

Autonomous Robots and Genetic Algorithms: Part I - The Autonomous Robot

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Abstract

An autonomous vehicle was constructed containing a Motorola 68HC11 microprocessor, a Vector-2X electronic compass module, infrared collision avoidance sensors, and a dc motor powered tracked platform. The robot competed in the 1997 IEEE Southeastern Conference (SECON) hardware contest hosted by Virginia Tech in Blacksburg, Virginia. The objective of the competition was to retrieve as many metal balls as possible in a timed, head-to-head competition with another robot. The metal balls were randomly placed at polar grid coordinate crossings on a twelve-foot by twelve-foot plywood playing field. A polar grid coordinate system was painted on the playing field. The random ball locations on the polar grid were provided to each team fifteen minutes before the start of each round.

The initial inclination was to follow the polar grid pattern as painted on the playing surface. However, this would not be the shortest path to collect all the balls. There are twenty balls on the table, and using conventional methods of finding the shortest pathway, the solution would require $19!$ (or 1.21645×10^{17}) possible paths to be calculated. Since there is only fifteen minutes to find the best path, another method needed to be used. A genetic algorithm was chosen, which is a self generating code based on organic evolution. It was found that using the genetic algorithm approach, after only 5 minutes of computation time, which allowed the examination of only 37,500 paths, excellent results were obtained for an efficient collection path.

Introduction

Contest: Engineering technology programs have the mandate to provide educational instruction with application based laboratories. What better way to encompass all disciplines of electrical and electronic engineering than through the creative design, strategic planning, problem solving, construction, and implementation of small autonomous* robots. Over the last couple of years, the University of Southern Mississippi's Student Chapter of IEEE has participated in the annual IEEE Hardware Competition. The 1997 competition consisted of a timed event with two robots

going head-to-head on a twelve foot by twelve foot playing field collecting as many balls as possible and returning the balls to their respective goals [6]. Points awarded for each type of ball were as follows: steel (3 points), brass (8 points), and nylon (-2 points). To increase the complexity of the contest, a polar coordinate grid was painted on the playing field, and the balls were placed randomly at the grid intersections. A ball location map was generated fifteen minutes prior to the beginning of each round and disseminated to each team. If the polar coordinate grid did not increase the complexity enough, a circular pit was cut into the center of the playing field.

Hypothesis: The USM IEEE Student Chapter meets on a regular basis, and it was the goal of the team members to keep the lines of communications open. Each team, and IEEE members would share ideas concerning the strategy of the competition. One afternoon a student presented a hypothesis to use a genetic algorithm to optimize the distance traveled by the autonomous robot. Instantly this became an acceptable idea and modification of the robot began. Remember the key to winning is strategy. The team with the most points at the end of the competition wins.

Genetic Algorithm: Interest in genetic algorithms began some 30 years ago with the work of Holland (1975) [11]. Since then the area has achieved wide attention. Some fundamental reading in the area would include Goldberg (1989) [10]. Genetic algorithms (GA) have as their model the evolution process found in nature and normally one does not associate genetic algorithms with autonomous robots [7,8]. However, they have been very useful in solving path optimization problems. The GA initializes with an "individual" and a solution considered the "gene". Each member of the initial population is evaluated for the fittest individuals and they are given the best chance of survival. The GA then eliminates the poorer individuals and a new population is generated from the strongest. The new generation is created using mutations by altering a small portion of a gene and using crossover, by combining the genes from two parents. After this new generation has been formed, the entire process is repeated again beginning with the evaluation

of the fitness of the new members of the generation. The process can be repeated as long as it is practical. The representation of the solution parameters as the gene and the determination of fitness value by evaluating the solution tend to be problem specific and represent the main challenge to applying GA to a particular problem.

