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From the Editor

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Comparing the Performance of ABC Algorithm and ACO Algorithm for Mobile Robot Path Planning in Dynamic Environments with Different Complexities

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Abstract: Mobile robot path planning is an important branch of research in robotics science. In this paper, a new approach for solving mobile robot path planning in dynamic environments, based on the Swarm Intelligence Algorithms feature of an optimized ABC algorithm is proposed. The proposed ABC will optimize the fuzzy rules' parameters that have been used for On-line path planning in dynamic environments. In this study, there is a proposed evaluation function, accordingly, the found path is smoother and cleaner than the previous studies using other algorithms. In this research, the ABC and ACO are combined with fuzzy logic; two algorithms are compared with each other. The performance of both combined algorithms in the execution speed and the number of occurrences for obtaining the optimal path in various unknown environments have been evaluated using MATLAB simulation methods. The obtained results from the comparison of the performance of these two algorithms developed optimization algorithms for mobile robots' path planning.

Keywords: *ABC algorithm; ACO algorithm; Fuzzy logic; Mobile robots; Dynamic environments.*

1. Introduction

Path planning with obstacles avoidance in dynamic environments is an effective issue in robotics. Path Planning for a mobile robot which is in an environment with different dynamic and static obstacles, is finding a Collision-free path from the starting point to the destination [1]. In this regard, issues such as minimizing the travelled distance, maintaining smooth trajectory or satisfying the clearance of route are important criteria affecting the optimality of the selected routes [1, 2]. In robotics, depending on the length of the path traveled by the robot and performance time, we need to follow an algorithm that it is able to plan safe collision free paths and find the shortest possible route [2, 3]. In a static environment, it is assumed that the roadmap is identified and the environments, with all its components, are known, thus the algorithm has the ability to create the shortest path to move the robot toward the desired destination. This approach in robotic path planning is called off-line method [4]. In an unknown environment, information from the immediate space is obtained during the robot motion and the robot is completely dependent on local information and its immediate position. Here, the goal is to obtain a reactive behavior in spite of slight data got from unknown environment [5, 6]. The second type of path planning is via the sensors; they are affected by environmental changes at the moment. This type of robotic path planning is called on-line. The traditional algorithms used for path planning in the field of change or combination include: possible road map [8], based on the map [7], and cell decomposition [9] which are based on mathematical programming. The second methods are heuristic. When the classical method of

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solving routing problems that have Np-hard nature are considered, Heuristic methods which were inspired from nature, were introduced for various challenges encountered during robot motion planning [6. 11]. In the category of exploration, soft computing includes: Neural Networks [10], Genetic algorithm [11, 12], the Simulated Annealing algorithm [13], the Ant Colony Optimization algorithm [14], and Particle Swarm Optimizer algorithm [15]. In the last decade, many optimization methods based on Swarm Intelligence Algorithms approaches have been proposed. Artificial bee colony algorithm (ABC) is one of the newest optimization algorithms which was introduced by Karaboga and is modeled based on the food seeking processes of the honey bees [16]. A bee colony consists of three bee groups: employed bees, onlooker bees, and scout bees [16, 17]. Bee colony algorithm is a population-based algorithm, and gains an optimal solution (or near-optimal solution) via a repetitive process, the global optimization problem is suitable in every field of path planning [17]. The problem in the use of the evolutionary algorithm for mobile robot path planning is the optimization process, which should be done before the robot moves (off-line), and then the robot will move on the path [6,18]. Thus, On-line routing methods must be used for mobile robot path planning in unknown environments with static and dynamic obstacles, where the position and movement of the obstacles are not predefined. Fuzzy logic is an efficient method in an on-line node to node path planning for mobile robots in dynamic environments [18, 19]. In this study, to determine the optimal path of mobile robots in an unknown and dynamic environment, a new procedure is presented based on the determination of fuzzy rule table, which has a very momentous efficacy on a fuzzy system performance. Due to path planning being a challenging problem of NP-hard issue, in this case ABC algorithm is used to determine the optimum fuzzy rule table. This research presents a new method that can plan local paths around the environment routes, and guide the moving robot toward the final destination. This goal is achieved by the optimization of fuzzy rules table for the mobile robot motion by utilizing the ABC algorithm. In this paper, the performances of ACO [20] and ABC algorithms have been compared in different complexity environments. In this regard, both algorithms with speed and number of repetitions are evaluated in different workspaces [21]. The workspaces included are: fixed obstacles with different shapes, sizes, positions and also, dynamic obstacles with different speeds and movement in different directions [21]. The second section of the paper presents the proposed Fuzzy-ABC algorithm, and robot's work spaces, which are designs fairly simple to highly sophisticated. In the third section, the performances of Fuzzy-ACO and Fuzzy-ABC algorithms are compared in unknown environments. The fourth section discusses the efficiency and effectiveness of these algorithms.

2. Method

The determination of fuzzy rules table is considered to be a very important and effective issue on a fuzzy control system, which is normally done by a skilled person manually confirming the table 1[19]. Manual determination of fuzzy rules cannot be fully optimized. In the present study, there are two inputs each with 5 membership functions and the output has also been fuzzified with 7 membership functions. As the result, total number of feasible solutions for the determination of fuzzy rules table is 725. Therefore, fuzzy rules table optimal preparation is an NP problem and the use of Swarm Intelligence Algorithms in this case seems to be very efficient. Our purpose, in this study, is to optimize fuzzy rules in order to improve the route (regarding the route length) by means of artificial bee colony algorithm. In fact, bee colony algorithm determines fuzzy rules in an optimal way with the aim to minimize the route length by the robot. It is necessary to mention that optimization is only done for one time for the adjustment of fuzzy parameters. Afterwards, the fuzzy control system will be optimized instantly for the future applications. The general flowchart for this proposal is provided in Fig. 1.

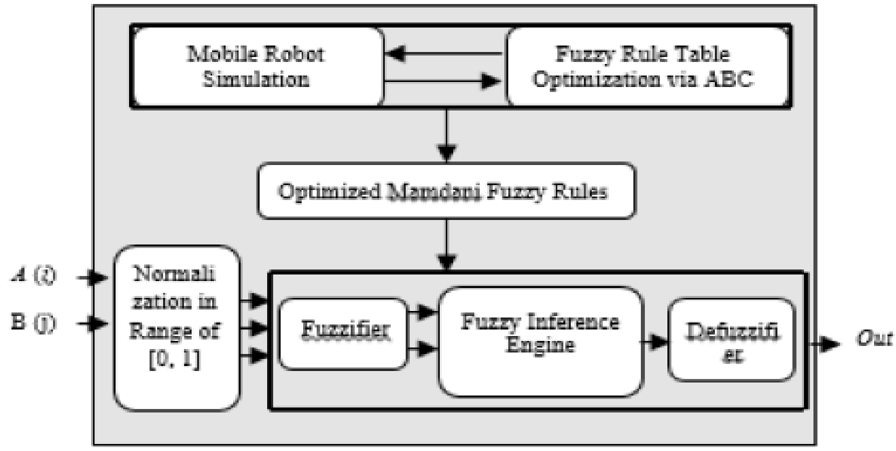

Figure 1: General flowchart for the proposed method of fuzzy rules table optimization by means of bee colony algorithm.

In [21], Routing of mobile robots has been considered in known dynamic environments in three workspaces, including relatively simple, moderately complex, and complex environments. Considering strengths and weaknesses of the evolutionary algorithms, , three workspaces listed in [21] were used to improve the optimality criteria for dynamic unknown environment. Bee colony algorithm is a population-based algorithm and gains an optimal solution (or near-optimal solution) via a repetitive process. Bee colony algorithm begins like other complementary algorithms and artificial intelligence with an initial random population, each of which is considered to be a nutrition source. The location of each nutrition source in N-dimensional space indicates a possible solution for optimization problem, in which N determines the number of optimization variables (N in this problem is the number of fuzzy rules and equal to 25. After evaluating the initial population, a number of population members having the smallest cost function value will be considered as the nominated employed bees (equivalent to the genetic algorithm). Upon producing the initial random population, there exists two general stages in each algorithm iteration: the assessment of produced solutions competence and population updating (producing the new population). These two consecutive stages are performed repetitively by the time of reaching the termination. In this study, we have determined the termination number of algorithm iterations. Population updating in the bee colony algorithm includes three phases: seeking the employed bees, onlooker bees, and scout bees.

2.1 Producing the initial population

In the present study, a feasible solution is taken into account for a problem with one sequence with the length of 25. Here, N is the total number of fuzzy rules, which equals to 25. As in Fig.2, if j membership function is allocated to i rule in a feasible solution, i index in the equivalent sequence will be equal to j value.

