Figure 3. *a*, Horizontal displacement (HD) of first sensor in the array, and *b*, simulated array movement.

The analysis revealed that the strong currents (> 1 m/s) in the shallow waters off Andaman during fair weather season significantly altered the position of sensors (~ 13 m in the vertical) in the moored array. As strong currents were observed during fair weather, they are not driven by local forcing, but are remotely forced. The study stresses the importance of a priori knowledge of the environment (mainly the sub-surface currents) for design of the array configuration and deployment of moorings. Moreover, logging of sensor positions at fine sampling interval is also recommended for any meaningful post-processing and analysis of data from moored sensors.

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Hydrocarbon reserve estimation using evolutionary programming technique

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The oil industry is riddled with risk and uncertainty. Both loom large at almost every stage – exploration, production and downstream. The industry is regarded as a classic illustration of the need for sophisticated approaches to risk assessment. In the present communication an attempt is made to use Evolutionary Programming technique for estimation of hydrocarbon reserves. The algorithm is applied to a prospect identified in Rajasthan basin, India.

WITH the advent of high speed computers having higher disk space and parallel processing environment, several global optimization techniques (simulated evolution, simulated annealing, very fast simulated annealing, etc.) are adapted to solve various inherent problems in inversion of geological and geophysical data. Several risk-analysis techniques are already in use for hydrocarbon reserve estimation[1–3]. In this communication, an optimization technique called Evolutionary Programming (EP) is used to reduce the risk and uncertainty in hydrocarbon reserve estimation.

EP brings risk and uncertainty centre stage as integral parts of the calculations rather than afterthoughts. Most importantly, it brings probability into the picture. Once the initial inputs for hydrocarbon distribution are estimated, the simulation procedure starts. In EP simulation, each of these inputs is randomly sampled and then the individual values are multiplied together (a procedure known as the trial). The result of a single trial provides one possible answer for recoverable reserves. The random sampling of each of the input distributions is repeated many times – typically between 1000 and 100,000 depending on the type of calculation required. With so many

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trails, the simulation will sample the most likely outcomes of each distribution more than the extremes, because there are more examples in that range. The end result is a new distribution curve – a range of possible, recoverable, reserve sizes and the probability of any particular value occurring.

A prospect identified in Rajasthan basin (Prospect E) is used to validate the algorithm. The initial result obtained is found to be encouraging.

In hydrocarbon reserve estimation, we are concerned with parameters like area (A), pay thickness (H), porosity (Φ), oil saturation (S_0), formation volume factor (B_0) and recovery factor (RF). For each parameter we have a pair of bounds, i.e. the upper and lower limits. We intend to find the exact solution within the specified domain. EP does this by using three main steps. These are generation of population, computation of fitness and mutation.

In the first step, n real coded individuals in the population are generated randomly within the specified bounds. Two important criteria for the generation of population are the population size and randomization seed number. The choice of the population size and random seed number depends on the computational efficiency desired. The individuals of the population are randomly created by considering n values between upper and lower limits of each parameter. The number of individuals generated can be shown in matrix form as given below

$$I = \begin{pmatrix} I_{11} & I_{21} & .. & I_{n1} \\ I_{12} & I_{22} & .. & I_{n2} \\ .. & .. & .. & .. \\ I_{1P} & I_{2P} & .. & I_{nP} \end{pmatrix}, \tag{1}$$

where suffix P represents parameter and suffix n represents values for each parameter.

The fitness function of each newly generated individual of the population is calculated by using the concept of chi-square error.

The chi-square error E is defined as:

$$\varepsilon = \frac{1}{N} \sum_N \frac{(P_O - P_C)^2}{(P_C)^2}, \tag{2}$$

where P_O is the observed parameter, P_C is the computed parameter and N is the number of observations.

The hydrocarbon reserve is estimated by using the following expression:

$$\text{Recoverable reserve (RR)} = \frac{(A \times H \times \Phi \times S_0 \times RF)}{B_0}, \tag{3}$$

where A is the area in km^2, H the thickness in m, Φ the porosity, S_0 the oil saturation, RF the recovery factor, and B_0 is the reservoir formation volume factor.

