An early warning system for elephant intrusion along the forest border areas

S. J. Sugumar[1,]* and R. Jayaparvathy[2]

[1]Coimbatore Institute of Technology, Coimbatore 641 014, India
[2]SSN College of Engineering, Chennai 603 110, India

Man–animal conflict has been on the rise in the forest border areas with herds of wild pachyderms straying into human habitation. The surveillance and tracking of elephant herds are difficult due to their size and nature of movement. In this article, we present an analytical procedure to study the behaviour of elephants along forest border areas by taking migration data into consideration using a three-state Markov chain. The migration data over the whole year is divided into four different periods for the study. We also develop an intrusion detection system to detect the intrusion of herds of wild elephants from the forests into the human habitation and to send an early warning through SMS to the forest officials to take necessary action. We validate the analytical results in comparison with the data obtained from the Forest Department. We also present a multi-class classification algorithm for providing zero false alarm rate. Species classification accuracy percentage is found to be 91.25.

Keywords: Early warning system, forest border areas, human–elephant conflict, migration data.

THE enormous increase in human population in Asian countries like India propelled by agricultural and industrial growth has led to the conversion of forest lands into human settlements. Due to this, the wild elephant and other animal populations face acute shortage of resources such as water and food, forcing them to often move into human habitats. Hence there has been severe man–elephant conflict. The conflict has been on the rise in the forest border areas with herds of wild pachyderms straying into human habitation. The surveillance and tracking of these herds are difficult due to their size and nature of movement. The time to recover from the danger is negligible; hence the loss due to destruction in the farms is more. The elephants are also subject to attack by humans resulting in danger to the life of elephants. Therefore, there is a need for intelligent elephant surveillance and tracking system. The magnitude of impact of human–elephant conflict can be viewed from the fact that globally around 5 lakh families are affected by human–elephant conflict per year. Minimizing human–elephant conflict to reduce the risk of life of both humans and elephants is of utmost importance.

Human–elephant conflict is a rapidly expanding area of research, with conservationists working hard to understand the circumstances under which tensions are highest between humans and elephants. A number of factors contribute to such conflicts, including population density of humans, elephant habitat structure, weather, time of year and animal life[1]. A study made in the region of interest shows that elephants move into human habitation due to many reasons.

- Fences and trenches compromised by people who need access to forests.
- Farm lands may funnel them to unprotected adjacent villages.
- Badly planned barriers that do not take elephant behaviour into consideration.
- Denying elephant access to a critical water source or foraging area.
- Human activities create abundant secondary vegetation that brings elephants closer to human settlements.
- Artificially maintained water sources attract elephants during drought.
- Traditional migration routes severed by human intervention (e.g. canals, power installations and cattle fences).

The obvious conclusion to be drawn is that there is no one cause or explanation to account for human–elephant conflict; situations are circumstantial and complex. Rather, elephants and agriculture mix in numerous ways with varying consequences. Human population growth and land occupation for settlement may heighten conflict with elephants. However, it is generally the borders of forests that are the focal points for conflicts.

There are several projects and initiatives on the mitigation of elephant–human conflict taking place around the globe. Traditional methods are devised by local communities and these include noise (shouting, beating drums, burning bamboo, bursting fire crackers), light (fire at entry points to fields, powerful spotlights) and missiles (stones, spears)[1]. The construction of elephant-proof trenches is being done all over the world. Fernando *et al.*[2] proposed solar fencing to avoid elephant–human conflict.

*For correspondence. (e-mail: sjs_cit@yahoo.co.in)