A Feasible solution	S_1	S_2	S_3	S_4	S_5	S_6	S_7	…	S_{25}
	4	1	2	5	7	3	1	…	3

	S_1	S_2	S_3	S_4	S_5	S_6	S_7	.	S_{25}
1	VV Small	VV Small	VV Small	VV Small	VV Small	VV Small	VV Small	.	VV Small
2	V Small	V Small	V Small	V Small	V Small	V Small	V Small	.	V Small
3	Small	Small	Small	Small	Small	Small	Small	.	Small
4	Medi um	Mediu m	Mediu m	Mediu m	Mediu m	Mediu m	Mediu m	.	Mediu m
5	Larg	Larg	Larg	Larg	Larg	Larg	Larg	.	Larg
6	V Larg	V Larg	V Larg	V Larg	V Larg	V Larg	V Larg	.	V Larg
7	VV Larg	VV Larg	VV Larg	VV Larg	VV Larg	VV Larg	VV Larg	.	VV Larg

Figure 2: A feasible solution for problem: In this solution, fuzzy membership function 4 (medium) is considered for the first rule output; membership function 1 (very-very low) is considered for the second rule; and membership function 2 (very low) is considered for the third rule.

At the beginning, we produce a random initial bee population in N-dimensional space, in which N is the total number of fuzzy rules. Equivalent to *Fig.2*, we determine parameters value separately from set {1, 2, 3… 7}. In other words, each bee determines one membership function among the feasible modes of {1, 2, 3… 7} for any of the 25 rules. To optimize the efficiency of this proposed method and to increase the algorithm convergence speed, we determine a symmetrical manual table as in Table 1 [19] as the heuristic data. In equation (1), each initial solution is determined.

$$s_k^{initial} = \begin{cases} HT(k) & if\ rand < \beta \\ rand\ \{1,2,3,\dots 7\} & otherwise \end{cases} \quad (1)$$

Where Sk-initial is the selected value for *k* rule membership function in an initial solution, *HT (k)* is the considered value *k* rule membership function in symmetrical manual Table.1 (19). In addition, β is a fixed parameter between 0 and 1, equaling to 0.8. Performance of the aforesaid technique is as follows: 80% of the fuzzy rules at each initial stage is determined randomly from the manual table. The remaining rules will be considered randomly between 1 and 7. In other words, initial solutions are determined randomly in the vicinity of the symmetrical manual fuzzy rules Table.1 (19).

2.2 Competency evaluation of the solutions (nectar amount)

At each iteration after population updating, the mistake related to solutions (bees) must be evaluated by the target function. Mistake of bee i is evaluated by (2) and nectar (competency) is gained through (3):

$$Cost_i = L_i \quad (2)$$
$$Fitti = 1/Cost_i \quad (3)$$

In the above relations, Costi and fitti are the mistake value and nectar value for bee i, respectively. Li is the total length of finished route by the mobile robot per each equivalent solution to i bee.

2.3. Equations Updating the solutions

2.3.1. Employed bees phase

In the beginning, the employed bees start seeking without knowing anything about the environment, select the initial solutions randomly, and keep their nutrition sources in their memory. At each iteration, each employed bee selects a nutrition source in the vicinity of its previous solution. As all the employed bees complete their seeking process, they will share their information of the nutrition source with other bees in the beehive. The more amount of nectar or better quality of nutrition source than the earlier ones, the bee keeps that new nutrition source in mind and forgets the earlier solution. Otherwise, it will keep the same earlier solution in mind (employed bees seeking phase).

2.3.2 Onlooker bees phase

At each iteration, a number of employed bees that have received the biggest amount of nectar will be selected and the onlooker bees will start seeking in their neighborhood. In fact, these onlooker bees start seeking near the nutrition sources with the biggest amount of nectar so as to be able to gain higher quality solutions in the vicinity of earlier sources (onlooker bees seeking phase). If we suppose M as the number of selected employed bees, number of onlooker bees allocated to any of these employed bees is gained through the following:

$$N_k = \frac{Nec_k}{\sum_{j=1}^{M} Nec_j} \cdot N_o \quad (4)$$

Where N_k is the number of onlooker bees that are located in the neighborhood of k selected employed bees, and Nec_j is the nectar value (fitness) of the i_{th} employed bee. In addition, No is the total number of onlooker bees.

2.3.3 Scout bees phase

At each iteration, those employed bees that had ineffective seeking during the recent iterations (with no optimization) will become scout bees. The, each scout bee will select a random solution as per relation (1) without knowing the environment (scout bees seeking phase). Selection of scout bees is done through a parameter called limit: if the mistake by an employed bee is more than limit value, that bee will become a scout one.

2.4 Proposed method for the neighborhood seeking in onlookers and employed bees phase

In this study, a method is proposed for the neighborhood seeking in onlookers and employed bees phase. In this method, number of fuzzy rules being changed in the solution are considered equal to a parameter called Nm for each bee seeking a new solution in the vicinity of an earlier solution. The value of this parameter along the program is determined from Nmmax to Nmmin linearly. The neighborhood in this proposed method, the algorithm searches globally in the initial iterations and this search becomes more localized as it approaches the end of the algorithm and optimal solution, as (5) below:

$$\mathrm{Nm} = \mathrm{Nm}_{max} + (\mathrm{iter}/\mathrm{iter}_{max}) \cdot (\mathrm{Nm}_{min} - \mathrm{Nm}_{max}) \quad (5)$$

Where *iter-max* is the total number of algorithm iterations and *iter* is the number for the present algorithm iteration. The above steps are repeated until the termination condition is established. In this study, the ABC termination condition is considered with the completion of iterations number of the algorithm. According to the previous information, in order to solve the problem of mobile robot path planning, using the optimization of fuzzy logic based on proposed ABC algorithm; expressed flowchart is shown in Fig.3. There are Two-dimensional maps (21), they are fixed obstacles with different numbers, shapes and coordinates in the environment. Moving obstacles with different speeds and in different directions are marked with red circles. Start and goal points are in different situations. This difference is due to the fact that a robot workspace is like the real world, in Table 1. To achieve a favorable comparison with the ABC to evaluate several times with different parameters and operators, and the best values of the parameters and the best operators are selected. The final parameters are shown in Table 2 below.

Table 1: The configuration of ant colony algorithm parameters.

Parameter	Value
Max Iteration	50
Population	10
Number of Employed Bees	5
Number of Onlooker Bees	5
β in Eq. (1)	0.8
Nm_{max}	3
Nm_{min}	1

Table 2. Details of the applied working space.

Item	Value
Working space length& width	5m&5m
Networking angle	45° (8 modes)
Number of square fixed obstacles	8
Number of triangular fixed obstacles	3
Number of circular fixed obstacles	4
Number of hexagon fixed obstacles	5
Number of movable obstacles	3
Max. robot view radius	30cm
Robot radius margin	10cm

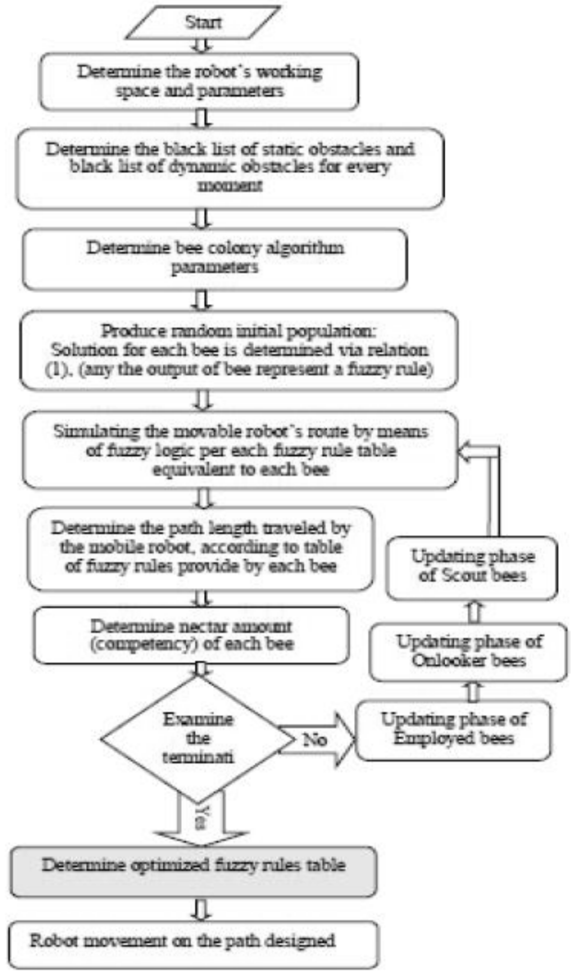

Figure 3: Proposed method flowchart based on bee colony algorithm

3. The Simulation Results

The simulation has been conducted on the three work spaces in order to evaluate the performance of bee colony algorithm. The proposed method finds a smoother, cleaner and safer route between the initial and final points; it is based on optimized fuzzy rules via proposed ABC algorithm. In other words, the production of random population means that each bee considers one output for each fuzzy rule, then the competency evaluation of each colony is obtained by each bee by considering the fuzzy rules table, which results in optimal routes for sets of starting and ending points. The average path length for different paths is considered as a criterion for suitability evaluation of bees. It should be noted that in proposed method based on the combination of fuzzy and ABC algorithms, routing is done only once in off-line mode, which results in optimization of parameters in fuzzy rules table.

