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Intelligent Path Planning for Rescue Robot

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***Abstract*—**In this paper, a heuristic method for simultaneous rescue robot path-planning and mission scheduling is introduced based on project management techniques, multi criteria decision making and artificial potential fields path-planning. Groups of injured people are trapped in a disastrous situation. These people are categorized into several groups based on the severity of their situation. A rescue robot, whose ultimate objective is reaching injured groups and providing preliminary aid for them through a path with minimum risk, has to perform certain tasks on its way towards targets before the arrival of rescue team. A decision value is assigned to each target based on the whole degree of satisfaction of the criteria and duties of the robot toward the target and the importance of rescuing each target based on their category and the number of injured people. The resulted decision value defines the strength of the attractive potential field of each target. Dangerous environmental parameters are defined as obstacles whose risk determines the strength of the repulsive potential field of each obstacle. Moreover, negative and positive energies are assigned to the targets and obstacles, which are variable with respects to the factors involved. The simulation results show that the generated path for two cases studies with certain differences in environmental conditions and other risk factors differ considerably.

***Keywords*—**Artificial potential field, GERT, path planning

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I. INTRODUCTION

SCHEDULING the mission of a rescue robot and generating a secure path for a mobile robot are the most challenging problems in rescue missions. For scheduling rescue mission, techniques of project management are dominant. The Critical Path Method (CPM) can be used to plan and control projects which are represented by a network of various activities and the precedence relationships between them. Program Evaluation and Review Technique (PERT) and Graphic Evaluation and Review Technique (GERT) are an attempt to formulate the probabilistic entity of the activities in projects and the uncertainty involved [1]. By means of CPM, PERT and GERT, the optimal sequence of activities satisfying certain criteria such as minimization of time or risk can be easily and systematically achieved.

Very often in management projects, a decision must be made between several choices. Multi Criteria Decision Making (MCDM) is an effective approach that yields decision values for each option based on the satisfaction of the predefined criteria. A new multi criteria decision making method was suggested in [2] based on GERT and CPM. This method enables applying decision making in the network of projects, where there are several final targets and a rescue priority based on the satisfaction of the criteria defined for intermediate activities. In fact the rescue priority specifies the order and sequence of the targets in rescue mission.

A flurry of research has been conducted on path planning of mobile robots. Path planning for rescue robots is structurally similar to path planning of mobile robots; however, there are additional constraints imposed by the risks involved in interaction with the injured. Recently some of the methods used for mobile robots' path planning have been extended to rescue robot path planning. Ant Colony Optimization technique [4], Fuzzy reasoning and control [5], Genetic Algorithms [6] have also been used for rescue robot path planning.

In this paper, we have proposed a method that schedules the rescue mission and generates a suitable path with minimum risk for the robot and the rescue team, and minimum time for rescue mission. The basic idea behind mission scheduling is the modified MCDM in our previous work [2]. Also, a heuristic method for path-planning by Artificial Potential Field technique is proposed. Based on the environmental parameters, the risk of obstacles specifies the strength of their corresponding repulsive field. In a similar way, the category and the number of the injured people and the relative degree of their exposure to danger along with the decision value assigned by the modified MCDM, defines the strength of the attractive field for each target. In fact, the algorithm is flexible and yields different responses in different situations. Not only the optimal sequence of intermediate rescue activities is achieved, but also the path planning algorithm implicitly follows the decision made by the modified MCDM and the robot is attracted towards the target with strongest attractive energy or equivalently the target with maximum decision value related to the degree of satisfaction of the defined criteria.

The rest of the paper is organized as follows: Section II briefly describes the basic concepts. Section III explains the proposed methodology and the contribution of the paper. Finally, section IV considers a certain case study with two different situations. The results of the simulations show that generated paths depend on the environmental situation and other discussed factors.

II. BASIC CONCEPTS

A. Artificial Potential Field Path planning

The potential field method has been studied extensively for mobile robot path planning [8]. The basic idea behind the potential field method is to define an artificial potential field

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(energy) in the robot's workspace in which the robot is attracted to its goal position and is repulsed away from the obstacles [1]. Despite the problems in architecture of potential field such as local minima and oscillation in narrow passages, this method is particularly attractive because of its mathematical elegance and simplicity [7, 9, 10]. We briefly describe the algorithm formulation in 2-D case.

