*International Journal of Latest Research in Engineering and Technology (IJLRET)*
*ISSN: 2454-5031*
*www.ijlret.com || Volume 06 - Issue 05 || May 2020 || PP. 01-05*

# Application of genetic algorithm to solve BAO problem

Nika Topuria[1], Omar Kikvidze[2]
[1]*(Technical Engineering, Akaki Tsereteli State University, Georgia)*
[2]*(Technical Engineering, Akaki Tsereteli State University, Georgia)*

**Abstract:** Beam angle optimization **(BAO)** is acomplex, multi-objective, non-convex problem with many local minima. Most modern approaches use deterministic or hybrid techniques to solve above-mentioned problem, however problem, however avoiding premature convergence and local minima entrapment is still quite a big problem for most algorithms. In this paper we demonstrate results of our PHD thesis, in which we apply Genetic Algorithm based approach to BAO problem with high success in comparison to clinically used Varian BAO system. MatRad open-source system was used as a software platform to implement our Bao module in MATLAB programming language.
**Keywords:** Algorithm, BAO, Genetic, MatRad, Optimization

## I. Introduction

Modern medical researches involve more math and calculations than ever, including the optimization of large experimental datasets and complex bio-chemical simulations. Radiation therapy heavily uses optimization algorithms[1],[2] to achieve best possible tumor irradiation while protecting the surrounding healthy tissue. To achieve this, the optimization algorithm must find best possible irradiation angles[3] and dose fluence maps based on multiple constraints set by a medical physicist. The problem here is a complexity of the optimization area (irregular tumor shape, irregular patient surface, multiple healthy organs surrounding the tumor) and the limited time to make an optimal treatment/irradiation plan. There are several commercial software solutions to above-mentioned problem, however they are expensive, quite slow and unreliable in terms of output quality. For most of these shortcomings the cause is deterministic nature of the applied algorithms. In this paper we show that heuristic approach, namely use of genetic algorithms[4]can give obvious improvements to both output plan quality and optimization time[5][6].

## II. Materials and Methods

Genetic Algorithm was initially described by John Holland in 1960s [11] and it is frequently used to solve modern complex optimization problems. There are several types of genetic algorithm, but each of them has a set of following five components:

- A genetic representation for potential solutions to the problem
- A way to create an initial population of potential solutions
- An evaluation function that plays the role of the environment, rating solutions in terms of their fitness to the environment
- Genetic operators that alter individuals for the composition of children
- Values for various parameters that the genetic algorithm uses (population size, probabilities of applying genetic operators, etc.)

As mentioned above Genetic algorithm uses population-based approach to the optimization problem. This means that there are several virtual entities or so called “seekers” in every GA instance, each representing a potential solution to the task. In our case each gene is a seeker is individual angle for the irradiation.In our case each “gene” in every seeker is an irradiation angle. We start optimization with initialization, during which, we generate predefined number of random angle-sets which then act as seekers.During each optimization step, we evaluate the quality of each seeker using the *fitness function*, this way we know which seeker is better in terms of solution quality. Next comes *selection*, which, like natural selection, gives the individuals with better fitness values higher chance to proceed to next generation. This step also acts as a purging mechanism for the seekers, since it will remove worst ones – simplifying search are for other individuals. Obviously, to diversify our population, we need a method to create new seekers which we do with *Crossover* operator. During this procedure we mix genes of two fittest individuals with random order and create two new ones. A simple example is shown below:

Parent 1 DNA: 01010110
Parent 2 DNA; 11100001
Crossover points: 3
Child 1 DNA: 01000001
Child 2 DNA: 11110110

As we have mentioned above, deterministic algorithms are prone to being entrapped in local extreme points of the optimization curve[7], in Genetic Algorithm, we use another operator, called *Mutation* which introduces random gene alterations in one or two individuals, putting them away from current location of the search space. This way we ensure that none of the seekers will ever be entrapped in a local minima or maxima. This loop goes on until we have no improvements for predefined number of iterations, or time limit is exhausted.

To implement this approach, we have used MatRad[8], [9] open-source system, written in MATLAB programming language. It contains most of the tools required for beam alignment[10], dose calculation and visualization. For every test case, we did two optimizations, one with Genetic Algorithm and the other with Varian BAO software. Optimization parameters were kept unchanged for both sides to avoid biasing. Final dose calculations were done in Varian Eclipse system, for increased precision. All the test runs were done on Dell Precision T5600 with 2x – E5-2620 and 32Gb Ram.