In this study, for the simulation, three different workspaces with four different initial and final positions were assumed. As a result, for the solution of each bee, 12 different paths are produced by using fuzzy logic. Average length of the route found by each bee in 12 different paths is considered as a criterion for eligibility evaluation of each colony. Then, path planning based on fuzzy logic for each point between start and end points is done by utilizing the optimized rules table. Also, the running time of proposed routing algorithm via the combination of ABC and fuzzy logic is very similar to routing elapsed time with fuzzy logic method (manually setting the table). However, here the track length traveled by the robot is much shorter and smoother than the path traveled with fuzzy logic [19] and with ACO based fuzzy [20]. The optimal table by ABC is demonstrated in Table 3. Run-time using a laptop computer with Intel Dual core processor with a processing speed of 4GHz and 16GB RAM, with Windows 8, by Matlab R2013 software, was 354 minutes, but then for routing for each specific input and output modes, based on fuzzy logic routing is performed using the optimized rules table. In fact, with this method, the ABC algorithm will determine the optimal elements of fuzzy rule table, with the aim to reduce the robot's path. According to Fig. 4, it is one of the peculiarities of routing in a quite complicated environment by the proposed Fuzzy-ABC algorithm.

Table 3. Table of optimized fuzzy rules obtained by ABC algorithm.

Input1: Distance to the nearest obstacle	**Input 2: Angle difference with respect to target**	**Output: priority of the next node election**
Very Low	Very low	Low
Very Low	Low	Very low
Very Low	Medium	Very low
Very Low	High	Very low
Very s Low	Very high	Very low
Low	Very low	Low
Low	low	Very low
Low	Medium	Very low
Low	High	Very low
Low	Very high	Very low
Medium	Very low	Low
Medium	Low	Very low
Medium	Medium	Very low
Medium	High	Low
Medium	Very high	Low
High	Very low	Low
High	Low	Medium
High	Medium	Medium
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Very high	low	Medium
Very high	Medium	Medium
Very high	High	High
Very high	Very high	Very low

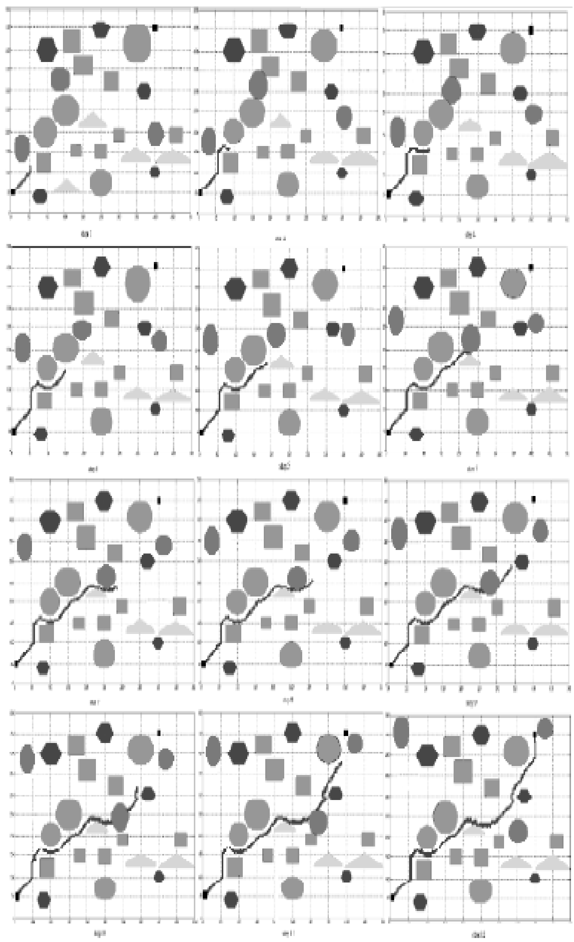

Fig.4. Routing with the proposed ABC-Fuzzy algorithm in quite complicated environment start at (5, 50) and end at (420,400), 723.82 cm path length.

The three environments are simulated in two-dimensional spaces, the proposed algorithm improved fuzzy rules table in [20] with the evolutionary characteristics of the ABC. Thus, the walking robot can select the optimal path in any situation without any collision with obstacles, which may be at any speed, direction, and shape in front of robots. Table 3, compares the performance of the proposed Fuzzy-ABC algorithm with the proposed Fuzzy algorithm in [20], and other algorithms combined with fuzzy. In different environments path length found by the proposed Fuzzy-ABC algorithm which is far less than the others optimal algorithms proposed in [21]. This is due to optimization of fuzzy rules table in [21] by a sophisticated expert with evolutionary ABC algorithm. The path length is expressed in centimeters.

Table4. Comparison of the proposed algorithm in different environments.

workspaces complexity	Starting Point	Target Point	Fuzzy	GA	ACO	ACO-Fuzzy	ICA-Fuzzy	ABC-Fuzzy
Relatively simple workspaces	(5,50)	(420,400)	965.38	906.35	869.91	825.63	756.77	696.68
Relatively simple workspaces	(20,55)	(450,465)	867.12	805.91	781.46	746.77	712.71	670.91
Relatively simple workspaces	(40,75)	(460,455)	854.36	807.41	760.95	683.41	614.32	589.17
Relatively complicated workspaces	(5,50)	(420,400)	977.93	918.89	882.89	838.51	769.42	709.53
Relatively complicated workspaces	(20,55)	(450,465)	879.91	816.19	794.15	759.51	725.69	683.78
Relatively complicated workspaces	(40,75)	(460,455)	869.73	822.08	775.51	698.39	629.17	604.15
Quite complicated workspaces	(5,50)	(420,400)	993.14	934.11	898.78	854.24	785.41	723.82
Quite complicated workspaces	(20,55)	(450,465)	895.45	832.17	810.13	775.49	741.65	689.73
Quite complicated workspaces	(40,75)	(460,455)	882.95	835.97	789.36	704.31	643.12	617.23

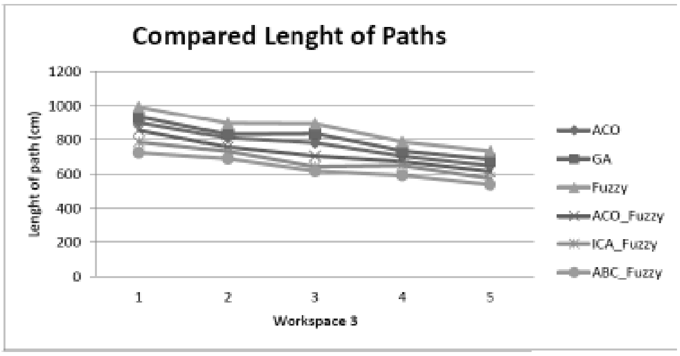

Fig. 5 Comparison of path length in quite complicated workspace by the Purposed Hybrid algorithms and ABC-Fuzzy.

Table5. Execution time of routing algorithms presented in quite complicated environment.

Workspaces complexity	*Quite complicated workspaces*		
Algorithm (s)	*GA*	*ACO*	*ABC*
Time (s)	2227.35	819.57	251.69

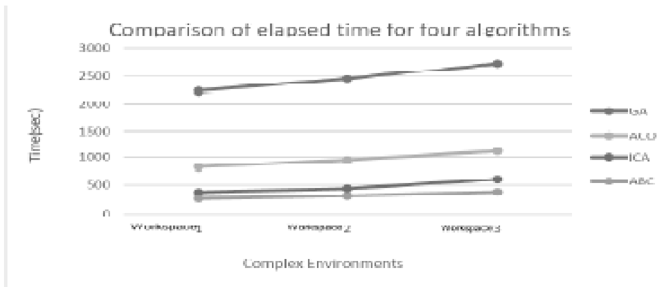

Figure 6: Comparison of running time of evolutionary algorithms proposed for routing in three workspaces

4. Discussion

Path planning plays an important role in all mobile robots in different fields. They must quickly and robustly perform useful tasks in a complex, dynamic, known and unknown environments. With respect to different environments of mobile robots, different algorithms and methods have been used. Between them for a known environment with fixed obstacles, ABC routing has better performance than ACO. There are a many methods in this field, but most work spaces for mobile robots are areas with fixed and moving obstacles in a different direction and speed, that are famous as the dynamic complicated known environments. There is less research in unknown dynamic environment field. Therefore, due to the lack of mapping and also the shortage of mobility functions of barriers, ACO in [18] and ABC alone are not working. Collective intelligence algorithms are useful in off-line methods, but it is necessary to have detailed information about the environment and mobility functions of obstacles, in these cases, real-time methods must be utilized. Thus, fuzzy rules table plays an important role in robots routing in complex environments. Fuzzy rules table is usually set by an expert; tables cannot be fully optimized. Therefore, the evolutionary ABC has been used in this study. With respect to optimality criteria, the purposed ABC affects the fuzzy table which has been set by an expert, and offers efficient routing of mobile robots. Hence, mobile robots can find their ways with optimality criteria, in every unknown environment with different complexity. In each iteration, each bee according to the selection probability relationship in proposed ABC, for each of the fuzzy rules, determine an output, and eventually produce a solution. As a result, fuzzy control systems based on the table produced for each bee, for all pairs of considered initial and final points routing is done.