We intend to calculate three values for RR. These are P10, P50 and P90 values where P is the percentile and

P10, P50 and P90 represent the minimum, most likely and the maximum reserves for a given prospect.

The mutation process consists of the repeated application of greedy operators to an individual until its fitness does increase (or a maximum number of iterations is reached). If the fitness of an individual is increased after the application of mutation, then the last mutation applied is retracted.

In this step, an equal number of individuals are generated by perturbing each member of the population by step-function mutation. The perturbation rate P_m during mutation is assigned depending upon the fitness of an individual. After several tests P_m is found to yield better convergence of a step-like distribution which is used as given in Table 1.

In Table 1, P_m is the random value generated by using the same seed value as that used for population generation, if $\varepsilon > 100$.

After selection of each individual in the hierarchy of fitness, a random number is generated using the same seed value. If the number is found to be greater than 0.5, the individual is perturbed by multiplying with the rate P_m. Otherwise, it is obtained by dividing with P_m. This continues till the entire population is exhausted and the mutation process is over.

Figure 1 depicts a prospect from Rajasthan. The prospect is a structural high sandwiched between two faults. The minimum closing contour is 1360 m and maximum

Table 1. Step-like distribution for mutation

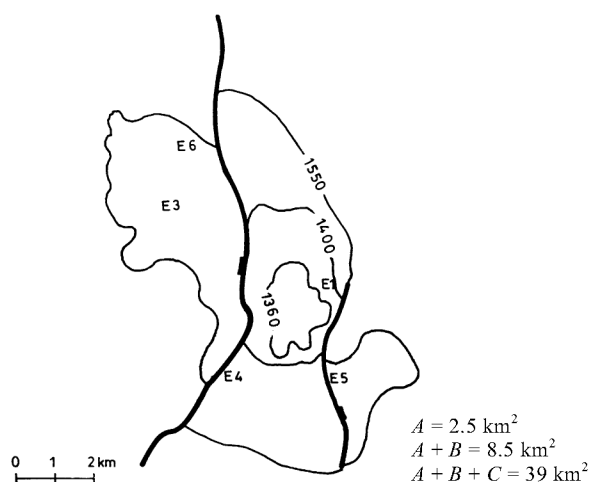|		
$P_m = 0.999$,	if	$\varepsilon = 0.5$
$= 0.985$,	if	$0.5 < \varepsilon \leq 1$
$= 0.970$,	if	$1.0 < \varepsilon \leq 2.0$
$= 0.950$,	if	$2.0 < \varepsilon \leq 5.0$
$= 0.870$,	if	$5.0 < \varepsilon \leq 10.0$
$= 0.770$,	if	$10.0 < \varepsilon \leq 25.0$
$= 0.650$,	if	$25.0 < \varepsilon \leq 50.0$
$= 0.500$,	if	$50.0 < \varepsilon \leq 100.0$.

$A = 2.5$ km^2
$A + B = 8.5$ km^2
$A + B + C = 39$ km^2

Figure 1. Prospect E from Rajasthan basin.

Table 2. Parameters for reserve estimation

Variable	Minimum	Most likely	Maximum
Pay (m)	4	17	31
Porosity (%)	10	12	15
B_0	1.0781	1.0782	1.0783
Saturation (%)	55	65	70
Recovery factor (%)	10	12	15

Table 3. Final seed values for simulation

Variable	Seed
Area (km^2)	14.461
Pay (m)	19.085
Porosity (%)	10.700
B_0 (v/v)	1.078
Saturation (%)	59.365
Recovery factor (%)	10.535

closing contour is 1550 m. The areas for minimum, most likely and maximum in-place hydrocarbon are determined from 3D seismic data. According to SPE definition, minimum, most likely and maximum reserves can be equated to P10, P50 and P90 reserves, where P represents percentile. The other parameters for reserve estimation are given in Table 2.