For simplicity, we assume that the robot is of point mass and moves in a two-dimensional (2-D) workspace. Its position in the workspace is denoted by $q = [x\ y]^T$. The most commonly used attractive potential and the corresponding attractive force takes the form:

$$U_{att}(q) = \frac{1}{2}\xi\rho^m(q_{goal}, q)$$

$$F_{att} = -\nabla U_{att} = \xi(q_{goal} - q) \quad (1)$$

Where ξ is a positive scaling factor, $\rho(q_{goal}, q) = \| q_{goal} - q \|$ is the distance between the robot q and the goal q_{goal}, and m = 1 or 2. For m = 1, the attractive potential is conic in shape and the resulting attractive force has constant amplitude except at the goal, where U_{att} is singular. For m = 2, the attractive potential is parabolic in shape. Also, the attractive force converges linearly toward zero as the robot approaches the goal.

One commonly used repulsive potential function and the corresponding repulsive force is given by:

$$U_{rep} = \begin{cases} \frac{1}{2}\eta\left(\frac{1}{\rho(q,q_{obs})} - \frac{1}{\rho_0}\right)^2, & if\ \rho(q,q_{obs}) \le \rho_0 \\ 0, & if\ \rho(q,q_{obs}) > \rho_0 \end{cases} \quad (2)$$

$$F_{rep} = -\nabla U_{rep} = \begin{cases} \eta\left(\frac{1}{\rho(q,q_{obs})} - \frac{1}{\rho_0}\right)\frac{1}{\rho^2(q,q_{obs})}\nabla\rho(q,q_{obs}), & if\ \rho(q,q_{obs}) \le \rho_0 \\ 0, & if\ \rho(q,q_{obs}) > \rho_0 \end{cases}$$

where η is a positive scaling factor, $\rho(q, q_{obs})$ denotes the minimal distance from the robot q to the obstacle, q_{obs} denotes the point on the obstacle such that the distance between this point and the robot is minimal between the obstacle and the robot, and ρ_0 is a positive constant denoting the distance of influence of the obstacle. The total force applied to the robot is the sum of the attractive force and the repulsive force which determines the motion of the robot. [3]

$$F_{total} = F_{att} + F_{rep} \quad (3)$$

B. Critical Path Method

The Critical Path Method is used to plan and control most modern projects. A CPM network represents various activities that comprise a project and the precedence relationships between them. The duration of the defined activities are analyzed to determine the criticality and float of activities; the level of resources needed during each day of construction; and the dates at which important milestones will be achieved. In fact CPM is the most fundamental tool in project management.

C. Program Evaluation and review Technique

Duration of activities is assumed deterministic in CPM method which is far from reality. Recognizing the uncertainty in the duration of activities as a function of the dynamic state of the project leads towards PERT where three values are assigned to each duration. In PERT mean values of durations of activities and their variances are calculated by:

$$\mu_i = \frac{1}{6}(a_i + 4m_i + b_i),\ \sigma_i = \frac{1}{36}(b_i - a_i)^2 \quad (4)$$

where a_i, m_i and b_i are the optimistic, most likely and pessimistic durations of activity i, respectively. Based on the Central Limit Theorem, the distribution describing a project's duration is approximately normal, with the mean value of the project duration equaling the sum of the means of the critical activities determined by calculations made based on the expected duration. The variance of the project duration is the sum of the variances of critical activities.

D. Graphic Evaluation and Review technique

In fact GERT is a generalized form of PERT, where the probability of occurrence of the activities of the project is taken into consideration. In other words in PERT, either an activity occurs (probability=1) or it does not occur (probability=0); however, in GERT the probability of occurrence of each activity can be a real number between zero and one. GERT approach addresses the majority of the limitations associated with PERT/CPM technique and allows loops between tasks. The fundamental drawback associated with the GERT technique is the complex program (Monte Carlo simulation) required to model the GERT system.

III. Proposed Methodology

Given the graph representing the sequence of activities in a disastrous situation, the first step is to obtain necessary information for making decision. The mentioned information consist of: a) parameters affecting the decision making, which are mostly predefined and weighted, and b) estimating approximate durations of the activities which may occur during the mission. The mentioned parameters are in two main groups; one of them deals with the degree of satisfaction of the criteria defined in tasks of the robot, and the other group is concerned with importance of targets. These parameters are listed in tables 2 and 4. To reach a more realistic situation, the given information is provided in three different manners: optimistic, pessimistic and realistic (most likely). Having gained the necessary data via a questionnaire of experts, PERT algorithm is used for the process of durations of activities. The resulted output is a part of the data needed for MCDM analysis which consists of: standard deviation, free

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slack and total slack for activities, and the probability of occurrence of activities before a certain time.