King *et al.*[3] presented results from a pilot study conducted to evaluate the concept of using beehives to mitigate elephant crop depredation. Singh and Chalisgaonkar[4] have discussed how railway lines, highways, irrigation and hydroelectric canals, industrial establishments and human settlements along the migration corridors have affected the migratory movement of the elephants. Loarie *et al.*[5] have discussed the role of artificial water sources which allow elephants to damage vegetation in forest border areas. Venkataraman *et al.*[6] have discussed the potential use of satellite technology as an 'early warning system' for conflict mitigation. However, this approach necessitates tagging the elephants with radio collars to which they react violently and also damage the radio collars. Wijesinghe *et al.*[7] have presented the design and implementation of an intrusion detection and alerting mechanism (eleAlert) for fences separating wildlife habitats and human settlements. An eleAlert is generated by a network of sensors to detect and locate damages instantly, and alert communities under threat via mobile communications network. Electric fences are harmful to elephants. There are cases of elephants being killed due to the large current passing through the fences. In turn, human deaths also occur due to such electric fences. Qi Hao *et al.*[8] described pyroelectric sensor modules that are able to detect the angular displacement of a moving thermal target. Fresnel lens arrays are used to modulate the sensor field of view. The sensor system has been used to track a single human target. The distance of sensing thermal target is less than 2 m which is hard to sense target moving at longer distance than 2 m. Alan Mainwaring[9] provided an in-depth study of applying wireless sensor networks to real-world habitat monitoring. Juang and Philo[10] discussed about the design tradeoffs and early experience in building sensor networks for position tracking of wild life. These sensor networks described[9,10] are to be laid above the ground level and work well when line of sight exists. But often the sensor nodes are destroyed by the elephants. Farmers and wood pickers may also disturb the sensor nodes as they are unaware of the importance of these devices. Graham *et al.*[11] have discussed the use of mobile phone communication in effective human–elephant conflict management in Laikipia County, Kenya.

An early warning system to minimize the human–elephant conflict in the forest border areas is proposed in this article. The system helps mitigate such conflicts in two ways:

(1) Provides warning to people about the anticipated entry of elephants into human habitation.
(2) Provides advance information to the authorities to take action to chase the pachyderms back to the forest.

We present an analytical procedure to study the behaviour of elephants taking migration data into consideration using a three-state Markov chain. We also propose the design of a hardware module for intrusion detection of the herds from the forests into human habitation and sending early warning through short messaging service (SMS) to the forest officials to take necessary action.

Region of study

India is home to 60% of the Asian elephant population. According to Project Elephant, a Government initiative for elephant conservation, there were 28,000 elephants in the country in 2011. Coimbatore forest division in Tamil Nadu is a habitat for elephants in India. Elephant intrusion along the forest border areas is a common problem in this division. Elephants intrude into farm fields and villages and cause damage. Statistical study was taken up in the region of interest (Coimbatore forest division bordering the Western Ghats in India). The number of incidents of elephants straying into farm lands was 680 in 2011, 844 in 2010 and 560 in 2009. The number of people killed in elephant attack in Coimbatore was 14 in 2011, 16 in 2010 and 11 in 2009. The number of elephants killed by such conflicts was 10 in 2011, 11 in 2010 and 12 in 2009 (Figure 1). Another human–elephant conflict in this region is the train hit accident which occurs when elephants try to pass the railway track along the Walayar–Coimbatore section in the forest area; this has resulted in the death of 20 elephants in the last five years. Agriculture crop damage by elephants is high in Manglapalayam, Karadimadai and Perumalkoilpathy.

In Coimbatore forest division[12], the specific sub-areas of study are Anaikatti, Periya Thadagam and Nanjundapuram. The entire forest division is divided into three forest fragments (Periya Thadagam, Nanjundapuram and Anaikatti) and with the following boundary restrictions: Forest areas around Somaynur, Periya Thadagam and Mankarai villages are considered as Periya Thadagam

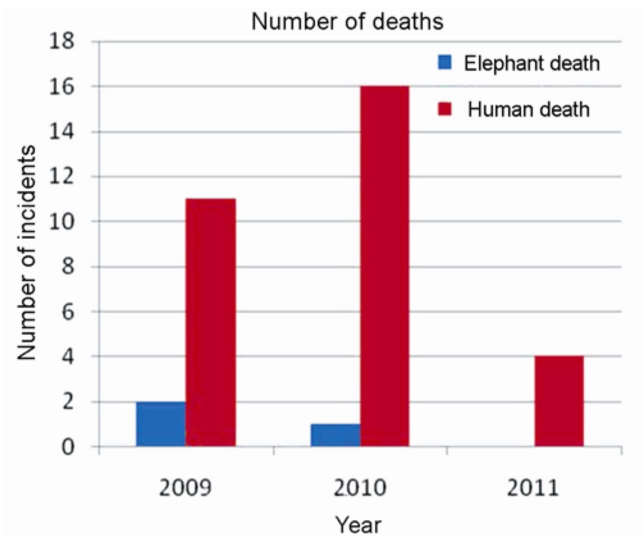

Figure 1. Number of incidents of elephants straying and deaths due to elephant–human conflict. (Courtesy: *Times of India*, July 2011.)

