (Degrees will be available in February 2008)

NOTE: The dates highlighted in red, are common between thesis timeline and RPI academic calendar.

Broader Impact & Intellectual Merit

The implementation of this algorithm if successful may be used to publish a paper in the future. This type of research will be essential for the development of autonomous mobile robots. The research's success will allow autonomous mobile robots to use such algorithms to find optimal solutions while reducing costs. Applications could be used towards many technologies from search-and-rescue using autonomous helicopters to autonomous vehicles that navigate on their own. This technology will provide autonomous mobile robots with a viable target acquisition method as well as a method for interactive problem solving.

References

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[7] Eberbach E., Duarte Ch., Buzzell Ch., Martel G., A Portable Language for Control of Multiple Autonomous Vehicles and Distributed Problem Solving, Proc. of the 2nd Intern. Conf. on Computational Intelligence, Robotics and Autonomous Systems CIRAS’03, Singapore, Dec. 15-18, 2003