Traveling Salesman: The traveling salesman problem can be described as follows: The traveling salesman must visit every city in his territory exactly once and then return to the starting point. Given the distance (or cost) of travel between all cities, how should he plan his itinerary for minimum total distance (or cost) of the entire tour? This simple sounding problem becomes very difficult to solve as the number of locations increases. Generalizing, the number of paths is $(N-1)!$ or the number of unique paths is $(N-1)!/2$. Either case quickly becomes a formidable number as the number of locations increase. For example, 5 locations yield 24 paths; and 20 locations yield 1.21645×10^{17} possible paths! This hard-to-solve but simple-sounding problem becomes rather important because many engineering and scientific problems can be reduced to a TSP. Also, many other NP-complete optimization problems are transformable into each other which increases the interest in solving TSP efficiently [13]. In fact, the literature on TSP is enormous. A good start in the literature would include the comprehensive survey by Lawler *et al.* (1985) [12].

Robot

Microcontroller: The autonomous robot utilized an embedded Motorola F68HC11™ microcontroller. New Micros, Inc. of Dallas TX provided a NMIX-002 single board computer containing the embedded microcontroller [1,14,15,16]. The NMIX-0022 measures four inches by six inches and is marketed as a ready to develop, ready to run complete embedded microcontroller system. The NMIX-0022 system features are: a F68HC11™ CPU, 5 parallel ports, RS-232, 8-channel, 8-bit A/D, 8-bit counter, 16-bit timer, 3 input captures, 5 output compares, 1/2K EEPROM, 8K RAM, 64K address space, flexible address decoding, and on-board power supply circuits. The NMIX-0022 has been a cost effective educational development system for the 68HC11 microcontroller taught in several of our courses. The software development steps can be reduced to: develop the assembly program, cross-assemble, and download the program into static RAM using the NMIX-0002 embedded monitor program.

Platform: The IEEE competition required the vehicles to fit into a one foot by one foot square, and not be taller than one foot six inches. The vehicle must be fully autonomous, in that it must be self-propelled, and may not be radio controlled. The robot uses a toy bulldozer "CAT Dozer D10N", New Bright Toys, No. 2191, and can be purchased at Toys-R-Us. The toy bulldozer platform is show in Figure 1. Optimizing financial and time resources were the major factors in selecting the toy bulldozer. The toy bulldozer is a tracked vehicle which allowed it to turn about its axis, and it came with a fully operating blade lift. The fully operational motorized lifting blade meant that a ball retrieval, sorting, and dumping system could be attached with minimum changes. Modification of the bulldozer was simplified by removing the engine compartment, cab, and rear excavation blade. The platform has three DC motors geared for an optimal speed versus torque ratio. Two DC motors control the tracks, and the third motor controls the blade mechanism.

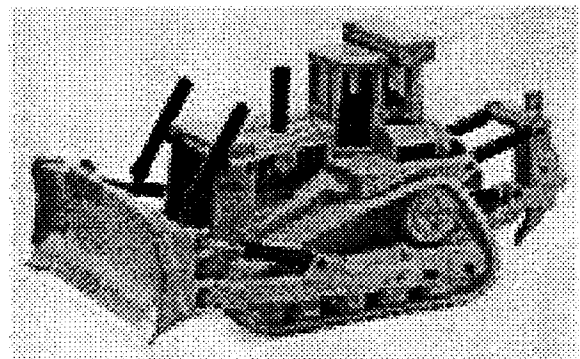


Figure 1. Toy bulldozer robot platform.

Motor Control: A transistor H-bridge, which is probably one of the most common types of motor drivers, was used to deliver current to all three DC motors of the autonomous vehicle. "H-Bridge" derived its name from the basic "H" configuration of the discrete transistors shown in Figure 2 [2]. The H-bridge connects the motor between two pairs of power switching transistors. These power switching transistors allow current to flow bi-directionally, or in either direction through the DC motor. Traditionally, the H-Bridge motor driver was implemented using discrete bipolar transistors, however, the ECG 1825 incorporates the latest in advanced modular design by combining two H-Bridge DC motor drivers into one package. The ECG1825 motor driver is used to control the speed, position, and torque of the DC motors.

raised above the goal. The brass balls weighed 9.8 grams, the steel balls weighed 8.2 grams and the nylon balls weighed only 1.2 grams. The large difference in weights allowed the fabric filter to easily sort the steel and brass balls from the nylon balls.