5. Conclusion

Optimal path planning is a principal problem in the mobile robot field. For navigation in an environment similar to real environments, on-line methods are needed. Among these methods, fuzzy logic is a good option for solving this kind of problem. Thus, the basis of fuzzy logic is the determination of fuzzy rules table, which is done by an expert. When, fuzzy rules table is determined manually, table cannot be completely optimized. Therefore, considering that determining the fuzzy rules table is a kind of NP problem, using ABC, this algorithm is inspired by collective intelligence. For instance, bees find areas (nods) which have flowers with huge amount of nectar, and this intelligence is used to find the best or optimal points in optimization problems. This proposed algorithm improves fuzzy rules table. The table is determined by an expert according to the optimality criteria. Optimality criteria include the time, the short and safe length and the smoothness of the path in this article and finally optimizes the elements of table. Then, the proposed hybrid algorithm enables the mobile robot to pass the optimal path at the right time to achieve the goal in every unknown environment with any obstacle. Also, the proposed algorithm has been able to improve the length distances travelled by a mobile robot in every unknown environment by changing the evaluation function. The shorter and smoother path resulted from the evaluation function proposed in the complex dynamic spaces. Advantages and limitations of both algorithms can bring together a variety of applications in planning the robot's path in future.

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Comparison of Equivalent Static Analysis and Mode Combination Method for Concrete Buildings According to Turkish Standard

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Abstract: This study aims to define the impact of analysis methods that are used to design buildings and offers their analysis. As a matter of fact, there are several methods for fundamental analysis of buildings and other civil engineering structures under seismic situations. Both can be differentiated in the shape of the seismic involvement and in the structure idealization. There are two measures to identify seismic design forces: one is the equivalent static force, and the other is dynamic analysis which can be in many forms. One of these forms is the superposition mode. This research aims to study the impact of these methods in the analysis of a six story concrete building; both results, obtained from the static and dynamic, will be ultimately compared. The results show that in a MDOF system, such as with six floors or more, the dynamic analysis will lead to displacements and smaller forces compared with the static process.

Keywords: *Equivalent earthquake loads, mod combination method, Turkish standard, SAP2000.*

1. Introduction

Structural analysis is mostly related with identifying the reaction of a structure when exposed to certain action. This action could be structure of load due to heaviness of stuff such as folks, storm, and snow or it could be some different type of disaster, such as earthquake. All these masses together are dynamic with the self-weight of the structure. Both the dynamic and static analyses can be distinguished mainly based on whether the applied action has appropriate acceleration compared to the structure's natural frequency or not. If a load is applied slowly, the inertia forces can be disregarded, and the evaluation can be shortened as static analysis. Structural dynamics is a kind of structural analysis which presents the reaction of structures that are exposed to dynamic loading [3].

The essential principle after earthquake analysis of structures is to transform the earthquake dynamic forces acting on the structure to equivalent static forces which can be utilized later on as input data in a static structural analysis to acquire the forces, deformations in the structure, and interior stresses [1].

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The static methods indicated that the building codes depend on a single mode reaction with humble rectifications, containing high-mode effects. Even though it is suitable for simple regular structures, however, simplified procedures are not taking all seismic behavior of sophisticated structures into consideration. Consequently, the most appropriate method for building designing with rare or irregular geometry would be the dynamic analysis. In order to do dynamic analysis, there are two methods to be used: First method is elastic response spectrum analysis which is the ideal method due to the fact that it can be easily used. Second method is elastic or inelastic time history analysis; this method can be used only if it is critical to signify inelastic response features or to include time dependent effects when there is a calculation of the structure's dynamic response. Structures which are built on the ground, extent vertically at a distance above the ground in returning of simple or complex oscillators during seismic ground motions. The simple oscillators are characterized as single degree of freedom systems (SDOF), and complex oscillators are characterized as multi degree of freedom (MDOF) systems. A simple oscillator is characterized as a mass supported by two columns or as a single lump of mass on the upper end of a vertically cantilevered pole, Figure 1 shows the single degree for system of freedom [5].

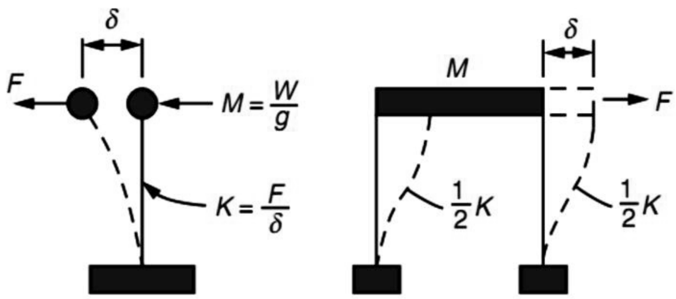

Figure 1: Single degree for system of freedom [5]

2. Implication Example

A 6-story moment resisting reinforced concrete framed building with 5m and 4 bays in both X and Y directions was selected. The plan and elevation of the model is shown in Figures 1 and 2; the building is assumed to have a fixed support at the base. ZB soil type, importance factor I= 1, R=4, D=2.5, the map of spectral accelerations of Turkey S_1 and S_S, found to be 0.243g and 0.87g, respectively (Figure 3), and a 5% damping ratio in accordance with Turkish provisions was selected. After calculating the base shear forces manually by using the equivalent static and mode superposition methods, the structure is modeled using SAP2000 software, then the internal forces such as normal forces, shear forces and bending moments for all members were found.