The outputs of PERT and the degree of satisfaction of criteria defined for intermediate actions of robot, along with the importance of each criterion are given to MCDM algorithm as inputs. MCDM makes a decision and assigns a decision value for each activity. These values are treated as the duration of each activity and are given to CPM. It is obvious that output E_s (Earliest Starts representing the decision indexes of missions) of CPM can be interpreted as the degree of fulfillment of the activities leading to a certain event. Comparing the E_s of the last events of several missions represented by graphs, we can deduce which mission fulfills our criteria more.

The ultimate objective of rescue mission is to help the injured people. The injured situations are divided into four groups: endangered, vulnerable, defenseless and prepared. To compare different groups of injured people 3 criteria are considered (Table 3). The importance of these parameters along with the degree of satisfaction of the defined criteria in each case is given to MCDM algorithm and a decision value is calculated for each group of injured people as targets. In fact ξ (the positive scaling factor for attractive force) for each target is calculated as follows, where *norm* is normalization operator and ADV_i is the Attraction Decision Value of the i^{th} target:

$$\xi_i = norm\ (E_{si}) + norm\ (ADV_i) \quad (5)$$

Considering environmental situation and defining certain criteria for degree of danger of each obstacle, a similar approach is possible for determining the scaling factor η of the repulsive force. The degree of satisfaction of each criterion is fed into MCDM and the resulting decision value equals the positive scaling factor of repulsive force where RDV_i is the Repulsive Decision Value of the i^{th} obstacle:

$$\eta_i = \text{norm}\ (RDV_i) \quad (6)$$

Having obtained the corresponding strength of the attractive and repulsive potential field, the path planning algorithm is established and the optimal path with respect to minimum time, minimum risk and maximum help to injured people is achieved.

IV. Simulation Results

We have assumed two identified groups of injured people, the number and category of the injured in two groups differ. One of the groups is located near a gas station, the members of which are endangered by the threat of explosion and the other group is next to a building and is threatened by the collision risk of the building. The rescue robot must choose one of the groups as the priority of its mission. Also it is expected that the rescue robot accomplishes several intermediate tasks such as searching for any injured person isolated from the identified groups of injured, taking picture of the surroundings and sending it to the rescue team, sensing the environmental factors that can signify explosion, etc. Fig.1 demonstrates the network for rescue mission.

The list of activities for the network represented in Fig.1, can be found in [2] and are not mentioned here for brevity. The criteria for intermediate actions of robot in choosing the path are listed in Table 1.

As mentioned before, 3 values for the duration of each of the activities in Table 1 and the degree of satisfaction of each criterion in Table 2 by each activity is estimated based on the experts' opinions. For brevity, only a small part of the data related to the degree of the fulfillment of the main criteria via each activity and the estimated durations are listed in Table 2. In these tables H, E and R indicate parameters concerning human, environment and the robot, respectively. The complete tables are available in [2].

Durations of activities (first column of Table 2) are given to the PERT algorithm and standard deviation, free slack and total slack for activities, and the probability of occurrence of activities before a certain time are obtained as the output of PERT. The output of the PERT and the degree of the satisfaction of the criteria by intermediate actions (H_1, H_2, E_1, E_2, H_3, R_1, R_2, R_3 and R_4 columns) are fed to MCDM algorithm which yields a decision value for each activity. These decision values are treated as the duration of each activity and comprise the inputs of the CPM algorithm. Since there is the possibility of obtaining negative decision values, to avoid assigning negative inputs to CPM, we have normalized the values in the range [1 10]. E_s in the output of the CPM represents the degree of satisfaction of each activity in each network (mission index). We have got 52.9434 and 27.0122 for the networks of the gas station and building, respectively. In fact these two values are the E_s values of targets 1 and 2:

E_{s1}=27.0122, E_{s2}=52.9434.

As defined in the previous section, a set of criteria is defined for the injured people to be able to distinguish which group of injured people are more at risk. These criteria are described in Table3.

The degree of satisfaction of these criteria along with the importance related to each criterion are the inputs of MCDM and the decision value for each target is the value assigned to ADV_i.

