Cognitive Mapping in Robotics Using Genetic Algorithms

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Abstract - One of the most challenging and important problems in robot programming is cognitive robot mapping. To solve this problem it is necessary to define and detect problem space. This means to find a complete set of possible states, generated by exploring all the possible states or moves, which may, or not lead from a given start state to supposed goal state. This paper has a goal to investigate the possibilities of use Genetic algorithms as an effective technique of analyzing the problem space and exploring the space of possible solutions.

I. Introduction

When all known intelligent beings first explore a new environment, what they remember are fragments of knowledge, composed from information about distance and orientation for each point of visited places [1]. This fragmentary knowledge varies depending on the cognitive characteristics of the species. This way of forming some mental picture of physical or spatial environment, which depend from abilities to sense and collect necessary information, called "cognitive mapping", is defined and investigated by Tolman in 1948 [2]. According to human and animal ways of behavior, all robots are able to create a cognitive map of their environment. There are a few different way of using mobile robots to explore unknown environment, depending of kind of used sensors, selected techniques for analyze and programming solutions for software development.

II. Cognitive mapping process

Cognitive mapping process can be analyzed through several basic stages [3]. All of these solutions are given in general, and their realization in practice depends on the working robotic platforms:

A. Exploration

This phase consist of process of gathering and pre-processing the necessary informations using sensors. There are two way of space exploration for in robotics:

- Direct approach which mean use of real environment for the robot navigation, where the learning is performed using experiments (make or not to make mistakes when moving).
- Virtual approach which mean use of virtual environment, where the learning process is performed under simulated virtual environment.

B. Analysis

In this phase multiple different ways are used, depend of particular methodology for data collecting. In both approaches (direct and virtual) after phase of exploration, resulting behaviors are used for control and organization of moving processes on real robot. Independent of data gathering ways, process of data analyzing have a goal to form "cognitive map" of investigated environment.

C. Learning

This is the last stage of the cycle mapping environment, in which the cognitive map is created or revisited. The process of learning consists of different strategies used for mapping and re-mapping.

This paper describes an approach for analyzing and learning behavior of robots using genetic algorithms. Genetic algorithms are used to learn navigation in order to prevent collision of robots with elements of working environment. This given approach reflects a particular methodology where learning process is performed under simulation model, but resulting behaviors is used to control actual robots. The use of virtual simulation environment as a substitute for the real system has the advantage, because making mistakes on real systems may be dangerous and expensive. Also, that choice sometimes has its weaknesses - such as errors in mapping and imprecise predictability reactions and movements in complex environments. [4].

III. Genetic Algorithms paradigm

Creation of cognitive map depends of mobile robot path planning and ability of motion control. Motion control depends of path planning, and the best solution is when the motion controller is able to follow this plan as closely as possible.

A. Potential for problem solving using genetic algorithms

Problem space as set of solutions, generated by exploring all the possible states or move, depends of features of environment, such as complexity and degree of correlation between tasks for motion control and path planning, the working environment can be:

- Static environment: physical space where the obstacles are fixed, in which case cognitive mapping process is relatively fast and simple. This situation is presented in this paper.
- Dynamic environment: the working space is created and composed by fast moving unknown obstacles. Many real-world mobile robots works in this type of environment.

In both cases, genetic algorithms can be used for solving auto-tuning mobile robot control depending of path planning tasks and type of obstacles [5]. Genetic algorithms are used as a path planning algorithms, tend to find collision free route that satisfy certain optimization parameters between two point, but when used in dynamic environments, every solution needs to be re-evaluated and adapted to changes of environment.

B. Genetic algorithm process description

Genetic algorithm is an evolutionary algorithm which models a form of evolution, that can be Darwinian or Lamarckian, depending on the way in which populations respond to changes in their environment. Each genetic algorithm have the following steps in a similar way: initialization of population, calculate fitness function, selection using fitness, use of genetic operators to make new generation, and repeat steps of calculation, selection and making new generation, unless given condition became satisfied.