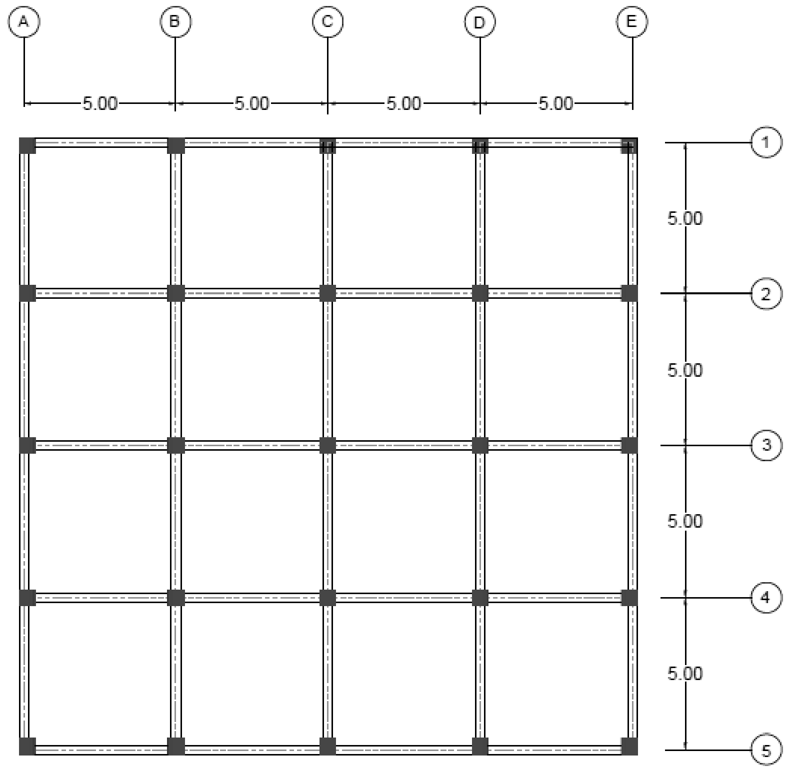

Figure 2: A Plan view of the building with its dimensions

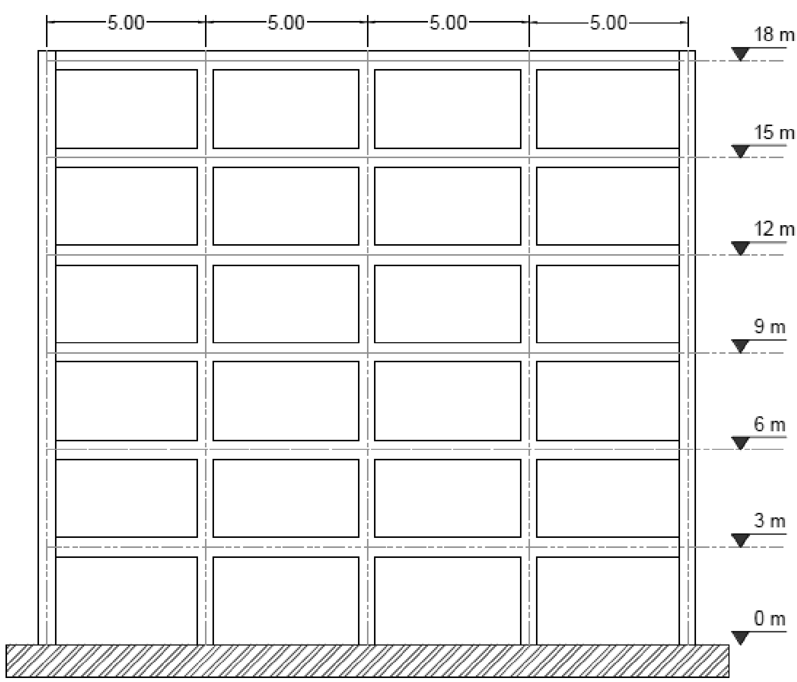

Figure 3: Section view of the building with its elevations

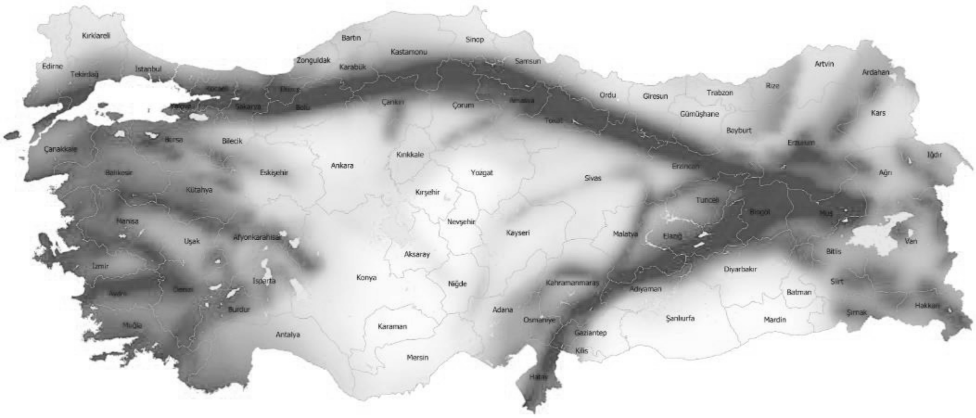

Figure 4: Earthquake map of Turkey [4]

3. Discussion

In accordance with the Turkish Standard (TBDY, 2018), the necessary data affecting the seismic action include the Mapped Spectral Response Accelerations S_1 and S_S, and Structural Occupancy, the Site Class, the Seismic Design Category, the Spectral Response Coefficients, SDs and SD1, Seismic Response Coefficient, and Seismic Importance Factor. The steps of calculation base shear by using Equivalent Static force are summarized below:

1. Based on Turkish Standard (TBDY, 2018), the base shear is found by the following equation

$$V_{tE} = m_t \cdot S_{aR}(T_P) \geq 0.04 \cdot m_t \cdot I \cdot S_{DS} \cdot g$$

2. The period is calculated

$$T_{pA} = C_t H_N^{3/4}$$

$C_t = 0.1$ is used for reinforced concrete frame system.

For horizontal-elastic-design spectral accelerations, $S_{ae}(T)$, which acts as the coordinates of the horizontal elastic design acceleration spectrum for any earthquake level considered, are described in the following Equation:

$$S_{ae}(T) = \left(0.4 \times 0.6 \frac{T}{T_A}\right) S_{DS} \qquad (0 \leq T \leq T_A)$$

$$S_{ae}(T) = S_{DS} \qquad (T_A \leq T \leq T_B)$$

$$S_{ae}(T) = \frac{S_{D1}}{T} \qquad (T_B \leq T \leq T_L)$$

$$S_{ae}(T) = \frac{S_{D1}\, T_L}{T^2} \qquad (T_L \leq T)$$

Reduced design spectral acceleration $S_{aR}(T)$ is found from the following correlation

$$S_{aR}(T) = \frac{S_{ae}(T)}{R_a(T)}$$

3. After the base shear is determined, an additional force applied to the top of the building shall be determined from the equation:

$$\triangle F_{NE} = 0.0075 \cdot N \cdot V_{tE}$$

So, the summation of base shear in X-direction, $V^{(X)}$ is:

$$V^{(X)} = \Delta F^{(X)} + \sum_{i=1}^{N} F^{(X)}$$

4. The total equivalent base shear other than $\triangle F_{NE}$, shall be distributed to the building floors using the following equation:

$$F_{iE} = (V_{tE} - \triangle F_{NE}) \cdot \frac{m_i \cdot H_i}{\sum_{j=1}^{N} m_j \cdot H_j}$$

The forces at the top of each story is summarized in Table 1

Table 1: Distributed story forces calculated by Equivalent Static method

Story No.	F_{iE} (kN)
1st story	38.177
2nd story	76.354
3rd story	114.531
4th story	152.710
5th story	190.886
6th story	266.843
Total base Shear	839.5

The steps of calculation base shear by using mode superposition method are summarized below:

1. The mass matrix of the building was formed as:

$$[m] = \begin{bmatrix} 460 & 0 & 0 & 0 & 0 & 0 \\ 0 & 460 & 0 & 0 & 0 & 0 \\ 0 & 0 & 460 & 0 & 0 & 0 \\ 0 & 0 & 0 & 460 & 0 & 0 \\ 0 & 0 & 0 & 0 & 460 & 0 \\ 0 & 0 & 0 & 0 & 0 & 460 \end{bmatrix} kg$$

2. In this step the stiffness matrix of the building was formed as:

$$[K] = \begin{bmatrix} 138888 & -69444 & 0 & 0 & 0 & 0 \\ -69444 & 138888 & -69444 & 0 & 0 & 0 \\ 0 & -69444 & 138888 & -69444 & 0 & 0 \\ 0 & 0 & -69444 & 138888 & -69444 & 0 \\ 0 & 0 & 0 & -69444 & 138888 & -69444 \\ 0 & 0 & 0 & 0 & -69444 & 69444 \end{bmatrix}$$

3. The Eigen value problem solved as the following equation

$$([k] - \omega_0^2[m]) = \{0\}$$

So, by assuming that $\omega_0^2 = \lambda$ the above equation was solved

$$[\lambda] = \begin{bmatrix} 1.7391 & 0 & 0 & 0 & 0 & 0 \\ 0 & 2.0911 & 0 & 0 & 0 & 0 \\ 0 & 0 & 2.9262 & 0 & 0 & 0 \\ 0 & 0 & 0 & 5.0805 & 0 & 0 \\ 0 & 0 & 0 & 0 & 13.0380 & 0 \\ 0 & 0 & 0 & 0 & 0 & 112.8398 \end{bmatrix}$$

Then

$$[\omega] = \begin{bmatrix} 1.7391 & 0 & 0 & 0 & 0 & 0 \\ 0 & 2.0911 & 0 & 0 & 0 & 0 \\ 0 & 0 & 2.9262 & 0 & 0 & 0 \\ 0 & 0 & 0 & 5.0805 & 0 & 0 \\ 0 & 0 & 0 & 0 & 13.0380 & 0 \\ 0 & 0 & 0 & 0 & 0 & 112.8398 \end{bmatrix}$$

4. In order to find the patriation factors and calculate the acceleration for each mode shapes, the following equation was solved and the results are summarized in Table 2

$$([k] - \omega_0^2[m])\{\Phi\} = \{0\}$$

Table 2. Acceleration for all mode shapes for the building

Mode Number (n)	λ_n	ω_n	t_n	S_{rn}	S_{t1}
1	0.0018	23.8595	0.2633	0.1846	0.7382
2	0.0021	21.7588	0.2888	0.1683	0.6732
3	0.0030	18.3936	0.3416	0.1423	0.5691
4	0.0051	13.9594	0.4501	0.1080	0.4319
5	0.0132	8.7139	0.7211	0.0674	0.2696
6	0.1140	2.9620	2.1213	0.0225	0.0916

After calculating the acceleration of each mode, the above data was inserted to SAP2000 and the analysis was run to find the internal forces for each member. Figure 3 and 4 show the building modeled in SAP2000.