Similar to the procedure above, a set of criteria is defined for the degree of danger of the obstacles based on the environmental situation. We have considered three kinds of obstacles: Risk of fire, Risk of electric shock, Risk of building collision. Table 4 summarizes the factors involved.

Similar to obtaining *ADV*s, *RDV*s (Repulsive Decision Values) are simply obtained by using MCDM algorithm on the importance of each criterion and the degree of satisfaction of them for each obstacle. For comparison purpose, we have considered two scenarios with different environmental

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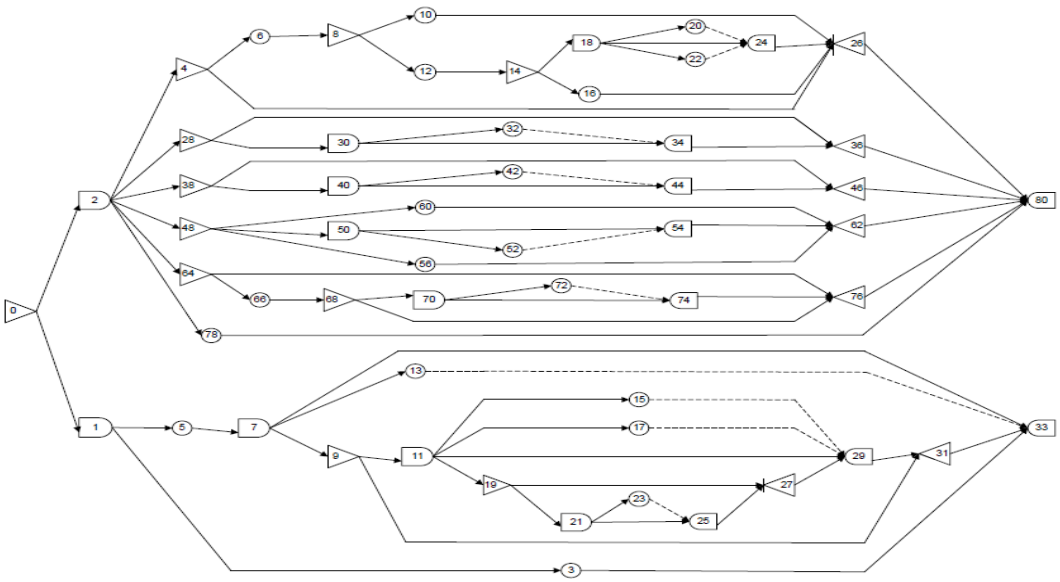


Fig 1 Network of project activities

TABLE I
MAIN CRITERIA FOR CHOOSING THE PATH

Human parameters	Environmental parameters	Parameters concerning the robot
• Capacity for reducing the life risk of the rescue team • Rescuing and preventing personal damage to the injured person	• Prevention of air poisoning in the surroundings • Prevention destruction of path for the rescue team • Prevention of fire danger in the peripheries	• Destruction of accessories • Annihilation of the robot • Repairable damage to the robot • Damage negligible for the robot to be able to continue its task

TABLE II
SAMPLE SECTION OF THE TABLE THAT INCLUDES DURATION OF ACTIVITIES AND DEGREE OF SATISFACTION OF CRITERIA VIA ACTIVITIES

Activity Numbers	Duration(sec)			H1			H2			E1			E2			E3			R1			R2			R3			R4		
	a	m	b	a	m	b	a	m	b	a	m	b	a	m	b	a	m	b	a	m	b	a	m	b	a	m	b	a	m	b
0-2	0	0	0	0.75	0.8	0.95	0.75	0.8	0.95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-4	2	5	8	0	0	0	0.75	0.8	0.95	0.5	0.6	0.7	0	0	0	0.5	0.6	0.7	0	0	0	0	0	0	0	0	0	0	0	0
2-28	2	6	10	0	0	0	0.75	0.9	0.95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-38	2	6	10	0	0	0	0.8	0.9	0.95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-48	2	6	8	0.65	0.8	0.85	0.65	0.8	0.85	0.3	0.5	0.6	0.2	0.4	0.5	0.5	0.6	0.8	0	0	0	0	0	0	0.4	0.25	0.1	0.5	0.3	0.2
2-64	3	7	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-78	3	6	10	0	0	0	0.25	0.35	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6-8	6	9	15	0.75	0.9	0.95	0.35	0.5	0.6	0	0	0	0	0	0	0	0	0	0.6	0.5	0.3	0.6	0.4	0.3	0.7	0.5	0.3	0.7	0.6	0.4