forest fragment (P). Forest areas around Nanjundapuram, Ramanathpuram, Madathur, Chinna Thadagam and Veerapandiputhur are considered as Nanjundapuram forest fragment (N). Forest areas from Anaikatti to Karl Kubel Institute for Development Education are considered as Anaikatti forest fragment (A). Till recently, the Coimbatore Forest Department had been using powerful searchlights, crackers and drums to push the wild elephant herds back into the jungle. The kumki (rescue) elephants were used more in hill areas to chase the wild elephant herds into the forests. We propose here an elephant surveillance and tracking system to detect elephant intrusion in the above region.

Elephant migration

Movement of elephants is considered to be one of the most important ecological factors which influences the distribution of other small herbivores. Elephants travel long distances as part of their migration activities and at the same time they stay within different forest habitats that are enriched with water and fodder[13,14]. Studies were made in the Coimbatore forest region, the data were collected from the Coimbatore Forest Department website, interviews with village people affected by elephants and relevant literature. Coimbatore district is richly endowed with hills, forests, rivers and wildlife. Geographical area of the district is 74,433.72 sq. km having a forest area of 693.48 sq. km (9.33%). The forest area of Indira Gandhi Wildlife Sanctuary is 958.59 sq. km (12.89%), while the total forest area of the district is 1652.07 sq. km. The Western Ghats of the district is home to rivers such as Bhavani, Noyyall, Aliyar and Siruvani, which provide drinking water and irrigation water for the people and farmers of Coimbatore.

The forest of Coimbatore district is divided into two divisions. South of Palghat Gap lies in the Anamalai Wildlife Sanctuary, which has been designated as a Tiger Reserve in 2008 (ref. 15). North of Palghat lies in the Coimbatore forest division. This division is bounded in the north and northwest by Sathiyamangalam, Erode, Nilgiris North and Nilgiris South forest divisions and in the west and southwest by Palghat forest division of Kerala. In the Coimbatore forest division, elephants while using the forest as a migratory route tend to raid crops such as maize, fodder, corn, sugar cane and banana raised along the fringes. The elephants are known to raid more than 10 types of crops raised in more than 50 hamlets along the forest fringe areas and crop raiding is highest during the fruiting of cereal crops, i.e. December and January. Generally, the peak raiding season starts after the northeast monsoon and lasts till March, which incidentally coincides with the migratory season. It is also seen that 2–3 elephants team up and carry excursions deeper into the human settlements even up to 10 km away from the forest fringe areas.

Elephants intrude into farm fields, villages and main roads and may cause damage to crops. The most common corridors in Coimbatore forest division are the Jaccanari–Vedar Colony corridor, Kallar–Jaccanari corridor, Kallar–Nellithurai corridor, Anaikatti–Veerapandi corridor, Maruthamalai–Thanikandi corridor and Kalkothi–Walyar corridor. The Jaccanari–Vedar Colony corridor has a length of about 12 km with width ranging from 0.2 to 1.5 km. Dry deciduous forests in the hill slopes and open thorn forests in lowland areas dominate this corridor. Unsuccessful teak and successful *Acacia* spp. plantations mostly dominate the vegetation of the corridor. Ghandhapallam and Kunukkumadu are the perennial water sources that attract the elephants during dry season. *Tamarindus* is the predominant fruit species available for the elephants. The Kallar–Jaccanari corridor has a length of 7 km with width ranging from 0.2 to 1.5 km. Elephants move through this corridor to cross the Ooty main highway following undulating contours of the corridors of the Jaccanari hills in the north. The elephant herds cross just below the first hairpin bend in the highway. Dry deciduous forests in hill slopes and mixed secondary growth woody forest in lowland areas dominate this corridor. The Kallar–Nellithurai corridor is 10.8 km long with width ranging from 0.25 to 3 km. Elephants prefer this corridor during their seasonal migration. Of late, elephants are migrating across the corridor by selectivity utilizing the lowland forests on the banks of the Bhavani river. The Anaikatti–Veerapandi corridor has a length of 21 km and effective width ranges from 0.1 to 1.5 km. The terrain consists of undulating plains and hillocks. Kodungaraipallam is a perennial stream that provides major water source to elephants in this region. Seasonal water sources such as Anaikuzhi Pallam and Moongil Pallam are also part of this corridor. Subtropical thorn and dry deciduous forests are the commonly found vegetation types. The tree cover is dominated by *Albizia amara*, with signs of over-browsing by elephants. The above-mentioned factors clearly indicate why elephant movements are found in the forest border areas of Coimbatore. Certainly there is high probability of human–elephant conflict in these areas.

