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# Root Shoot Coordination Optimization: Conceptualizing Ascent of Sap and Translocation of Solute in Plant

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# Root Shoot Coordination Optimization: Conceptualizing Ascent of Sap and Translocation of Solute in Plant

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***Abstract*— A new nature inspired evolutionary technique called Root Shoot Coordination Optimization (RSCO) has been proposed here. This optimization method has been developed on the basis of conduction procedure of plant. Water and solute i.e. food circulation phenomena maximizes on the fruitful coordination between root and leaves/shoot. This circulation procedure in plant incorporates two vital processes which are ascent of sap and translocation of food. Ascent of sap occurs due to the combined effect of adhesion and cohesion tension of water molecules and transpiration pull for the evaporation of water through stomata of shoot. Translocation of food takes place due to the pressure difference of solute in the shoot and root. This thought has been mathematically modeled as a new soft computing tool. This method has been tested for some benchmark problems. This method showed its effectiveness with encouraging results.**

***Keywords- root shoot coordination optimization (RSCO); ascent of sap; hydrotactic; pressure diffrence; transpiration pull***

## I. INTRODUCTION

Evolutionary Algorithm based on the concept of natural process has been giving birth of efficient searching tool for optimization. The research on this particular field of soft computing based artificial intelligence further proceeds towards new era and new dimensional optimization method. The era of heuristic technique for searching has been modified and made of higher searching tool to build up metaheuristic technique for higher level searching. This helps to find out the global optimum value of highly constrained multivariable optimization problem of real world. Genetic Algorithm [1] was proposed by Holland as an evolutionary technique. This was developed on the gene evolution phenomena. Simulated Annealing [2] then was thought on the metal melting phenomena. Cultural Algorithm [3, 4] was developed as the cultural evolution of human being taking initial concept from Genetic Algorithm. Dorigo et al. proposed Ant Colony Optimization [5]. This soft computing technique was developed on the concept of ant's pheromone hormone secretion phenomena to find food or wanted object. Memetic Algorithm [6] was proposed by taking fundamental concept from Genetic Algorithm and martial art. Particle Swarm Optimization [7] based on the swarming behavior of bird or fish had become an encouraging optimization tool. Cuckoo Search [8, 9] algorithm was proposed by Yang. It was based on the hatching procedure of cuckoo. Seref et al. proposed Monkey Search algorithm [10]. This was based on the food searching procedure of monkey in a forest. Firefly Algorithm [11] had been developed by mimicking the bioluminescence or glowing behavior and mating procedure of firefly. Glowworm Swarm [12, 13] optimization method had also been proposed more or less on the same concept of firefly algorithm. Bees Algorithm [14], Bee Colony Algorithm [15], Artificial Bee Colony Algorithm [16, 17] had been proposed on the basis of food searching phenomena of honey bee. Bacterial Foraging Algorithm [18-20] had been proposed on the basis of bacterial foraging procedure in the human stomach. Enzyme Algorithm [21] had been developed on the concept of enzyme reaction in the human being. Bat–Inspired Algorithm [22] was developed as a balanced mixture of Particle Swarm Optimization and bat's echo locating procedure. Hunting Search and Echolocation Optimization method had also been proposed as nature inspired optimization method [23, 24].

Physiological behavior of plant had also been mathematically developed as soft computing tool. Photosynthesis Algorithm [25] had been developed on the basis of dark phase and light phase of glucose production phenomena of plant at leaf. Plant Growth Simulation Algorithm [26] and Plant Growth Optimization [27] were the two examples of soft computing technique which were based on plant growth. Plant Growth Simulation Algorithm had been developed on the concept of phototropism of plant.

In this paper a new optimization technique is developed on the concept of physiological behavior of plant. But it is thought out on the conduction and translocation procedure for water and mineral upward circulation to the leaf and glucose mixed water circulation throughout the whole plant body respectively. To do this necessary work, plant's root and leaf or shoot coordinate with each other in such a way that the total conduction phenomena in all respect maximizes the growth of plant. The conduction phenomena incorporate ascent of sap [28-30] and translocation of food [31-36]. Ascent of sap was proposed by Dixon [28-30] and Joly [28]. Translocation of food on the basis of mass flow or pressure flow hypothesis had been stated by Curtis [31-32] and Munch [34-36].

