A Centralized Evolutionary Target Tracking System

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Abstract: *In this paper, a surveillance system is presented. The system is composed of two stages. To insure the optimization of the usage of sensors provided, yet maintaining maximum coverage, the first stage is the optimization of a network of agents containing ultrasonic sensors within a pre-specified coverage area. Stage two is the target tracking phase. Sensors are activated based on need according to the tracking requirement of the moving object. To optimize power usage and hence minimize human intervention for maintenance purpose, unneeded sensors are kept in a low-power stand-by state. Sensor agents have the capability of communicating with a centralized server to report on target location and direction. The central server powers-up those agent sensors needed for proper tracking of the moving object.*

1. Introduction

One of the main applications for surveillance systems is in military. The design and development of surveillance systems for military purposes is experiencing an increased growth. Such systems are intended to detect, locate and track moving targets, which include humans, trucks, tanks etc. The accuracy of these systems depends on a number of factors. Some of theses are 1) the integration of information from several sensors, 2) the optimization of the location of sensors in order to achieve complete coverage of the desired area, 3) the efficient use of the system's resources (e.g. maintenance of sensor's battery life for a longer life-span), and 4) reliable real-time communication in the midst of harsh environmental conditions and/or changes in the system. As a result of such a dynamic environment a lot of research has been done into the development of autonomous systems, capable of achieving the goals of surveillance (target detection, location, tracking etc) in the midst of constantly changing conditions.

The work presented in this paper focuses on two aspects of surveillance: the optimization of the location of sensors (with the intent of maximizing the amount of area covered by the sensors) and target tracking. Genetic Algorithm is utilized to achieve an optimum solution for the location of sensors. The rest of this paper is organized as follows: Sections II provides the following information: a) a detailed description of the Optimization Program and how it is implemented in order to achieve goal of maximizing the area covered by these sensors, and b) a description of the techniques used to track objects that enter the surveillance area.

The results obtained so far are presented in section III, while section IV gives a summary and a conclusion.

2. Target Tracking

A. The Optimization Program

The Optimization Program utilizes Genetic Algorithm to maximize the area covered by sensors within a surveillance region. The sensors used (the SRF04 Ultra-Sonic Ranger) are directional sensors with a detection range from 3cm to 3m (see Figure 1 for the beam pattern of the sensors). Within this program, the sensors can point in one of four directions: North, South, East or West.

Figure 1. Beam Pattern for the Ultra-Sonic Ranger

The area within which these sensors are placed is a rectangular grid, measuring 1000 cells by 1000 cells, with each cell representing an area of about 3cm by 3cm. Similar to any Genetic Algorithm, each solution is embedded in a chromosome, and a sample chromosome that is manipulated within this program is shown in Figure 2.

The Optimization Program is coded in MATLAB (Matrix Laboratory), which is a mathematical programming language and environment, optimized for matrix operations [1]; as such, the chromosome is represented in a row vector.

There are about 7500 cells within this chromosome and a maximum of 2500 sensors are needed to cover the entire area.

The first cell of this vector specifies how many sensors are used within the region. The second cell (and every third cell after this) specifies the direction of each sensor (1-North, 2-East, 3-South and 4-West). The third and fourth cells (and every third cell after each one) specify the Cartesian coordinates of each sensor, while the last cell indicates the fitness of the chromosome. The values that each cell within the chromosome can hold are given in Table 1. The first 34 sensors within the chromosome are used as boundary sensors; these are always turned-on, while the other sensors are internal sensors and are turned-on as needed.

TABLE I
VALUES HELD WITHIN EACH CELL OF THE CHROMOSOME.

Cell	Values cell can hold
1	0 to 123
2, 5, 8, … 365, 368	1, 2, 3 or 4
3, 6, 9, … 366, 369	50 to 950
4, 7, 10, … 367, 370	50 to 950
371	0 to 100

One unique fact about the Optimization Program is its ability to either generate a new population of chromosomes or work on a pre-existing population, where each population contains 100 chromosomes. The operators used within the optimization program are Reproduction, Crossover and Mutation. The reproduction operator is based on the Roulette Wheel technique.