Elephant-affected villages

Crop raiding by elephants and human–elephant conflict are on the rise in Coimbatore[15]. All the villages adjacent to forest regions with cultivation being the main occupation face a lot of problems. Table 1 shows the forest ranges and the affected villages surrounding them.

Three-state Markov chain approach for elephant migration analysis

An analytical model to capture the behaviour of elephants using a Markov chain is developed. Three areas, namely

Table 1. Elephant-affected villages

Range	Village
Coimbatore	Periya Thadagam, Somayanur, Mattathukadu, Anaikatti
Karamadai	Aathimathayanur, Ansoor
Bolampatti	Maruthamalai and adjoining areas, Poondi North, Thevarayapuram, Kembanur
Mettupalayam	Tan India Saragam
Periyanayakanpalayam	Govanur, Nathukadu, Moolakadu, Neelampalayam, Nanjundapuram
Sirumugi	Sedayurvayal, Thekampatti, Nellithurai

Nanjundapuram, Periya Thadagam and Anaikatti in Coimbatore forest division have been considered for the study. The developed analytical procedure has been applied for seasonal elephant migration data of 20 years (1990–2010) obtained from Coimbatore forest division.

A Markov chain is a finite process that models a sequence of events that have a fixed number of states and their specified probabilities. Given the present state, the future depends on the present state and is independent of the past states[16]. At each step the system may change its state from the current to another state, or it may stay in the same state according to a probability distribution. These changes of state are called transitions, and the probabilities that are associated with various state changes are called transition probabilities. In simpler terms, a Markov chain is just a random process or series of events that occur by chance and evolve in time with different probabilities[17]. These random processes or series do not depend on future or past states.

A Markov chain is a stochastic process that satisfies the Markov property

$$P(X_{t+1} = S_j \,|X_t = S_{i,t}, X_{t-1} = S_{i,\,t-1},\ldots, X_0 = S_{i,0}) = P(X_{t+1} = S_j \,|X_t = S_{i,\,t}), \quad \text{for each } t = 0, 1, 2, 3\ldots. \tag{1}$$

We can think of a Markov chain as a random chain of events that occur at discrete points $t = 0, 1, 2, 3\ldots$ in time, where X_t represents the state the system is in at time t, as given in eq. (1). Markov chains have states $S \in \{1, 2, \ldots, n\}$, where n is finite. The starting state s_0 may be fixed or determined by a prior distribution $P_0(s_0)$. The system transitions from the current state s_t to the next state s_{t+1} and the transitions satisfy the first-order Markov property $P(s_{t+1}|s_t, s_{t-1},\ldots, s_0) = P_1(S_{t+1}|s_t)$. This resulting system generates a sequence of states $s_0 \to s_1 \to s_2 \to s_3 \to \ldots$, where s_0 is from $P_0(s_0)$ and s_{t+1} is from $P_1(s_{t+1}|s_t)$. This stochastic nature of the Markov chain results when the system decides randomly which state to move to next. Markov chains are typically represented in terms of transition probability matrices and state diagrams. Markov modelling has been used for many real-time world applications, such as study of pattern of occurrence of rainfall, pattern of economic recession, etc.[16,18]. Here, a three-stage Markov model is used to determine the probability of elephant movement from one village to another[18]. The values of the derived probabilities assist in determining the habitat and migration behaviour of elephants during various seasons. The corridors in the forest border areas which the elephants cross during migration to enter human habitation could be easily identified using the derived information. The model is used to find the probability of elephants habituating in one region.