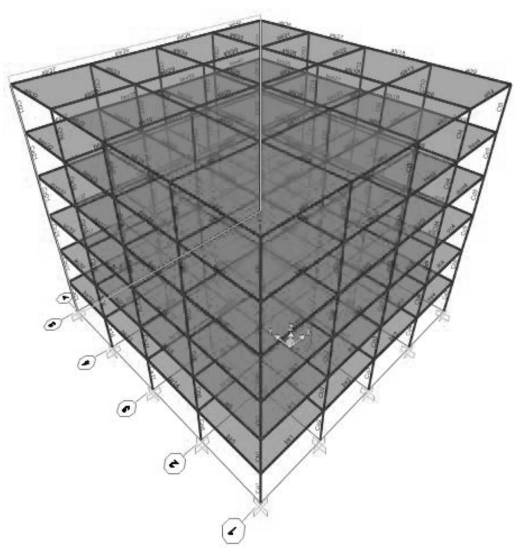

Figure 5: 3-D Model of the building in SAP2000

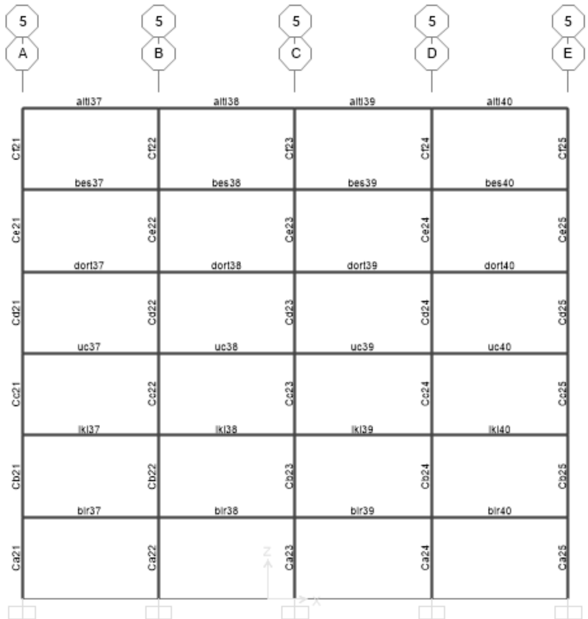

Figure 6: Elevation view of the building in SAP2000

4. Results and Conclusion

The main challenge for structural engineers is how to determine a realistic seismic response for MDOF systems. Two methods were utilized: the identical static analysis strategy that a set of static horizontal forces have applied to the structure. These forces are planned to coordinate the greatest impact in a structure that a dynamic analysis would forecast. This method works fine because our structure is modest and slight.

However, a dynamic analysis is the default method as identified by several building codes. We have used the modal analysis method as this method is the simplest type of dynamic analysis. This method entails of a dynamic analysis to define the mode shapes and age of the structure. In order to define the response of each mode, the method continues using response spectrum. It has been approved that the response of each mode is independent of the other modes, and then the modal responses were joint to define the total structural response.

For MDOF systems, such as six floors or more, dynamic analysis will lead to displacements and smaller forces compared with static process.

As a conclusion, there are two different analyses for floor forces. For the floor forces at the upper floors acquired by modal analysis are less than the static forces, however, this result does not continue with the lower floors; the opposite can be observed. This difference between the higher floors and the lower floors is due to the influence of the higher modes on the floor forces. In order to maintain the required safety level, as seismic design is achieved by using equivalent static analysis procedure, the forces on the level of the floor must be used in linking the floors to the lateral load resisting elements.

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High gain UWB Antipodal Vivaldi Antenna Design for GPR Application

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Abstract: An antipodal Vivaldi Antenna (AVA) with dielectric lens for Ground Penetrating Radar (GPR) application is proposed. Impedance bandwidth and antenna gain have been increased to 140 % (from 2.8 to 16 GHz) and 15 dBi respectively. Simulation process and related results of each step have been presented in the text. The dimension of the antenna has been reduced to 50 × 70 ×0.76 mm^3. The designed antenna is a good candidate for UWB GPR application.

Keywords: *AVA, dielectric lens, UWB and GPR.*

1. Introduction

Ground penetrating radar (GPR) is a radar which detects objects and interfaces buried beneath the earth's surface. It is considered as a very effective tool for non-destructively sensing of the subsurface environment since the radar can detect any object that has different electrical properties than the surrounding soil. Thus, it senses both metallic and nonmetallic targets as opposed to metal detectors [1]. The GPR system basically consists of a transmitter antenna connected to a source and a receiver antenna linked to the signal processing equipment [1-4].

The types of antenna and parameters of the antenna like starting frequency, bandwidth and gain of antenna are important in the detection of the target in putative depth. The antenna plays an important role in GPR systems. The antenna could be categorized in three states that are monostatic, bi-static, and multi-static. In the monostatic state, transceivers of signals are implemented on one antenna but in bi-static state, minimum two or more antennas can be utilized for transmission and reception. In multi-static state, the system uses more than one antenna for transmitting and receiving [5]. The efficiency of the antenna is also an important part of the system. The high efficiency provides more and reliable information. Having better antenna efficiency depends on the optimization works in antenna's physical features [6].

Civil and military sections are the most popular areas for the GPR applications. In military area, it is commonly used for finding unexploded bombs, underground warehouses, bomb shelters, discovering enemy communication channels or secret rooms [7]. In civil life, GPR is commonly applied for finding buried pipes and undetected voids. Together with these, GPR is also used for detecting people behind the rubble [8]. According to the application area, target details and penetration depth, GPR is used in many applications such as archeology, medicine and military from 0.01 to 10 GHz [9].

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Ultra wideband (UWB) antennas are used in GPR as in various applications. UWB GPR antenna is a good point of view and research interest for the authors [10]. Many works in the literature have been developed for wideband application including loaded bowtie antenna [11], TEM horn antenna [12], Vivaldi Antenna and so on.

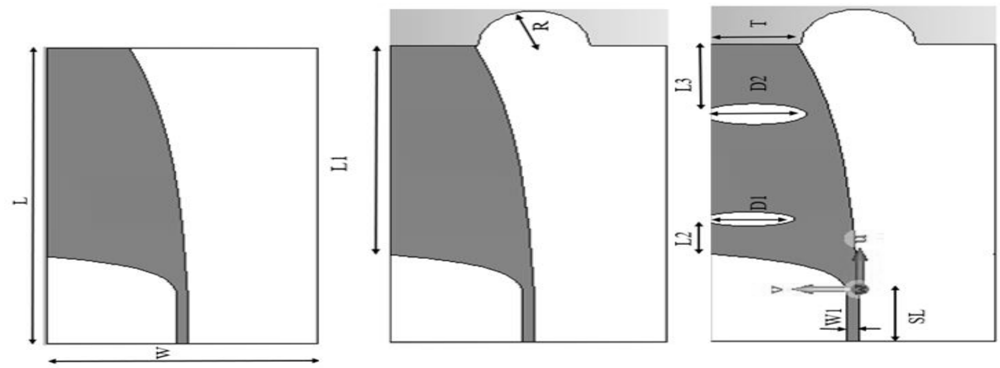
Vivaldi antenna has many advantages such as simple structure, low cost design, high stable gain air-coupled antenna, end fire direction, easy to construct and UWB properties. It also provides a smooth transition between the guided wave travelling in the transmission line and a plane wave which is radiated. Vivaldi antennas are planar antennas that work over a wide frequency range. They provide an acceptable gain depending on the length of the taper and the shape of the curvature [13].

In this article, an antipodal Vivaldi Antenna (AVA) has been developed and simulated fed by 50 Ohm coplanar waveguide. In the next sections, antenna configuration and the simulation results are presented. The simulations are done using CST studio suite 2018.

2. METHODOLOGY OF ANTENNA DESIGN AND RESULTS DISCUSSION

Figure 1(a) shows the construction of the proposed AVA with dimensions of 50 × 70 mm^2 on a substrate of Taconic with εr of 3.55 and 0.76 mm height. The antenna consists of one plate and two slots at front and back sides with the thickness of 0.035 mm.

However, this design suffers from low and inconsistent gain and directivity.