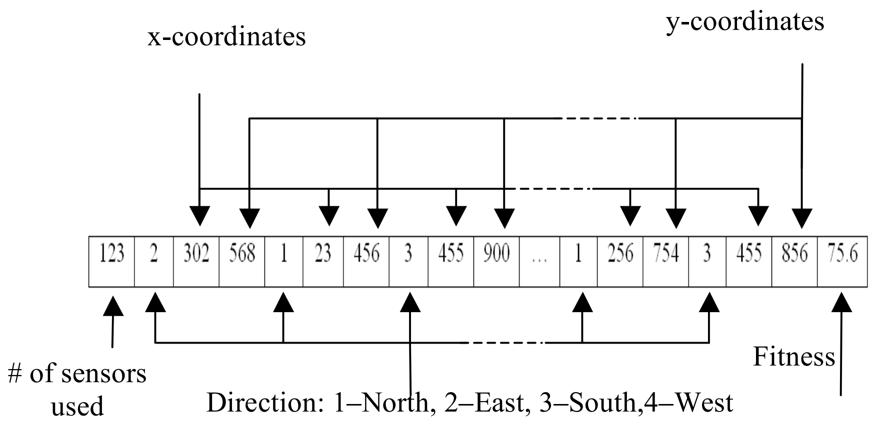


Figure 2. Chromosome Structure

In addition, the four most-fit chromosomes are always reproduced to the next generations. The Crossover operator performs a variable-length two-point crossover; the points are chosen so as to only affect the internal sensors. For the Mutation operator, a mutation rate of 5% is utilized and only the coordinates of the internal sensors are mutated. This is done in such a way as to minimize the amount of change in its location. Lastly, the fitness of each chromosome is based of two factors: A) how much of the area is covered and B) how many sensors are used. The formula that defines the fitness is shown in the following equation.

$$Fitness = A*B = \left[\left(\frac{x}{1000000}\right)*100\right]*\left[\left(\frac{35.05}{35}\right)-\left(\left[\frac{0.03}{35}\right]*z\right)\right]$$

where x is the number of cells covered by all the sensors (in terms of MATLAB) and z is the number of sensors used within the current chromosome.

B. The Tracker

The second part of this research is the tracking program. It is designed to track the movement of objects that enter the surveillance area. As mentioned in the previous section, there are two types of sensors within the surveillance region: the boundary sensors and the internal sensors (see Fig. 3). The boundary sensors are always turned-on and are able to detect objects as they enter the region, while the inner sensors (which are on stand-by) are turned-on as needed. Communication within the tracking system is carried out between the sensors and the central processing system; there is no communication amongst sensors.

Once the program has generated an optimal solution, the direction and distance of each sensor with respect to the others is generated. Next, all the boundary sensors are turned-on and checked to see if any of them has detected an object. When a boundary sensor detects an object, it then alerts the central processing system, which in turn alerts all sensors (boundary and internal) that are within a 300-cell radius of the detecting sensor of the presence of an object (Fig. 4). A 300-cell radius was chosen in order to ensure that all neighboring sensors (of the sensor that detected the object) are chosen.

When the object is detected by another sensor (from the group of "alerted" sensors), its direction is determined with the help of geometry and all other currently alerted sensors are turned-off. With the presumed direction of the object determined, every sensor that lies within a radius of 300-cells and 180° of the presumed direction of the object are alerted and turned-on (the choice of 180° was to ensure the detection of the object if it traveled in a direction other than what was assumed, as shown in Fig. 5. The object is then detected and the whole process continues until the object exits the region.

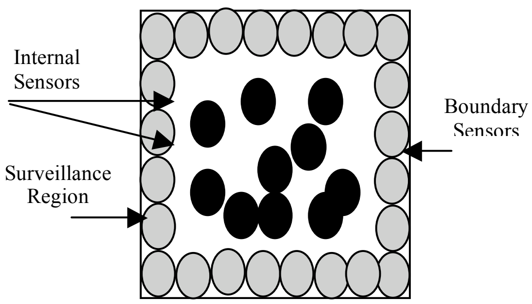


Figure 3. The types of sensors within the surveillance region

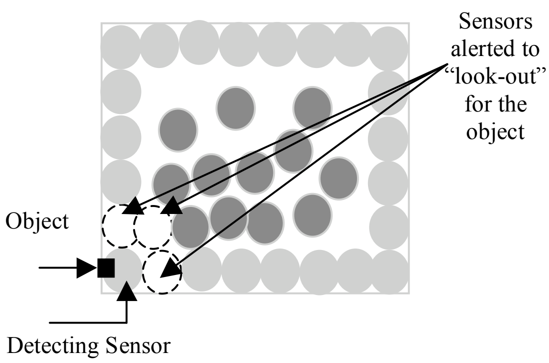


Figure 4. Detection of an object by a boundary sensor.