The following assumptions have been made for migration analysis:

(1) The whole year is divided into four different periods, viz. wet season (1 October–28/29 February), wet to dry season (1–31 March), dry season (1 April–31 August) and dry to wet season (1–30 September).
(2) Elephants stay in a corridor if they spend the entire day in that corridor only.
(3) Elephants migrate between habitats if they do not spend an entire day in a corridor.

For example, elephants migrating between Periya Thadagam and Somayanur village border stay in the Periya Thadagam corridor.

Analytical procedure

The data observed over time can be regarded as a three-state Markov chain with state space $S = \{\text{P, A, N}\}$, where P denotes Periya Thadagam, A denotes Anaikatti and N denotes Nanjundapuram. The equation for transition probability of corridors is given by

$$P = P_{ij} = P\ (j/i), \qquad \text{where } i, j \in S. \tag{2}$$

For the three-state Markov chain approach[18], we require the values of P_{ij} (i, j = P, A, N) and these values can be estimated from the frequency table whose entries are derived using observed values as given in Table 2 .

In Table 2, N_{ij} (i, j = P, A, N) is the observed number of elephants in either of these corridors, where N_{ij} is the number of observations in state i at time t and j at t_1, i.e. $N_{\text{PP}} = N(\text{P}|\text{P})$, the number of elephants habituating in Periya Thadagam, having been in that village; $N_{\text{PN}} =$

N(P|N), the number of elephants migrating from Periya Thadagam to Nanjundapuram; $N_{PA} = N(P|A)$, the number of elephants migrating from Periya Thadagam to Anaikatti, and so on.

$$N_{PP} + N_{PN} + N_{PA} = N_{P*},$$

where N_{P*} is the total number of elephants habituating in Periya Thadagam.

Similarly,

$$N_{NP} + N_{NN} + N_{NA} = N_{N*},$$

where N_{N*} is the total number of elephants habituating in Nanjundapuram, and

$$N_{AP} + N_{AN} + N_{AA} = N_{A*},$$

where N_{A*} is the total number of elephants habituating in Anaikatti. Three habitats taken up for analysis are represented as a three-state Markov chain, as shown in Figure 2. The maximum likelihood estimators of P_{ij} (i, j = P, A, N) are given by $P_{ij} = N_{ij}/N_{i*}$ where $P_{PP} = P(P|P)$ is the probability of elephants habituating in Periya Thadagam preceded by a day at the same village; $P_{NP} = P(P|N)$ is the probability of elephants migrating to Periya Thadagam preceded by a day at Nanjundapuram. $P_{AN} = P(N|A)$ is the probability of a elephant migrating to Nanjundapuram preceded by a day at Anaikatti and so on. The transition probability matrix is shown in Table 3.

Table 2. Observed frequency table

Current day	Habitat	Next day PT	NP	AK	Total
	PT	N_{PP}	N_{PN}	N_{PA}	N_{p*}
	NP	N_{NP}	N_{NN}	N_{NA}	N_{n*}
	AK	N_{AP}	N_{AN}	N_{AA}	N_{a*}

Table 3. Transition probability matrix

Current day	Habitat	Next day PT	NP	AK
	PT	P_{PP}	P_{PN}	P_{PA}
	NP	P_{NP}	P_{NN}	P_{NA}
	AK	P_{AP}	P_{AN}	P_{AA}

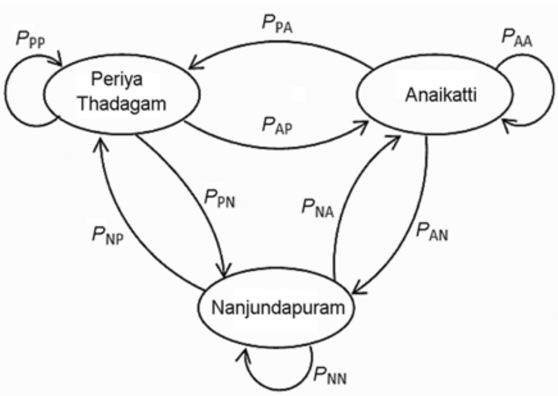

Figure 2. Three-state Markov chain representation.