TABLE III
CRITERIA FOR EVALUATION AND PRIORITY ASSIGNMENT FOR TROUBLED GROUPS

Category and Number of the troubled people	Exposure to dangerous situation
• Category of the troubled people: endangered, defenseless, vulnerable, prepared • Number of the people in each category • Health status of the injured people	• Adjacency of the danger

TABLE IV
CRITERIA FOR MEASURING THE DANGER OF EACH OBSTACLE

Type of the obstacle	Criteria and factors involved
• Fire • Building collision • Electric shock	➢ Temperature – existence of flammable material in the vicinity – rainy/dry weather ➢ Humidity – fundamental robustness of building – possibility of building collision ➢ Humidity – rainy/dry weather

situations and different groups of troubled people.

Scenario 1- group 1: 25 people near gas station comprised of 15 endangered (injured) 5 vulnerable, 5 defenseless and group 2: 15 people near a building with possibility of collision comprised of 4 injured and 11 defenseless.

We have run the algorithm twice, once for hot weather and once for cold weather. Results are illustrated in fig. 2. Priority is given to the second target by robot. As the temperature increases, the risk of explosion is increased and the rescue robot tries to get as far as possible from the gas station.

Scenario 2- group 1: 15 people near gas station comprised of 15 endangered (injured), 5 vulnerable, 5 defenseless and group 2: 25 people near a building with possibility of collision comprised of 4 injured, 11 defenseless.

We have considered the mentioned environmental conditions and the results are illustrated in fig.3.

Note that priority is given to the first target by rescue robot. In case one, when it is cold the possibility of explosion is low, so the robot gets closer to the gas station. But when it is rainy, robot tries to be as far as possible from the risk of electric shock. The results of the simulation show the fact that the introduced algorithm is flexible in terms of the environmental conditions and the factor involved in targets.

To further illustrate the conceptual basis of the utilized potential field, a 3D representation of the risk potential function and the corresponding optimal path are represented in fig. 4.

V. Conclusion

In this paper, a heuristic method is proposed for simultaneous task scheduling and path planning of rescue robots. Project management techniques along with risk analysis are the efficient tools used for rescue mission scheduling, while artificial potential field path planning method is used for path planning. The algorithm is flexible in terms of the environmental situation and the effective factors in risk analysis. In fact the proposed method merges the path planning methods with rescue mission scheduling, and path generation method implicitly obeys the decisions made by the decision making process. The results of the simulation show that the generated paths fully depend on the defined criteria.

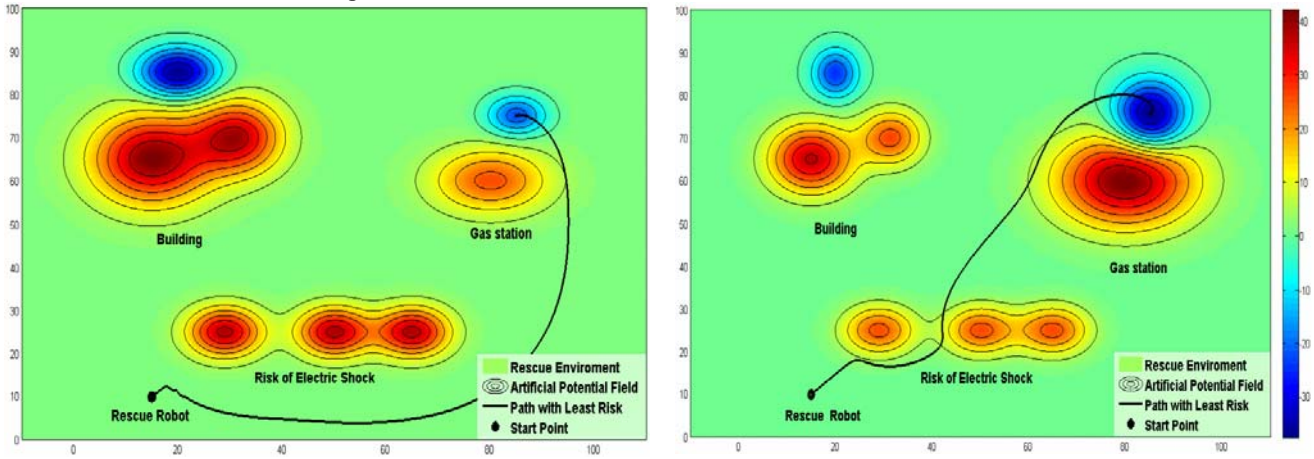


Fig.2 Generated path for the first scenario: (a) cold and rainy condition, (b) hot and dry condition