On the other hand Transpiration is a necessary evil. It is necessary to pull up the soil water sucked by root against gravitation but if this phenomenon occurs at a maximum rate then the water content of plant will be evaporated which may lead to wilting and further increment regarding this issue may lead to plant death. Guard cell in leaves controls the transpiration and protects the plant from the adverse effect of it.

However plant does coordinated optimization with the transpiration, ascent of sap and translocation of food to fulfill its basic needs and to grow larger and faster smoothly. This concept is mathematically represented in this paper as Root Shoot Coordination Optimization (RSCO). This soft computing technique has been implemented for two test bed optimization problems. The description of this soft computing technique is discussed in section II. How this technique has been mathematically developed is described in section III. Section IV and V demonstrate the test bed function evaluation and the simulation results after implementation of this method. Scope of further research with conclusion and reference citation are briefly written thereafter.

## II. ROOT SHOOT COORDINATION OPTIMIZATION (RSCO)

Plant, may it be a long tree or a bush produces its food in the presence of sunlight, carbon di-oxide and water. Sunlight is free for all living being in the earth i.e. without making any effort any one can get the solar ray in day time. Carbon di-oxide is also there in adequate quantity due to the exhalation procedure of living being and combustion phenomena. But there is scarcity of soil water which is usually taken by plant with minerals. Mainly capillary water is sucked by the root of the plant by endosmosis. This water with minerals i.e. sap is circulated upwards to leaf by the xylem tissue of plant. The food i.e. glucose mixed with water or solute is circulated throughout the plant body by phloem tissue. This conduction phenomenon in plant occurs satisfactorily if the root and shoot coordinate with each other in an efficient manner. The ascent of sap can be possible with the transpiration pull and adhesion and cohesion tension of water. The adhesion and cohesion tension helps the water molecules to remain as column. Transpiration which is a necessary evil in the plant helps to evaporate the water through the lenticels or stomata of leaves/shoot. This evaporation pulls the water column in the xylem tissue and helps to reach at the leaf of the plant. So the number of leaf or the area of chlorophyll zone actually determines the intensity of transpiration pull. Now the food which is produced in the leaf as glucose becomes solute in day time taking water from the phloem tissue. The pressure increases in the leaf cell due to the increment of fluid and the pressure decreases in the root or other area of the plant due to suction of water. This pressure difference helps to circulate the solute throughout the whole plant. The translocation of food happens in this way. This food which comes at root strengthens it and helps for doing ramification and crushing more than the previous stage. This thought has been mathematically developed as Root Shoot Coordination Optimization. The conceptual diagram of this newly proposed method is shown in Fig. 1.

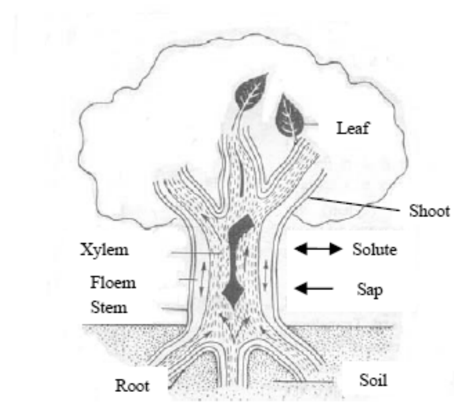


Figure 1. Root Shoot Coordination Optimization (RSCO) [Root and Shoot are coordinating with each other for satisfactory circulation of sap and solute] [37]

Root Shoot Coordination Optimization mainly enlightens the conduction phenomena in plant. Conduction or circulation is very important physiological phenomena in living being. It helps to circulate oxygen, nutrients, vitamins and hormones to every cell of the living being. But the medium of circulation in plant is water and mineral for the conduction in xylem and solute i.e. mixture of glucose and water for conduction in phloem. So, it has two parts; one is ascent of sap and the other is translocation of food. Both the parts have been taken care of to formulate the optimization method. The plant has inborn sense of availability of water content in the soil and also the availability of adequate sun light. This leads to the static movement of plant towards the desired location for searching the ingredients to prepare food. It has its hydrotactic movement by its instinct. This has been mathematically conceptualized as the initial hydrotactic generation of plant for the root development.

However this concept has been mathematically developed through some empirical relation and logical expression in the next section.

## III. MATHEMATICAL DEVELOPMENT OF ROOT SHOOT COORDINATION OPTIMIZATION (RSCO)

Root Shoot Coordination Optimization has been mathematically developed as a soft computing optimization tool. How this has been developed through mathematical equations is explained below.