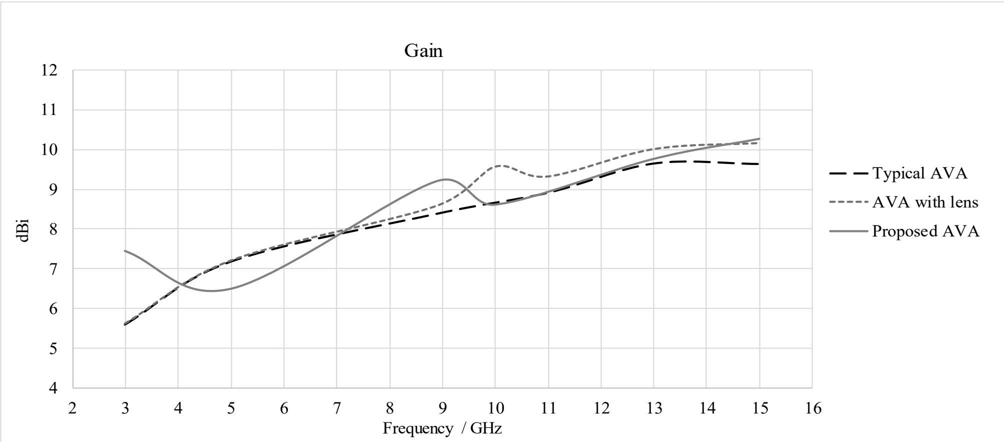


(a) (b) (c)

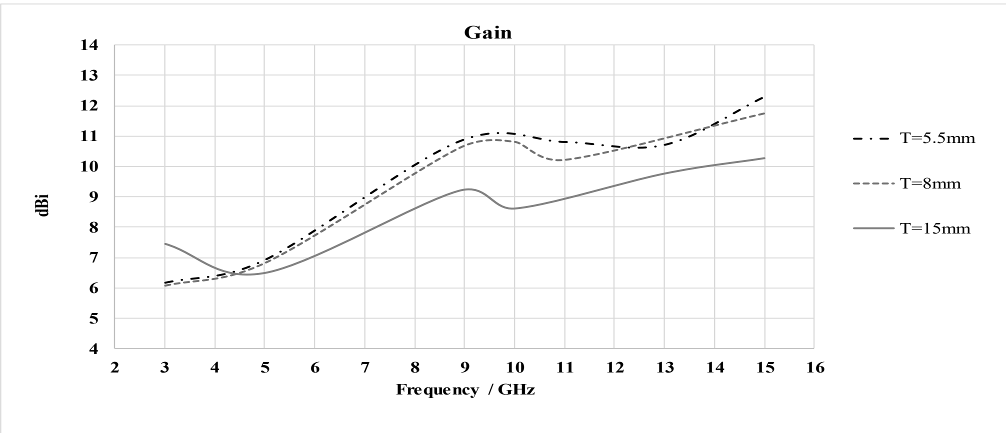
Figure 1: Structures of AVAs. (a) Typical AVA (b) AVA with lens (c) Proposed AVA.

For this, a dielectric lens is added as shown in Figure 1 (b); the lens tends to limit their wide spread utilization. They are costlier due to complex fabrication processes [14]. Also, for getting a good radiation pattern at low frequencies and to make improvement in S_{11} parameter readings an elliptical curvature edge is inserted to the slots as shown in Figure 1 (c).

According to Figure 2 (a), the maximum gain of proposed antenna was at 15 GHz (10.2dBi) whereas the highest gain at typical AVA and AVA with lens was less than this result. Moreover, at low frequencies (3 GHz) the antenna has been improved from 7.4 dBi to 5.7 dBi with elliptical curvature edge.



(a)

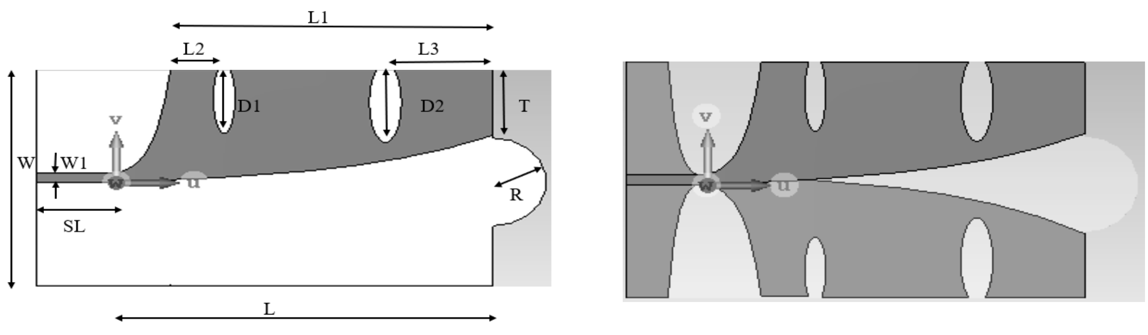


(b)

Figure 2: Antenna gain (a) Typical AVA, AVA with lens and Proposed Antenna (b) Proposed AVA with different T Distance.

On the other hand, the gain varies depending on the length of the taper and shape of the curvature [13]; according to the shape of curvature the distance between two curves at slot T have reverse relation with gain at high frequencies as shown in Figure 2 (b).

When T=5.5 mm at 15 GHz the gain is 12.2 dBi, and the gain is 11.8 dBi when T= 8 mm at the same frequency, however the proposed antenna with T=15 mm has the advantage with highest gain. At low frequency (3 GHz) the gain is 7.4 dBi whereas at the same frequency the gain was 6.1 and 6 dBi at T=5.5 and T=8mm respectively. Figure 3 represents the proposed antenna and Table 1 shows the dimensions of the antenna. The dielectric lens is used to improve the gain of Vivaldi antennas as represented in Figure 2 (a). In order to design the dielectric constant and shape of the lens the antenna parameters will be effected [15-16].



(a) (b)

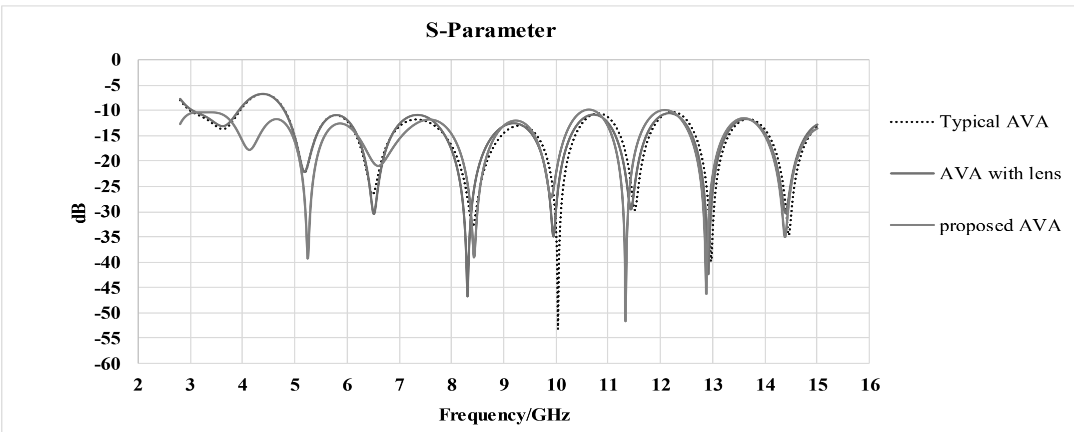
Figure 3: (a) Proposed AVA, (b) Proposed AVA two slots.

To improve the S_{11} results the elliptical curved edge is inserted to design the antenna with special dimensions.

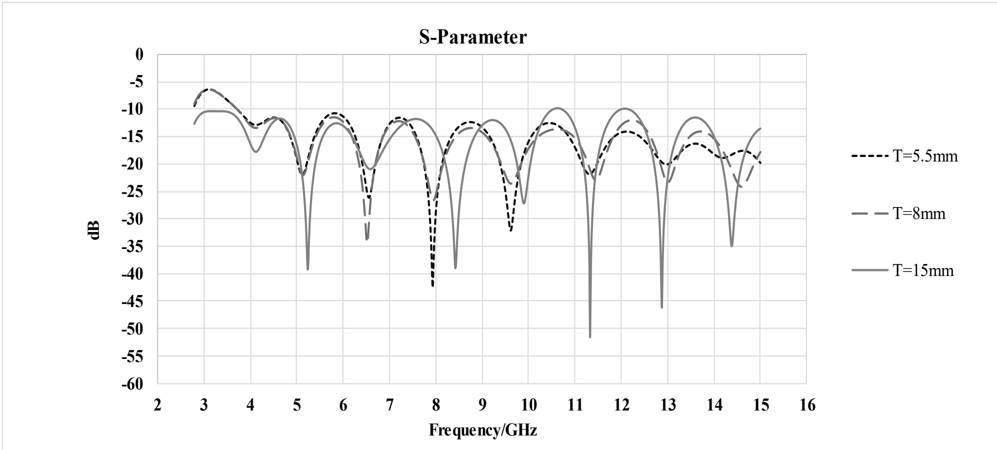
Figure 4 represents the S_{11} results of the antennas at different T distances.

Table 1: Proposed AVA Antenna Dimensions.