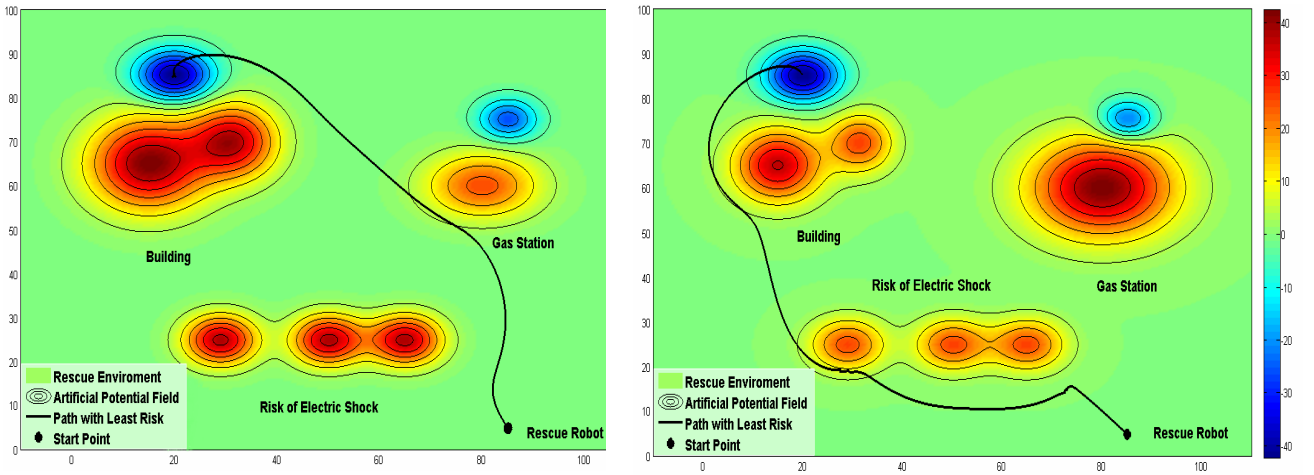


Fig 3 Generated path for second scenario:(a) cold and rainy condition, (b) hot and dry condition

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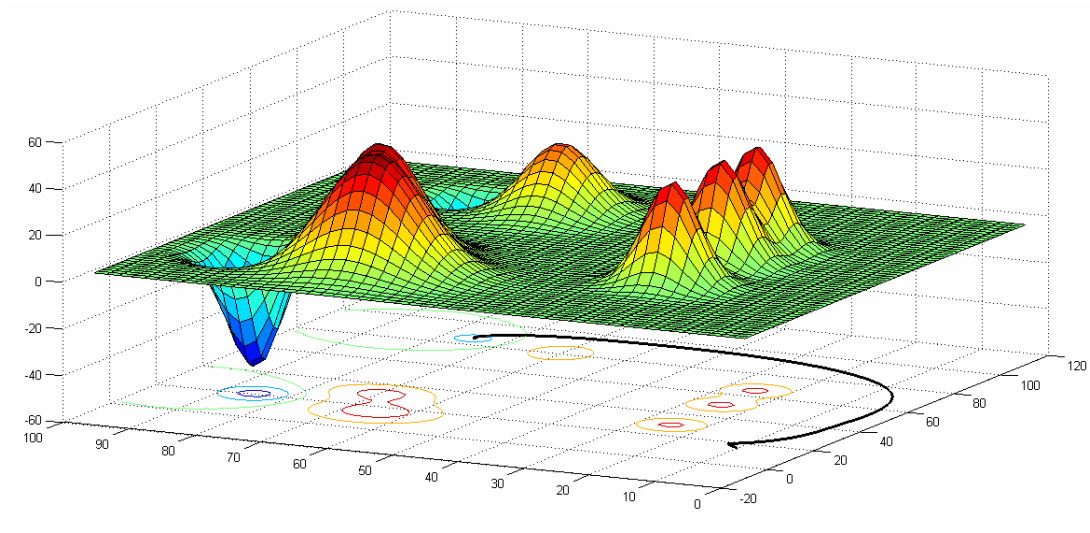


Fig 4 Artificial potential field and the obtained path with minimum risk

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