Initially a population or hydrotactic generation for root has been generated randomly with a certain number of populations. In this optimization method this number of population is defined by $Pop^{size}$. Each individual of this population i.e. each solution is checked by the objective function related to the optimization problem. The minimum/maximum value of objective function amongst all the individuals of population at certain iteration gives the selected pressure difference value i.e. $Pdiff^{sel}$ for minimization/maximization problem. This pressure difference actually helps to circulate food throughout the whole body of plant and also determines the number of leaves. The number of leaves is correlated with the pressure difference in (1) as;

$$N^{leaf} = N_{ini}^{leaf} + Pdiff^{sel} \tag{1}$$

In (1) the terms $N^{leaf}$ and $N_{ini}^{leaf}$ define the number of leaves developed and initial number of leaves chosen for the optimization problem respectively. Transpiration pull is associated with the greenly or chlorophyll based area of plant. It is influenced by the number of leaves in a certain fashion. It is expressed in (2) as;

$$\begin{aligned} Trans^{pull} &= \alpha \times N^{leaf} \quad if\, N^{leaf} \le g^N \\ &= \alpha \times N_{guard}^{leaf} \quad if\, N^{leaf} > g^N \end{aligned} \tag{2}$$

In (2), the term $Trans^{pull}$ defines the tension or pull created due to the transpiration phenomena. The term $\alpha$ in (2) is a constant. The term $N^{leaf}$ defines the number of leaves created by the circulation of food due to pressure difference of solute between root and shoot. It is conditionally liked with guard cell number. Guard cell number $g^N$ is an important factor to select the number of leaf. The term $N_{guard}^{leaf}$ is set as number of leaf if $N^{leaf}$ crosses the value of $g^N$. The value of $N_{guard}^{leaf}$ can be taken as any value greater than set $g^N$. In this research work it is considered to be taken as 100. The transpiration pull created indirectly with the effect of root shoot pressure difference defines the factor of crushing in (3) as;

$$F^{crsh} = \left\lceil \frac{Pop^{size}}{\exp(\lambda \times Trans^{pull})} \right\rceil \tag{3}$$

In (3), the terms $F^{crsh}$ and $Pop^{size}$ are factor of crushing and population size respectively. The term $\lambda$ in the denominator of the R.H.S of (3) signifies the ramification tuning factor. It has been considered as 1 for all the test cases studied in this research work. Factor of ramification, for root in the search of more water and mineral, is defined in (4) as;

$$F^{ram} = Pop^{size} - F^{crsh} \tag{4}$$

In (4), $F^{ram}$ defines the factor of ramification. Factor of crushing and ramification are integers but if fractional value comes then near about integer value is considered for enumeration. Factor of ramification decides for what or how many times the new solution for water searching will be selected randomly. On the other hand the factor of crushing intensifies the searching procedure concentrating on the best value found so far i.e. it crushes more or search in depth. The best solution value found so far is modulated with the value of crushing. The value of crushing is defined in (5) as;

$$\begin{aligned} crush^{val} &= \left\lceil \frac{rootshoot^{rng}}{F^{crsh}} \right\rceil \quad if\, 0 < F^{crsh} < Pop^{size} \\ &= \left\lceil \frac{rand}{F^{crsh}} \right\rceil \quad if\, F^{crsh} = Pop^{size} \end{aligned} \tag{5}$$

In (5), the terms $crush^{val}$ and $rootshoot^{rng}$ define the crushing value for the new root shoot population generation and the crushing range respectively. The term *rand* signifies a random number between 0 and 1 in (5). This term is used to denote that mentioned value in all the expressions written in this paper.

However, the new solution with the influence of crushing value is generated according to (6) as;

$$\begin{aligned} X_j(i)^{new} &= X_j(i)^{sel} + crush^{val} \times m \times rand_j^i \\ i &\in \{1, \ldots\ldots, F^{crsh}\} \\ m &= +1 \quad if \quad t > P^{crsh} \\ &= -1 \quad \text{otherwise} \end{aligned} \tag{6}$$

In (6), the term $X_j(i)^{new}$ is the developed new solution for $j^{th}$ variable and $i^{th}$ individual of population by the influence of crushing. The term $X_j(i)^{sel}$, achieved at certain iteration by this optimization method RSCO, defines the selected solution value concerning to $Pdiff^{sel}$ in (6). The term *m* defines the tuning factor for crushing. It helps to create new solution on the basis of probability of crushing $P^{crsh}$ and variable *t*. The value of *t* is considered as a uniform random number between 0 and 1. This has been used with the condition shown in (6).