Genetic algorithms use evolutionary approach in processes of finding an optimal solution exploring the population from all the possible solutions. The common name of this population is “solution space”. There are differences between this “solution space” and previously defined term "problem space", which mean set of all possible states which may, or not lead to solution. The solution space is formed by parameters, where every possible solution is represented as an individual of a population. Furthermore, each gene of an individual represent parameter. This means complete set of genes can describe each individual of a population [6]. Every new generation is formed from the parent generation, using processes of selection of best individuals and applying evolutionary methods like recombination, mutation and crossover. When new individuals are generated, they pass the process of testing with fitness function. The best individual are chosen as the parents of the next generation, using ($\mu+\lambda$) strategy, where μ represent the number of parents, while λ represent the number of generated children for the next generation. The best individuals are chosen as the parents of the next generation, using ($\mu+\lambda$) strategy, where μ is the number of parents, while λ is the number of generated children.

C. Encoding process and fitness function

For the purpose of use genetic algorithms for path planning and space mapping it is necessary to encode path. Each individual represent a possible path who may or not lead from the start- point to end –point, which are not part of that individual. The chromosome is composed from particular points(genes), and ends at the moment when robot comes in touch with some obstacle. According to that different chromosomes have variable length.

Fitness function is way how to count fitness value. For each different problem both of them represents how much an individual is suited to the environment. In this case of use genetic algorithms for path planning fitness value will present how long robot can move in the environment without touching obstacles.

IV. AN EXAMPLE OF COGNITIVE MAPPING USING GENETIC ALGORITHMS

According to previous discussions, an example is processed for a static environment, using virtual model based on an NXT Lego robot platform based on approach presented in [7]. Robot model is equipped with sonar sensors, Bluetooth, and two motors. Sonar sensors measures the distance from obstacles. The RobotC software is used for this example. According distance measured from obstacles, the data will be sent through Bluetooth. The data have format of one or four letter long message, stating which direction to move. Received data are used like constants in switch expression. Depending content of message, there are four combinations, each one for different direction: forward, backward, left, right. Furthermore, depend of direction, there a four combination for control power and direction of move of the two motors. Placed in real environment, this robot going to make some mistakes, and stopped every time when came in touch with obstacles.

According to previous discussions, virtual experiments, like another possibility of environment exploration opposite use of real robots, are only software concept. There are two basic concept of use genetic algorithms, depend of criteria which are used for evolution modeling process: Darwinian and Lamarckian evolution. They both are very similar, expect Darwinian algorithm stated that an individual does not evolve until offspring are born, but Lamarckian algorithm works with assumption that an individual can give directly own genes that is acquired during its lifetime to its offspring and fitness function is calculated twice in a generation for each gene.

A. Cognitive mapping and maze problem solving

Following example demonstrate one of possible solution when used Darwinian genetic algorithm for create a program, where environment for work is a virtual world, which is also explored using a virtual robot. In this program, the goal is to create virtual path for the robot. Every simulated path is an individual, which will evolve each generation to solve the maze. Evolving process consist in fact that each new generation of individuals will tend to have longer path, because the change of gene actually is kind of experience transfer and some kind of partial cognitive mapping. This process accompanied by changes of fitness function leads, step by step, to final solution and cognitive mapping of whole environment.

B. Gene Encoding

To apply genetic algorithms to the maze problem, it is necessary to make strategy for encoding genes, which means making plan about values of genes and how to calculate fitness function. To simplify the process of finding solutions, it is assumed that each square for maze has a dimension that corresponds to the distance that exceeds the robot in the time interval between two Bluetooth messages about the direction of movements. In this case, conclusions from the virtual world can be used with acceptable precision in real environment. Every gene is composed by chromosomes. In this example, the genes have information for moving direction: Forward=1, Left=2, Right=3, Backward=4.