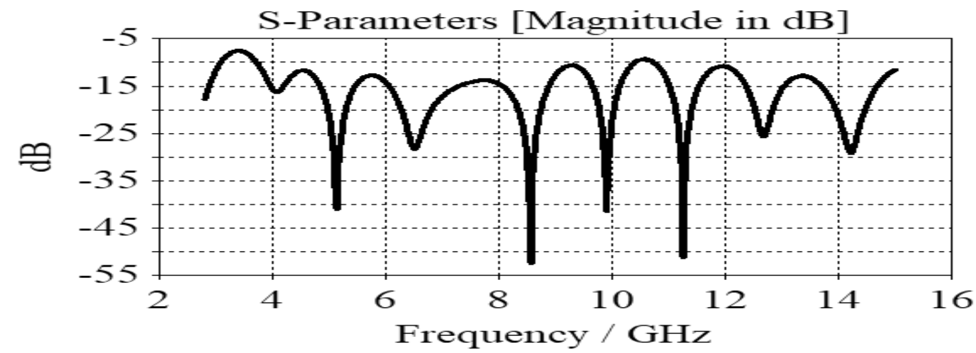
Parameters	Value (mm)	Parameters	Value(mm)
L	70	D1	14
L1	60	D2	17
L2	8.85	W1	2
L3	18.35	T	15
SL	15	R	10
W	50		



(a)



(b)



(c)

Figure 4: S_{11} results, (a) Typical AVA, AVA with lens, Proposed AVA, (b) Proposed AVA at different T Distance, (c) proposed antenna S_{11} result.

According to Figure 4 (a), S_{11} results of typical AVA and AVA with lens are started from 4.9 GHz, which means these designs do not work in good way at low frequency. According to this, the dielectric lens doesn't have a role in making improvement in S_{11} at low frequency. Because of this, proposed AVA has been designed with elliptical curvature edges. These edges improve S_{11} at low frequency and enhances the results in high frequency too. According to this, the elliptical curvature edges are the most important parameters for designing this AVA with good S_{11} at all frequencies.

As shown in Figure 4 (b), S_{11} for proposed antenna at T=15 mm is better than at T=5.5 and T=8 mm , but with using T= 15 mm the results are improved at low frequency (3 GHz).

Proposed AVA, with the dimensions of this design, has the best radiation pattern and S_{11} parameter reading.

All factors work together to apply these requirements, they depend on each other. The radiation pattern in 3D at low and high frequencies are presented in Figure 5. Figure 6 shows the gain and radiation efficiency of the proposed antenna.

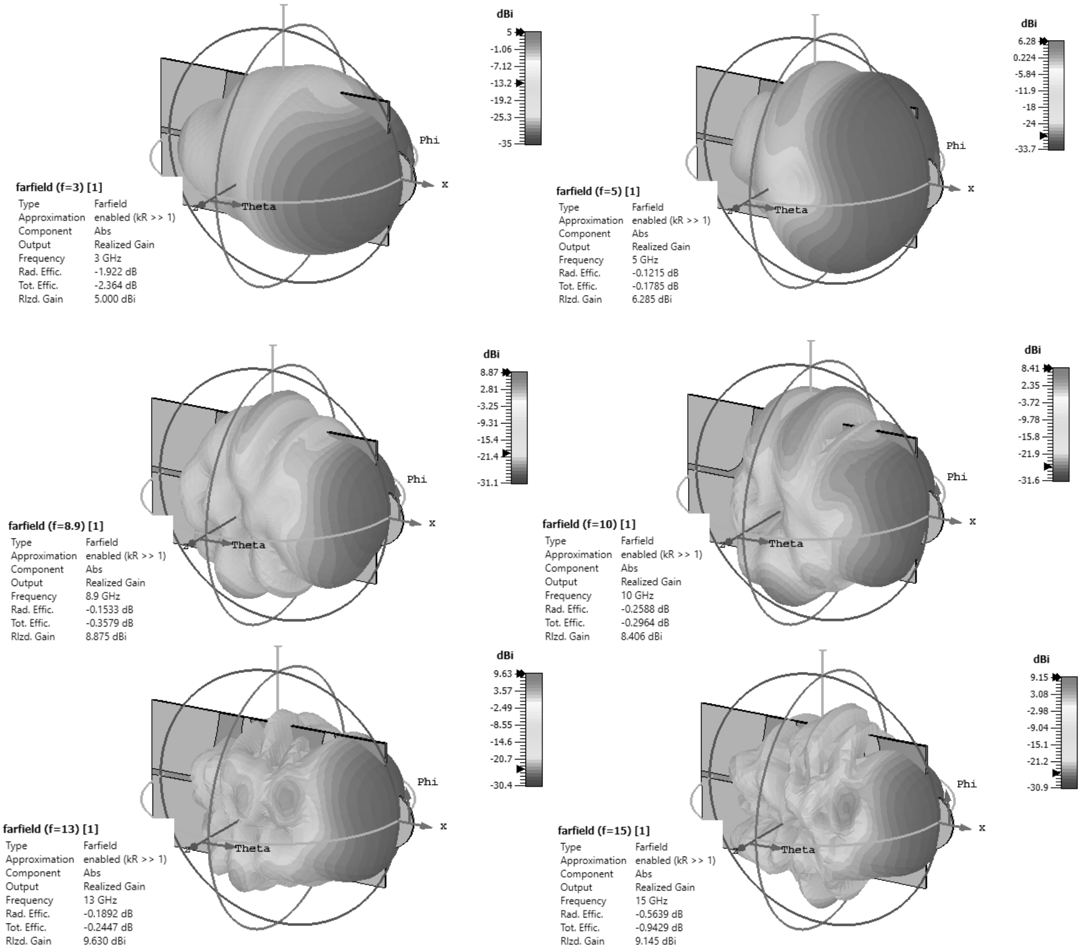
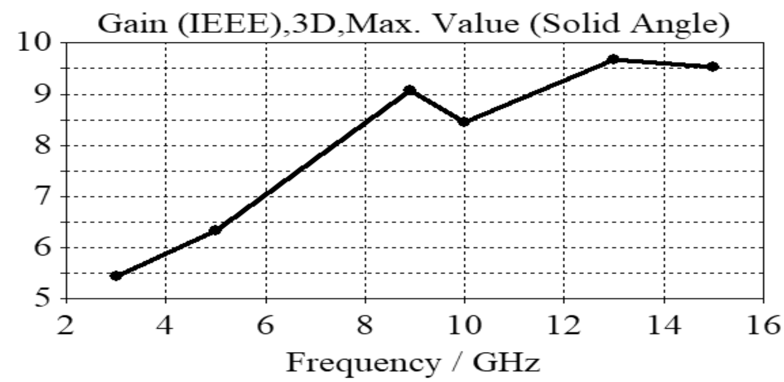
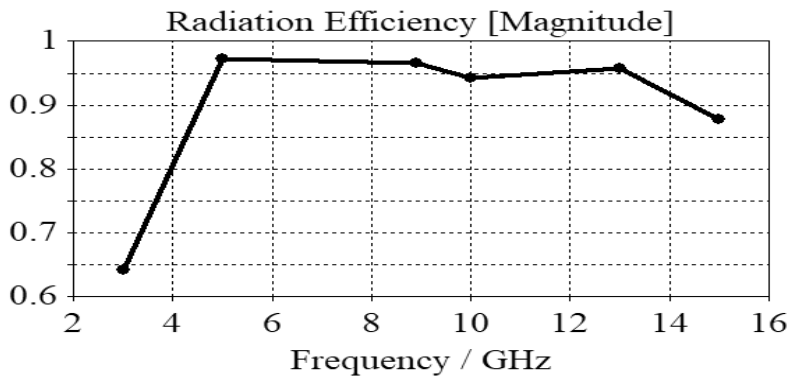


Figure 5: Simulated radiation pattern of the antenna at 3 GHz, 5 GHz, 8.9 GHz, 10GHz, 13 GHz and 15 GHz.



(a)



(b)

Figure 6: a) gain and b) radiation efficiency of proposed antenna.

Table II, illustrates the antenna parameters and dimensions in comparison with other antennas in the literature.

Table 2: Comparison of Antenna Characteristics and Literature.

REF.	Dimensions(mm3)	Frequency(GHz)	ε and material	Freq. GHz (Gain dB)
[12]	178×140×251	0.83-12.8	2.2 AN-79	0.83 (0) 12 (10)
[13]	96×50×3.15	3-18	2.55 ArlonAD255	3 (5) 18 (14)
[15]	130×76×1	3.1-14	4.2 FR4	3.1 (5.8) 10 (7.26)
[16]	90×40×0.508	3.8-40	3.3 RO4003C	3.4 (8) 19.5 (12.8)
This Paper	70×50×0.76	2.8-16	3.55 Taconic	3 (5.2) 15 (9.9)

3. Conclusion

The paper represents the Antipodal Vivaldi antenna for GPR application in frequency range from 3 to 16 GHz. The antenna is designed and simulated by CST studio software. The designed antenna has a maximum gain of 9.15 dBi at 15 GHz. The antenna is designed on Taconic substrate with εr of 3.55. The presented structure gives stable radiation characteristic, along the whole frequency band, which makes it a good candidate for GPR application.

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