For estimation, 10,000 trials were considered. After 10,000 iterations, optimum seed values for each parameter were estimated (see Table 3) from the range of minimum and maximum bounds of parameters shown in Table 2. For example, the seed for pay (in m) will be chosen from a range between 4 and 31 m. The process of fitness computation and mutation in successive iterations will lead to optimized seed value.

The optimized in-place reserve is calculated using the following formula:

$$\text{In-place reserve} = (6.29 \times \text{area} \times \text{pay} \times \text{porosity} \times \text{saturation})/B_0, \qquad (4)$$

where B_0 is the formation volume factor defined as the volume one stock tank barrel of oil (at 14.7 psi and 60°F) will occupy under reservoir conditions. It is a ratio of volume/volume. 6.29 is a multiplier to convert one cubic metre to one barrel (BBL). The recoverable reserve is calculated by multiplying the in-place reserve with the recovery factor. The optimized recoverable reserve for Prospect E was calculated to be 10.78 MMBBL.

The chi-square error test for area and pay are shown in Figure 2 a and b. The reserves for P10, P50 and P90 are estimated as shown in Table 4.

The estimation shows that the recoverable reserve of Prospect E ranges between 0.45 and 111.31 MMBBL, with a most likely value of 9.54 MMBBL. Using standard crystal-ball software, it has been found that the reserves range between 0.3 and 120 MMBBL, with P50 value equal to 10 MMBBL. This is in line with the results
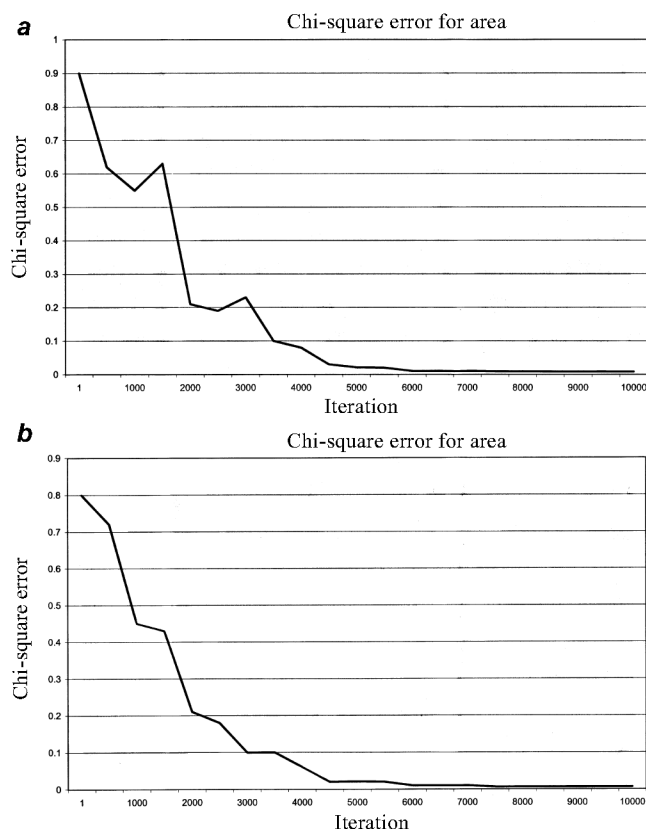
Figure 2. Chi-square error graph for a, Area and b, Pay.

Table 4. In-place and recoverable reserves estimated for Prospect E

Reserve	P10	P50	P90
Oil in place (MMBBL)	3.21	65.82	742.05
Recoverable reserve (MMBBL)	0.45	9.54	111.31

obtained using EP. All the tree values are important during exploration, since P10, P50 and P90 can be equated to Proved (1P), Proved + Probable (2P) and Proved + Probable + Possible (3P) reserves, respectively[4] (Appendix 1).

The first step in any rational analysis of an oil field is a subjective estimation of reserve with a certain level of confidence. The size of a reserve is uncertain, but the range of uncertainty declines with the use of optimization tools like EP. The preliminary results obtained using field data are found to be satisfactory in nature.