## III. Calculations and Results

The algorithm was tested on 9 actual cases (resulting plans was not used for treatment). 3 Brain tumor, 3 Lung tumor and 3 Lymphoma cases. Since the optimization results were consistent throughout all 9 cases (genetic algorithm giving best results both in terms of dose distribution and overall plan quality, sometimes even with smaller number of fields.) and trend was clear in each one, in this paper we represent results only for brain tumor cases.

*Patient A* has tumor mass located behind left eye (Fig. 1). Irradiation dose is prescribed as follows: 50Gy in 25 fractions. Organs at risk are eyes, lenses, optic nerves and chiasm. Optimization was done using both Genetic and Varian approaches, using same constraints and parameters. Final dose calculations were performed in Varian Eclipse treatment planning system. Note, that for now, our genetic implementation works only for coplanar fields, hence this and every other tests only use coplanar fields for optimization process.

Fig. 1. Tumor (red) location for patient A

Results show that genetic algorithm could meet all the constraints while using only 3 fields, while Varian BAO required 5 fields to converge, still giving worse results (Table 1). It is also worth noting, that field direction chosen by Varian BAO enter patient body from healthy part of brain and healthy eye, this is a clear demonstration of local optimum entrapment (Fig 2).

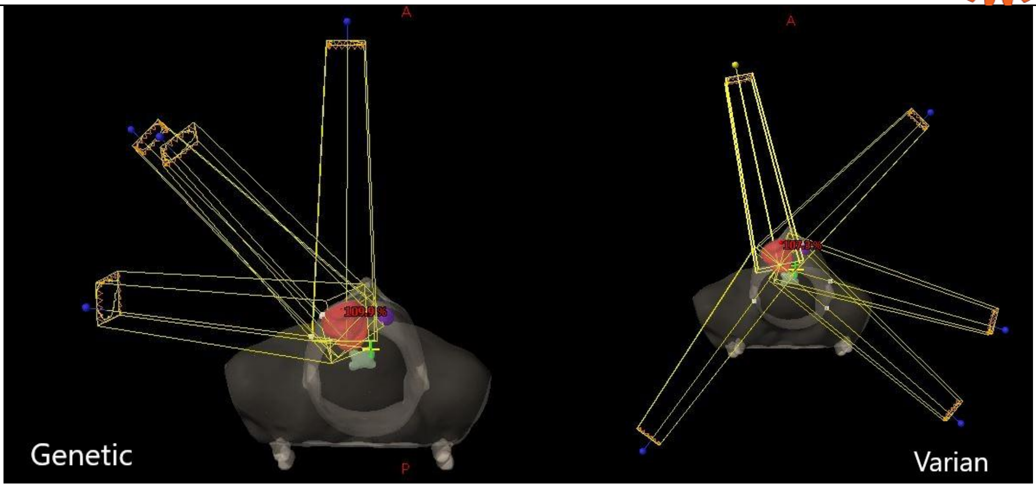


Fig. 2. Irradiation field angles given by Genetic and Varian algorithms

Table1. Comparison of dosimetric results from both plans

| OAR | Dose Constraint | Dose from plan (Genetic) | Dose from plan (Varian) |
|---|---|---|---|
| Orbit (right) | Mean < 35 Gy<br>Max < 50 Gy | Mean = 5.1 Gy<br>Max = 16.8 Gy | Mean = 10.7 Gy<br>Max = 28.2 Gy |
| Lens (right) | Max < 7 Gy | Max = 2.8 Gy | Max = 8.9 Gy |
| Optic Nerve (right) | Max < 55 Gy | Max = 44.7 Gy | Max = 42.4 Gy |
| Chiasm | Max < 55 Gy | Max = 47.6 Gy | Max = 47.5 Gy |

Patient B has tumor located in the upper part of right hemisphere (Fig. 3). Prescribed dose is 45Gy in 25fx.

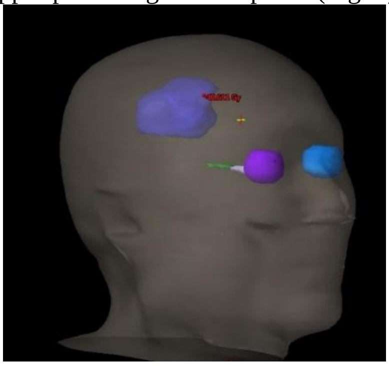

Fig. 3. Tumor (purple) location for patient B

Organs at risk are optic nerves and pituitary gland. Fig. 4 shows, that in this case our algorithm used only 4 fields to achieve acceptable results, while the other one used 9 fields to get inferior results (Table 2).