C. Initialization of the population

At the same beginning of the program, the first activity is to initialize a population, and place it into

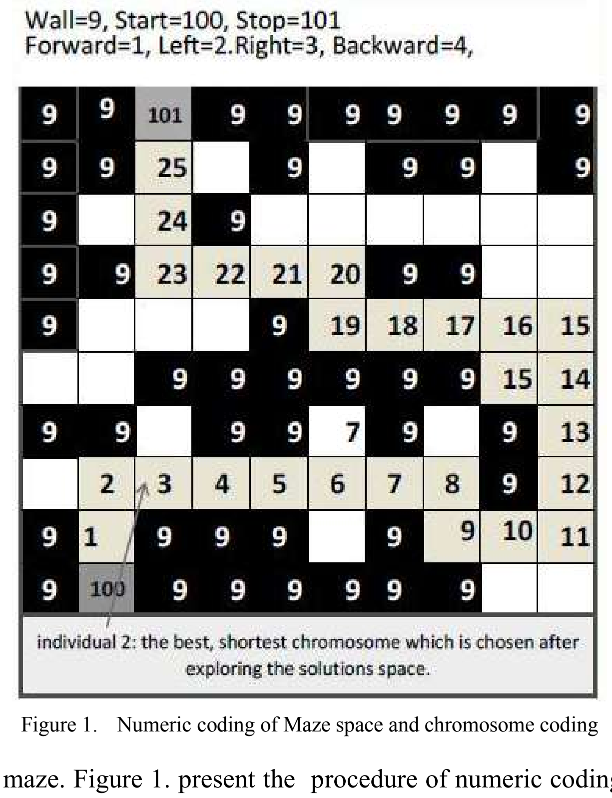

Figure 1. Numeric coding of Maze space and chromosome coding

maze. Figure 1. present the procedure of numeric coding of maze, also used to initialize the free path of the maze, which actually present the chromosome placement array.

This array is done using someone of iteration structures, to assigns random movement values (1, 2, 3 or 4). Array length is equal with the shortest chromosome which is part of solution space, formed from individuals who are passed the maze without making mistakes. The next part of the program is used to generate chromosomes.

D. Calculating the fitness function

According the real world, where the process of exploration is terminated every time when the robot crashes an obstacles, for each filled individual in the maze, fitness function give information about the number of passed squares before making mistake. Figure 2 represent the process of filling chromosomes for some individual in the maze and procedure of calculating fitness function. The process will end when individual are tested, or an endless loop is detected.

E. Selection of best individuals

Furthermore, after testing individuals and calculation of all fitness functions, follows the process of the selection of the best individuals. This mean use the fitness values as a sorting criteria, for choosing the best adapted individuals. Compared with behavior of robot in real world, fitness function shows how long length can robot pass in the maze before crashing some obstacles. After selection of best individuals using the genetic operators like mutation and crossover follow the forming of new generation. Figure 2. presents the comparison parameters used for selecting the best individuals. Basically, the process of selection and test individuals is the process of cognitive mapping of the environment too,

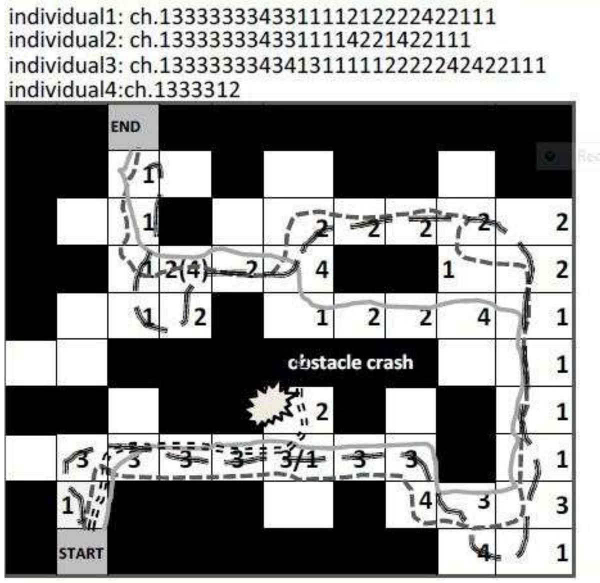

Figure 2. Selection and comparison of the individuals

which will end when the fitness function converges to the length of the entire maze. When the fitness function reaches the minimum possible value of 2, it means that mapped the entire maze, excluding the starting and final point.