Appendix 1.

Oil and gas reserve definitions – SPE/World Petroleum Congress

Reserves are those quantities of petroleum which are anticipated to be commercially recovered from known accumulations from a given date forward. All reserve

estimates involve some degree of uncertainty. The uncertainty depends chiefly on the amount of reliable geologic and engineering data available at the time of the estimate and the interpretation of these data. The relative degree of uncertainty may be conveyed by placing reserves into one of two principal classifications, either proved or unproved. Unproved reserves are less certain to be recovered than proved reserves and may be further sub-classified as probable and possible reserves to denote progressively increasing uncertainty in their recoverability.

Proved reserves are those quantities of petroleum which, by analysis of geological and engineering data, can be estimated with reasonable certainty to be commercially recoverable, from a given date forward, from known reservoirs and under current economic conditions, operating methods, and government regulations. Proved reserves can be categorized as developed or undeveloped.

If deterministic methods are used, the term reasonable certainty is intended to express a high degree of confidence that the quantities will be recovered. If probabilistic methods are used, there should be at least a 90% probability (P10) that the quantities actually recovered will equal or exceed the estimate.

Unproved reserves are based on geologic and/or engineering data similar to those used in estimates of proved reserves – but technical, contractual, economic or regulatory uncertainties preclude such reserves being classified as proved. Unproved reserves may be further classified as probable reserves and possible reserves.

Probable reserves are those unproved reserves which analysis of geological and engineering data suggests are more likely than not to be recoverable. In this context, when probabilistic methods are used, there should be at least a 50% probability (P50) that the quantities actually recovered will equal or exceed the sum of estimated proved plus probable reserves.

Possible reserves are those unproved reserves which analysis of geological and engineering data suggests are less likely to be recoverable than probable reserves. In this context, when probabilistic methods are used, there should be at least a 10% probability (P90) that the quantities actually recovered will equal or exceed the sum of estimated proved plus probable plus possible reserves.

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Agrobacterium tumefaciens-mediated transformation of Brahmi [*Bacopa monniera* (L.) Wettst.], a popular medicinal herb of India

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Agrobacterium-mediated genetic transformation of Brahmi [*Bacopa monniera* (L.) Wettst.] was standardized using the *Agrobacterium tumefaciens* strain EHA105 that harboured the binary vector pBE2113 containing genes for β-glucuronidase (GUS) and neomycin phosphotransferase. Putative transformants were selected by the ability of the leaf explants to produce kanamycin-resistant calluses that regenerated into kanamycin-resistant plantlets. Successful transformation was confirmed by histochemical assay for GUS activity, PCR analysis and RT–PCR. The frequency of transformation from the leaf explants was more than 60% and a period of nearly two months was required for the regeneration of transgenic plantlets from the explants. The morphology of the transformed plants resembled that of the parent. The development of an efficient transformation protocol for Brahmi can lead to the genetic improvement of the plant for secondary metabolite content in future.

METABOLIC engineering is emerging as one of the important approaches to improve and modify secondary metabolite contents of medicinal and aromatic plants. Recently, some examples of successful genetic manipulation of secondary metabolite pathway through metabolic engineering for increased metabolite content[1–5] and exploitation of the plants as bioreactors for the production of natural or recombinant secondary metabolites of commercial interest[6] have been presented. The rapid progress in the area of crop biotechnology is mainly because of the development of efficient regeneration and suitable *Agrobacterium*-mediated transformation protocols for different crop species[7]. Similar success can be achieved in medicinal plants by developing efficient regeneration and *Agrobacterium*-mediated transformation protocols, which in turn could be used for the enhancement of their secondary metabolite content. Brahmi [*Bacopa monniera* (L.) Wettst.] is an important ayurvedic herb used in India for more than 3000 years. The plant is a member of Scrophulariaceae family and is quite widespread throughout the tropics, where it is found on the banks of slow-flowing rivers and lakes. The herb is primarily used for

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