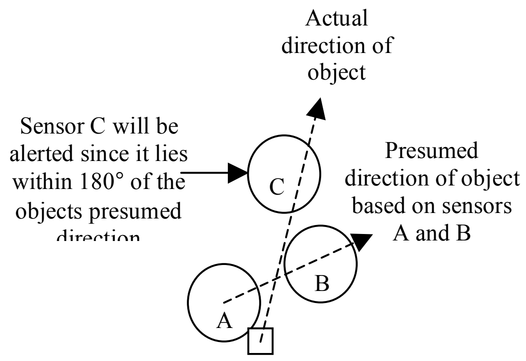


Figure 5. Reason for the choice of 180°

3. Results

C. Results of the Optimization Program

The program was executed numerous times over a period of about two months, with an average of 250 generations produced per run. It took about an hour to generate a generation from its predecessor (i.e. through the process of reproduction, crossover and mutation). After producing about 5000 generations, the maximum fitness that was achieved was about 76.12 % (starting from 60.05%; see Fig. 6). This was achieved using 122 sensors. Figure 7 gives a comparison of the amount of area covered by the sensors within two chromosomes (one with a fitness of 60.05% and the other with a fitness of 76.12%).

D. Tracking an object

Once an optimum solution had been generated (based on the fact that there was no change in the maximum fitness of the population over a long period), the tracking system was executed and tracked the movement of an object from the time it entered the region till it left. The objects movement was designed in such a way that it moved in one of three directions (based on its entry-point). For example, if the object entered from the Southeast direction, then it would move towards the North or the East or a combination of both.

Three common target tracking testing routes were tried. Figure 8 shows the actual path of an object moving diagonally through the target area. The bright dots represent the sensors that were used in the detections and tracking of the moving object. Figure 9 shows an object moving in a S-shape through the target area. This is considered one of the challenging routes since the moving object changes its direction while moving diagonally in the same time. The agent system managed to detect the object movement successfully as shown in the Figure. A U-shape movement is shown in Figure 10.

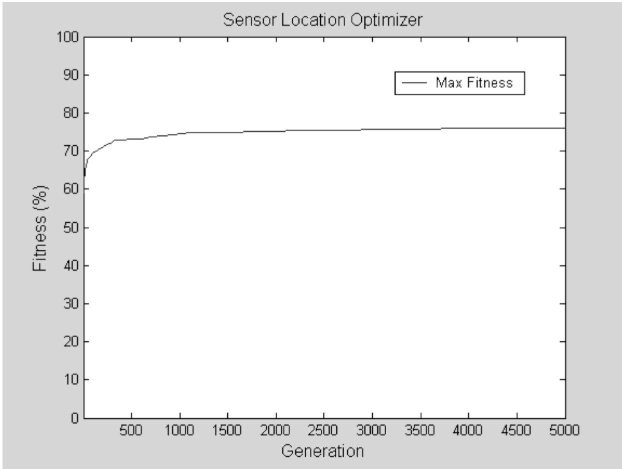
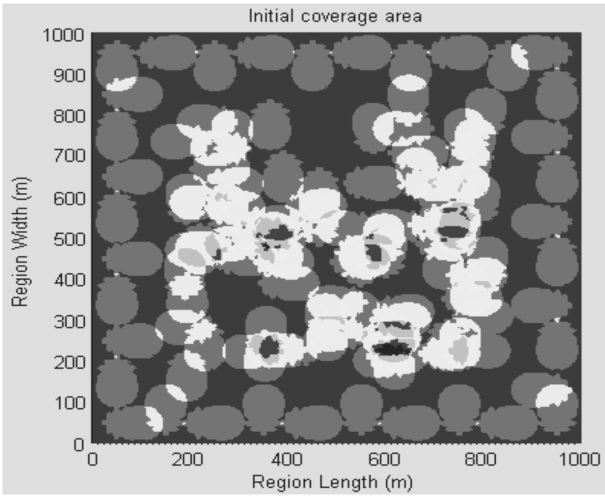
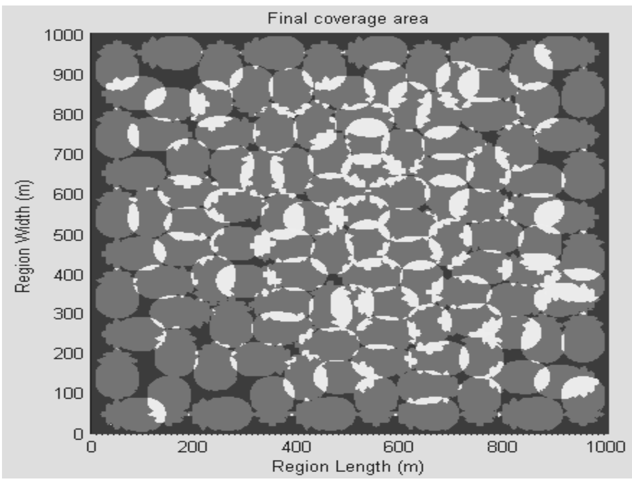