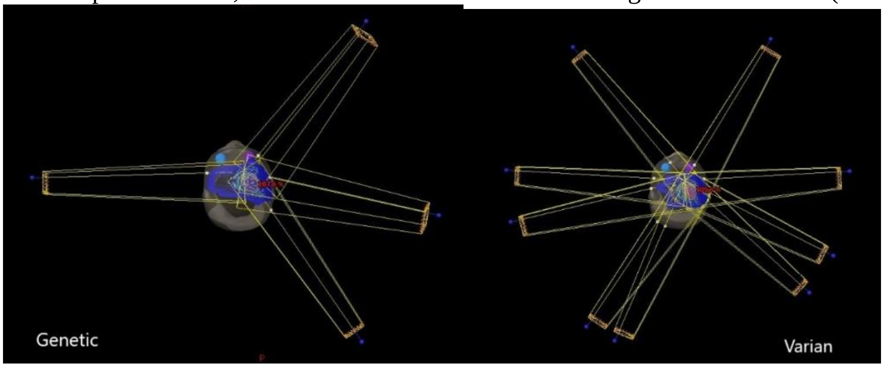


Fig. 4.. Irradiation field angles given by Genetic and Varian algorithms

Such noticeable difference in field quantity translates into increased treatment time and higher probability of target motion during treatment.

Table2. Comparison of dosimetric results from both plans

| OAR | Dose Constraint | Dose from plan (Genetic) | Dose from plan (Varian) |
|---|---|---|---|
| Optic Nerve (left) | Max < 55 Gy | Max = 16.5 Gy | Max = 16.2 Gy |
| Optic Nerve (right) | Max < 55 Gy | Max = 5.9 Gy | Max = 21.5 Gy |
| Pituitary Gland | Max < 45 Gy | Max = 12.24 Gy | Max = 47.5 Gy |

*Patient C* has tumor located in posterior area of brain (Fig. 5). OARs are both hippocampus and uninvolved areas of brain.

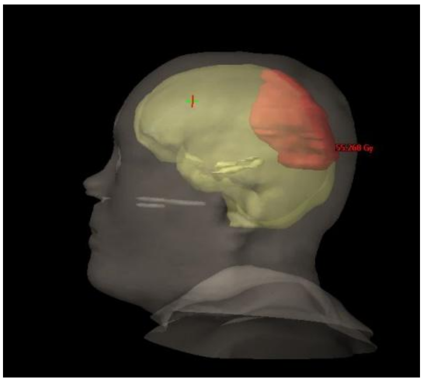

Fig. 5. Tumor (red) location for patient C

Field number for both algorithms were same in this case, but Varian chose two fields entering body directly via eyes, which is not acceptable for clinical use, because of this, dose distribution results (Table 3) are not deciding factor in this case. But numbers show that some of the constraints were successfully met, this most likely indicates another case of local minimum entrapment. Genetic algorithm meets all the constraints and field angles are distributed in sensible manner (Fig. 6).