The number of $Pop^{size}$ is the accumulation of $F^{ram}$ and $F^{crsh}$. After creation of new solution under influence of crushing, the rest of the $Pop^{size}$ is created by the effect of ramification. The new solution generated due to ramification is shown in (7) as;

$$X_j(i)^{new} = X_j^{lower} + |X_j^{upper} - X_j^{lower}| \times \beta_j^i \quad (7)$$
$$i \in \{1,........, F^{ram}\}$$
$$\beta_j^i = rand_j^i \quad if \quad h > P^{ram}$$
$$= rand^i \quad otherwise$$

In (7), the term $X_j^{lower}$ and $X_j^{upper}$ are the lower and upper limit of the $j^{th}$ variable. The term $\beta_j^i$ is the tuning factor for ramification for $j^{th}$ variable and $i^{th}$ individual of population. This is a uniform random number between 0 and 1. It is chosen according to the ramification probability $P^{ram}$ and variable $h$. The value of variable $h$ is also a uniform random number between 0 and 1.

The objective function evaluation stopping criteria is considered on selected value of tolerance. This has been developed based on no further improvement of objective function value with the change of iteration number. When this factor reaches to its set maximum limit, then the iteration procedure is stopped and totally new hydrotactic population is generated randomly for new search. The global iteration termination condition has been considered on the basis of maximum iteration number. The pseudo code of this optimization procedure is described below in Fig. 2.

***start***
*hydrotactic generation for root development*
*set maximum iteration number and tolerance value*
***Until termination condition***
*set guard cell number* $g^N$
*convergence criteria satisfied? If* ***yes stop***
*Otherwise*
***Repeat until tolerance value is reached***
*calculate* $N^{leaf}$ *with* $Pdiff^{sel}$
*evaluate* $Trans^{pull}$
*modify* $F^{ram}$ *and* $F^{crsh}$
*determine the* $crush^{val}$
*develop the* $X_j(i)^{new}$ *according to* $F^{ram}$ *and* $F^{crsh}$
***end***
***end***
***stop***

Figure 2. Pseudo code for Root Shoot Coordination Optimization

This Root Shoot Coordination Optimization method has been implemented for three unconstrained widely used functions for convergence testing. This is described in the next section.

## IV. Convergence Criteria and Test Bed Functions

Root Shoot Coordination Optimization method has been applied on three functions. The functions namely *B2*, *Goldstein and Price (GP)* and *Rosenbrock ($R_2$)* have been taken for checking the effectiveness of this newly developed optimization method. All the test cases are solved with a certain convergence for doing minimization of the above mentioned cases [38, 39]. It is given in (8) as;

$$\left| f - f^* \right| < \varepsilon_1 f + \varepsilon_2 \quad (8)$$

In (8), the term $f$ and $f^*$ are achieved minimum function value and true minimum value respectively. The terms $\varepsilon_1$ and $\varepsilon_2$ are two constants which are taken to be considered as $10^{-4}$ in this research work [39].

### A. B2 Function

*B2* function is a multimodal function. It is a function of two variables. The variable range has been selected between +100 and -100 for this test bed problem [38]. The *B2* function is shown in (9) as;

$$f(x) = x_1^2 + 2x_2^2 - \frac{3}{10}\cos(3\pi x_1) - \frac{2}{5}\cos(4\pi x_2) + \frac{7}{10} \quad (9)$$

The true minimum value for this function is zero and it lies at (0, 0).

### B. Goldstein and Price Function(GP)

Goldstein and Price function is a multimodal unconstrained function. It has huge number of local extremums. The expression for this function is given in (10) as;

$$f(x) = (1 + (x_1 + x_2 + 1)^2 (19 - 14x_1 + 13x_1^2 - 14x_2 + 6x_1x_2 + 3x_2^2)).(30 + (2x_1 - 3x_2)^2 (18 - 32x_1 + 12x_1^2 - 48x_2 - 36x_1x_2 + 27x_2^2)) \quad (10)$$

Range of variable considered for this case is (-2, 2) [38]. The true minimum value for this function is 3 and it lies at (0,-1).

### C. Rosenbrock Function($R_2$)

Rosenbrock function or banana function is a multimodal function. Its variable range for checking the optimality of this newly proposed method is considered in between -5 and 10. The rosenbrock function has been shown here in (9) as;

$$f(x) = \sum_{i=1}^{d-1} (1 - x_i)^2 + 100(x_{i+1} - x_i^2)^2 \quad (11)$$

The dimension $d$ in (11) is considered in this research work for evaluation is 2. This function has a global minimum value at (1, 1) of zero [38].