Figure 6. Resulting maximum fitness of each population, from one generation to the next



(a)

Figure 7. A pictorial representation of the amount of area covered by two groups of sensors (encoded in two chromosomes), one with a fitness of a) 60.05% and the other b) 76.12%. The brighter regions indicate more overlap



(b)

Figure 7. b) 76.12%. The brighter regions indicate more overlap

4. Conclusion

A two-stage surveillance system has been introduced. First, an evolutionary based technique for sensor location optimization has been utilized. Then, a centralized target tracking system has been presented. In stage one, the network of sensors and their locations are optimized in terms of area coverage and power consumption. In stage two, tracking of a moving target is achieved through inter-agent communications within a centralized system to coordinate sensors activation. To save power, sensors within close proximity to the moving object only are powered.

Other sensors stay in a stand-by power saving mode until activated as target approaches them. Currently, we are looking at expanding the system to include different terrains and wooded areas. In addition to that, we are considering mobile sensors that would adapt to change in environment, such as failing sensors within the network.

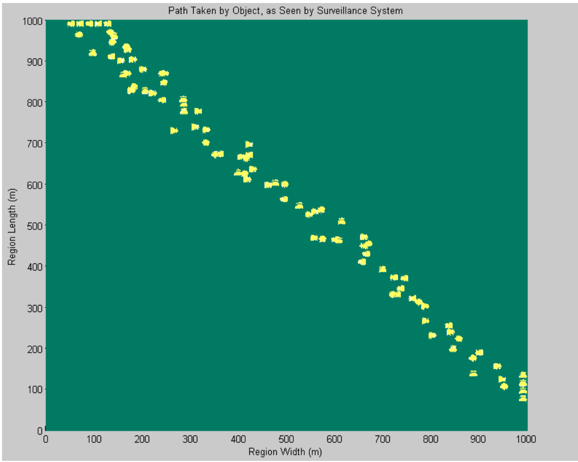


Figure 8. Tracking of an object within the surveillance region. Note the starting point of the object

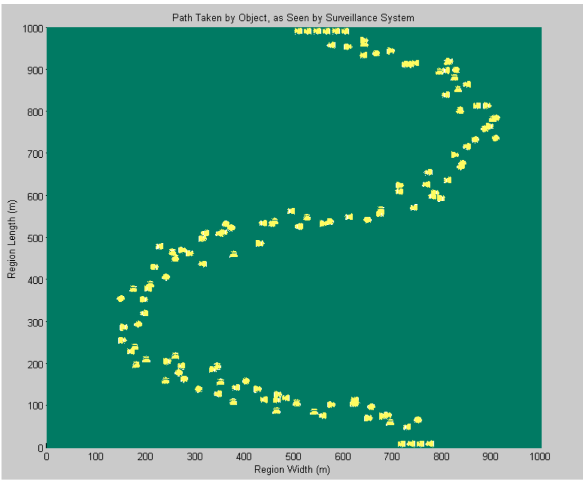


Figure 9. Tracking of an object within the surveillance region. Note the starting point of the object

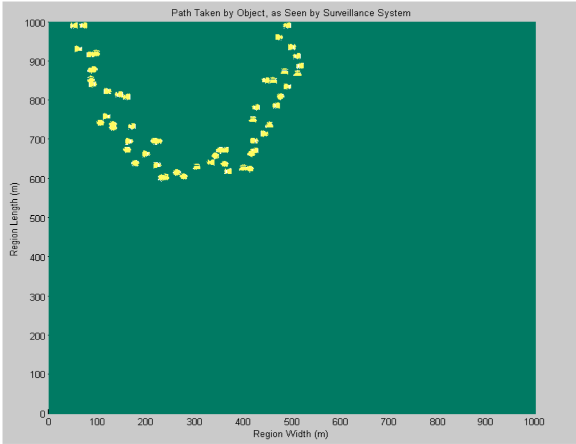


Figure 10. Tracking of an object within the surveillance region. Note the starting point of the object

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5. Biography

Dr. Yaser Khalifa is an assistant professor at the Electrical and Computer Engineering Department at the State University of New York at New Paltz. Dr. Khalifa obtained his BSc, from Alexandria University, Alexandria, Egypt, in 1992 and his PhD from Cardiff University of Wales, Cardiff, UK in 1998. Dr Khalifa research interest in the application of artificial intelligence in deign and optimization of digital, analog and mixed signals. Dr. Khalifa's research interests also include evolutionary music composition and the application of AI in creative activities.
Mr. Ehi Okoene has finished his Masters of Science in Electrical Engineering at the State University of New York at New Paltz in December 2004. Mr. Okoene is now an Engineer with E3 Incorporated, Highland, New York.

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