Implementation of the Genetic Algorithm: Visual Basic was used as the programming language to implement the genetic algorithm. Graphical windows were developed to indicate the process of the genetic algorithm as it evolved into an optimized path for the robot as shown in Figure 5. A Pentium-based laptop was used at the competition to optimize the path. With the path optimized, the vector based table was inserted into the 68HC11 assemble code.

Results

The infrared proximity detectors were able to sense the wall at a distance of three inches in a lighted room. They showed no signs of interference from outside light sources, including camcorders. Accuracy of the electronic compass proved to be teams largest hurdle. Any deviation in the magnetic field caused by the table, floor, or steel structure of the building would influence the compass reading. With the aid of the genetic algorithm, the accuracy of the distance encoder, and by using the largest ball retrieval bucket possible, any error in the compass was reduced. The ball retrieval was installed on the front of the robot and connected to the bulldozer's blade lift mechanism. Since the robot was allowed 1.5 feet of vertical height, the robot would raise the bucket during robot sizing, and then lower the bucket at start time.

The GA would often generate a path that would range up to 30% shorter than the path given by the nearest-neighbor heuristic. This is remarkable considering that the nearest-neighbor heuristic produces very good solutions on its own. Path optimization was without regard to the center pit. When the GA had completed its optimization, an expert system would then modify the path to allow the robot to avoid the center pit. The robot path was further modified for wall/robot clearance. The required computer time of 5 minutes was just about the right time since there was some time needed before the GA to enter the locations of the 20 balls on the table and there was time needed afterward to download the shortest path information to the robot.

Discussion

At any given point in time, there are inevitably many solutions available to the problem. The key is to never

overlook an obvious solution. Teamwork and open lines of communications were the keys to this years robot project. If it were not for the openness of the two teams, then this solution would have not been seen.

During competition, all robot teams, but two, chose to track the painted polar coordinate grid system. When the USM robot proceeded across the table without regard to the grid lines, the crowd was ecstatic. The noise from the crowd grew larger when the robot teetered on the pit edge then backed off, turned around and moved on in another direction.

Even though the USM IEEE team did not win the competition, they gained the valuable experience of looking at problems from other angles.

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* An autonomous vehicle must be self-propelled, and may not be controlled by any outside communications.

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William Russell graduated from Southern Arkansas University in 1987 with a BS in Engineering Physics. In 1989, he earned his MS degree in Electronics and Instrumentation from the University of Arkansas at Little Rock and completed his doctorate in 1994. While working his way through school Dr. Russell has tested Sparrow Missiles for General Dynamics, and was the Engineering Manager for Scanning Technologies, Inc., which is a bar code industrial automation company. Before returning for his doctorate, William worked as an automation engineer for a startup company called ESI Automation. After his doctorate was completed, he continued his ultrasonic diagnostic equipment research in obstetrics for the University of Arkansas for Medical Sciences. Dr. Russell is now an assistant professor for the University of Southern Mississippi. He is continuing his obstetrical research which includes: precision low noise circuits, RF instrumentation, embedded microprocessors, digital signal processing, printed circuit board design and fabrication, and automation.

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Eyler Robert Coates graduated from Louisiana State University in 1979 with a Bachelor of Science degree in Industrial Engineering. He has worked at Cincinnati Milacron, Hatteras Yachts and Davis Yachts as an industrial engineer. He obtained a Master of Engineering Science degree from Louisiana State University in 1996. He has completed his doctoral coursework at LSU and plans to complete his dissertation in 1998. Eyler Coates is currently an assistant professor at the University of Southern Mississippi in Hattiesburg.