## V. Simulation Results and Discussion

The three test functions described in the previous section have been considered for doing minimization. Root Shoot

Coordination Optimization method has been coded on technical software MATLAB 7.0. The code has been developed in house. The hardware/processor used for this enumeration purpose is Intel Core i3 2.4 GHz. The maximum iteration number is considered as 100. The tolerance factor, mentioned in section III, has been considered as 10 after several checking for finding the desired convergence. The size of population i.e. $Pop^{size}$ is taken as 20 for all the test functions. The inherent parameters of RSCO chosen for implementation are given in Table I.

TABLE I. PARAMETERS CHOSEN FOR FUNCTION EVALUATION

| ***f(x)*** | $N_{ini}^{leaf}$ | $g^N$ | $P^{ram}$ | $\alpha$ | $*RS^{rng}$ | $P^{crsh}$ |
|---|---|---|---|---|---|---|
| ***B2*** | 0 | 7.5 | 0.5 | 0.8 | 12 | 0.5 |
| ***GP*** | 20 | 4 | 0.5 | 0.0036 | 1.5 | 0.5 |
| $R_2$ | 0 | 2 | 0.5 | 0.5 | 12 | 0.5 |

$*RS^{rng} = rootshoot^{rng}$

It can be observed from Table I that the initial number of leaf i.e. $N_{ini}^{leaf}$ in (1) is considered as zero for two test functions i.e. *B2* and $R_2$ but it is taken as 20 for *GP* function. The constant value $\alpha$ for the transpiration pull detection in (2) is considered as 0.8, 0.0036 and 0.5 for *B2*, *GP* and $R_2$ respectively. The value of $g^N$ chosen for three cases are 7.5, 4 and 2 respectively. The crushing range $rootshoot^{rng}$ is taken to be considered as 12, 1.5 and 12 respectively. The probability for crushing and ramification i.e. $P^{crsh}$ and $P^{ram}$ are both considered as 0.5.

However, by choosing different parameters value from Table 1, RSCO has been applied for minimization of the test bed problems. The results after implementation of this optimization technique are shown in Table II.

TABLE II. RESULTS OBTAINED AFTER IMPLEMENTATION OF RSCO

| ***f(x)*** | **Number of function evaluation** | **Computation time (second)** | **Minimum value achieved** | **Minimum point** |
|---|---|---|---|---|
| ***B2*** | 700 | 9.634635 | $3.65056\times10^{-5}$ | 0.001545, 0.000262 |
| ***GP*** | 1540 | 1.618814 | 3.00037 | 0.001276, -0.999541 |
| $R_2$ | 680 | 0.31111 | $1.50359\times10^{-5}$ | 1.002750, 1.005236 |

It can be observed from Table II that RSCO reaches the desired convergence by evaluating the *B2*, *GP* and $R_2$ function for 700, 1540 and 680 times respectively. RSCO reaches to the minimum value of $3.65056\times10^{-5}$ for *B2* function with that set desired convergence in (8). The minimum point found out by RSCO for this function is at (0.001545, 0.000262). It is shown in Table II that minimum function value for *GP* function, achieved by RSCO is 3.00037 and the minimum point found is at (0.001276, -0.999541). It is also shown in Table II that RSCO reaches minimum value of $1.50359\times10^{-5}$ for $R_2$ function and minimum point for that value is (1.002750, 1.005236). It can be further observed from Table II that RSCO reaches the desired convergence for *B2*, *GP* and $R_2$ function by taking time of 9.634635s, 1.618814s and 0.31111s respectively. The *GP* function is more critical than $R_2$ function but the solution range of *B2* is the highest amongst all the functions taken in this research work for evaluation. That's why the RSCO takes maximum time to reach the set convergence for *B2* function in comparison to others.

## VI. CONCLUSION

Root Shoot Coordination Optimization has been proposed as a new nature inspired soft computing optimization technique. It has been developed on the basis of conduction phenomena of herb. This has been applied to three unconstrained functions to check the optimality and convergence. It has shown encouraging results. This method is at its infancy and has further scope of research. It can be more effective if it is tuned further for the factor of ramification and crushing. Hybridization of this newly proposed RSCO with other well established technique will also be a good move in this regard.

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