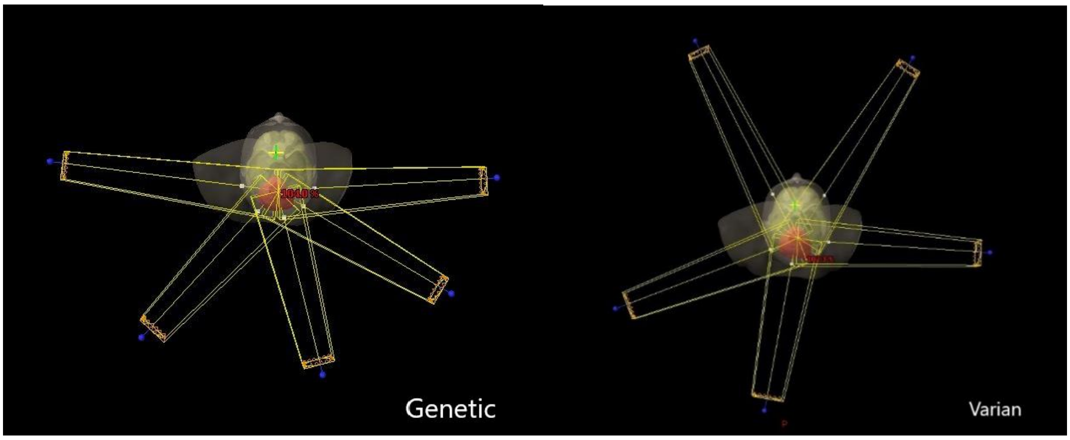


Fig. 6. Irradiation field angles given by Genetic and Varian algorithms

Table3. Comparison of dosimetry results from both plans

| OAR | Dose Constraint | Dose from plan (Genetic) | Dose from plan (Varian) |
|---|---|---|---|
| Hippocampus (left) | D100% < 10 Gy<br>Max < 17 Gy | D100% = 8 Gy<br>Max = 18.4 Gy | D100% = 1 Gy<br>Max = 29.2 GyGy |
| Hippocampus (right) | D100% < 10 Gy<br>Max < 17 Gy | D100% < 8.2 Gy<br>Max = 18.2 Gy | D100% = 4 Gy<br>Max = 30 Gy |
| Brain (normal) | Max < 72 Gy | Max = 55.6 Gy<br>Mean = 20 | Max = 54.8 Gy<br>Mean = 24.8 |

## IV. Conclusions

This paper describes the upper hand of Genetic algorithm in comparison to deterministic alternative in terms of resulting treatment plan quality, showing that the application of genetic algorithm for multi-variable, hard constrained, large scale optimization tasks can be a good optionconsider. Two major key points can be formulated as follows:

- Genetic algorithm effectively prevents search process from premature convergence and local minima entrapment.
- Heuristic approach can give same or better result compared to deterministic ones using same or smaller number of fields.

Testing indicates that genetic algorithm in radiation therapy has quite promising future and points out important areas where improvements can be made. Further development can decrease required time for optimization (Using GPU for ray tracing and large matrix manipulations)[11] and pre-optimization filtration of obviously infeasible field angles can shrink the search area, while added non-coplanar mode will increase resulting plan quality.

## References

[1] D. Djajaputra, Q. Wu, Y. Wu, and R. Mohan, "Algorithm and performance of a clinical IMRT beam-angle optimization system," *Phys. Med. Biol.*, vol. 48, no. 19, pp. 3191–3212, 2003.

[2] H. Rocha, J. Dias, T. Ventura, B. Ferreira, and M. do C. Lopes, "A derivative-free multistart framework for an automated noncoplanar beam angle optimization in IMRT: A derivative-free multistart framework for an automated BAO," *Med. Phys.*, vol. 43, no. 10, pp. 5514–5526, 2016.

[3] M. Ehrgott, A. Holder, and J. Reese, "Beam selection in radiotherapy design," *Linear Algebra Appl.*, vol. 428, no. 5–6, pp. 1272–1312, 2008.

[4] Y. Li, J. Yao, and D. Yao, "Automatic beam angle selection in IMRT planning using genetic algorithm," *Phys. Med. Biol.*, vol. 49, no. 10, pp. 1915–1932, 2004.

[5] N. Topuria and O. Kikvidze, "Application of Genetic Algorithm in Common Optimization Problems," *Int. Ann. Sci.*, vol. 8, no. 1, pp. 17–21, 2019.

[6] N. Topuria, O. Kikvidze,"Use of genetic algorithms to solve multi-variable optimization problem" Akaki tsertlis state university scientific journal "Moambe", no. 11, pp. 229–237, 2018.

[7] M. Mitchell, "Genetic algorithms: An overview," *Complexity*, vol. 1, no. 1, pp. 31–39, 1995.

[8] N. Topuria, "matRad: An open source multi-modality radiation treatment planning sytem." [Online]. Available: https://github.com/topuchi13/matRad. [Accessed: 31-Mar-2020].

[9] H.-P. Wieser *et al.*, "Development of the open-source dose calculation and optimization toolkit matRad," *Med. Phys.*, vol. 44, no. 6, pp. 2556–2568, 2017.

[10] N. Topuria, O. Kikvidze, "Geometry of body movement in the IMRT optimization problem" Akaki tsertlis state university scientific journal "Moambe", no. 2, pp. 183-188, 2019.

[11] N. Hou, F. He, Y. Zhou, Y. Chen, and X. Yan, "A Parallel Genetic Algorithm With Dispersion Correction for HW/SW Partitioning on Multi-Core CPU and Many-Core GPU," *IEEE Access*, vol. 6, pp. 883–898, 2018.