After cognitive mapping process using genetic algorithms, the next step is to make connection between maps of environment, and activities for checking the movement of the real robot. For each mapped location must be planed and prepared control signals for direction of move. Figure 3 show connection between different programming activities where genetic algorithms are used, and real robot movement.

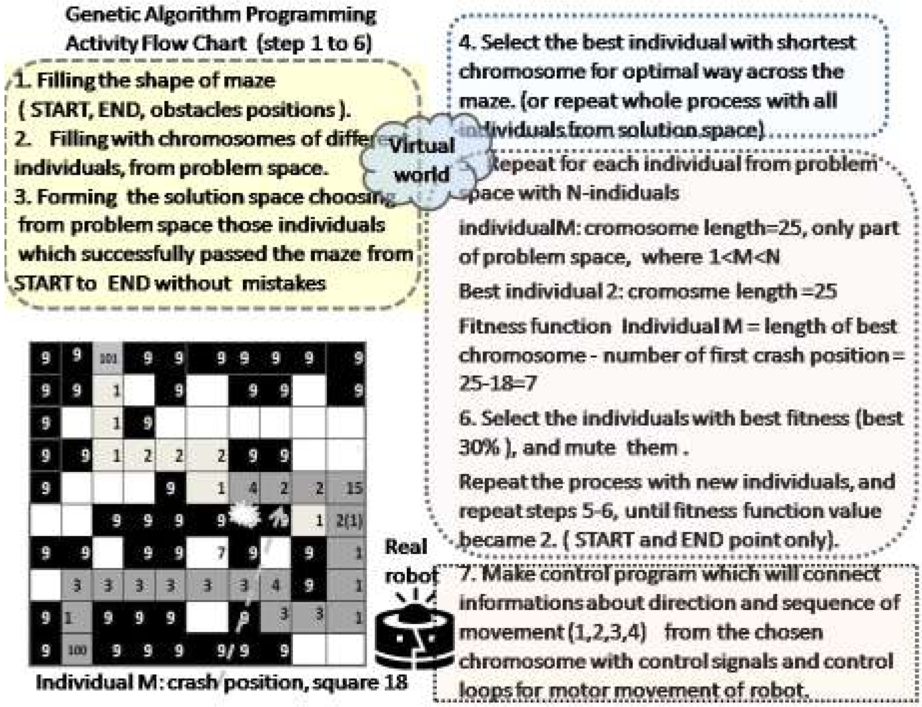

Figure 3. Genetic Algorithm programming activity description

Genetic algorithms are not the only way of planning time through evolutionary techniques for robot path planning. Other ways of cognitive mapping exist also, where the other kind of parameters are in use [8]. For this purpose, it is necessary to plan the future directions of movement for each mapped location in the space, with the aim to create a program for the control of robot motors. This is a point of convergence, among the virtual and real space in robotics, when information obtained by mapping space using genetic algorithm can be used for programming behavior of the robot in a real working environment.

V. Conclusion

This paper presented the principles of cognitive mapping using genetic algorithms, in virtual world using simulated robot, such alternative possibility for exploration of environment opposite use of real robots. Using virtual simulation environment as a substitute for the real system, has the advantage because making mistakes on real systems working with robots may be dangerous and expensive. Finally, working with genetic algorithm is a very imaginative process, because it provides a range of options to solve the same problem using the forms of experience using living organisms. This solution gives only an idea from a set of possibilities of combining and implementation techniques for solving real problems.

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