The steady-state probabilities $\{\pi_1, \pi_2, \pi_3\}$ are calculated as

$$\pi_1 = \frac{(be-cf)}{(ab-cd)},\ \pi_3 = \frac{(af-de)}{(ab-cd)}, \pi_2 = 1-\pi_1-\pi_3, \quad (3)$$

where $a = (P_{PP} - 1 - P_{NP})$, $b = (P_{AP} + 1 - P_{NN})$, $c = (P_{AP} - P_{NP})$, $d = (P_{PN} + 1 - P_{NN})$, $e = -P_{NP}$ and $f = (1 - P_{NN})$.

Expected length of different spells of migration

A Periya Thadagam spell 'P' is defined as a sequence of consecutive days of elephants habituating in Periya Thadagam preceded and followed by a day at Anaikatti or Nanjundapuram. The probability of habituating in Periya Thadagam is given by

$$P(\mathrm{P}) = (P_{PP})^{\mathrm{P}-1}(1 - P_{PP}), \quad (4)$$

and expected length of the Perilya Thadagam spell is (i.e. the number of days the elephants will stay in Perilya Thadagam)

$$E(P) = (1 - P_{PP})^{-1}. \quad (5)$$

A Nanjundapuram spell of length 'N' is defined as a sequence of consecutive days of elephants habituating in Nanjundapuram preceded and followed by a day at Anaikatti or Periya Thadagam. The probability of habituating in Nanjundapuram is given by

$$P(\mathrm{N}) = (P_{NN})^{\mathrm{N}-1}(1 - P_{NN}), \quad (6)$$

and expected length of the Nanjundapuram spell is

$$E(N) = (1 - P_{NN})^{-1}. \quad (7)$$

An Anaikatti spell of length 'A' is defined as sequence of consecutive days of elephants habituating in Anaikatti preceded and followed by a day at Nanjundapuram or Periya Thadagam. The probability of habituating in Anaikatti is given by

$$P(\mathrm{A}) = (P_{AA})^{\mathrm{A}-1}(1 - P_{AA}), \quad (8)$$

and expected length of the Anaikatti spell is

$$E(\mathrm{A}) = (1 - P_{AA})^{-1}. \quad (9)$$

Migration cycle (MC) is given by

$$E(\mathrm{MC}) = E(\mathrm{P}) + E(\mathrm{A}) + E(\mathrm{N}). \quad (10)$$

The number of days (N) after which the equilibrium state is achieved is equal to the number of times the matrix 'P' is powered till the elements of a column of the matrix $P^{(N)}$ become equal.

Thus, the nth power of the transition matrix P is the n-step transition matrix for the chain P. Matrix P is shown in eq. (11).

$$P^{(N)} = \begin{bmatrix} \pi_1 & \pi_2 & \pi_3 \\ \pi_1 & \pi_2 & \pi_3 \\ \pi_1 & \pi_2 & \pi_3 \end{bmatrix}, \quad (11)$$

where π_1 is the probability of an elephant habituating in Periya Thadagam, π_2 the probability of an elephant habituating in Nanjundapuram and π_3 is the probability of an elephant habituating in Anaikatti. The values of the derived probabilities assist in determining the habitat and migration behaviour of elephants during various seasons. The corridors in the forest border areas which the elephants cross during migration to enter the human habitation could be easily identified using the derived information.

Hardware implementation

We have developed a hardware to be implemented in specific pockets identified based on the analytical results along the forest border areas where the elephants can intrude from the forest into human habitation. This work aims at providing a viable solution for the elephant intrusion problem persisting in the forest border areas due to the migration of the animals. The block diagram of the system is shown in Figure 3. The hardware set-up consists of geophone string, threshold comparator with amplification module, embedded microcontroller, GSM and the power supply. The footfall of the elephant produces a vibration in the ground which is sensed by the geophones[19,20] that are buried underground, as shown in Figure 4. Each individual sensor has ground signal coverage range with radius of about 24 m. The geophone generates an electrical signal of small voltage (mV) when an vibration is sensed. The output of geophone is amplified and compared with a threshold value which is set according to the voltage caused by the vibrations produced by a single elephant in a specified range. When the ground vibration generated by the footfall of an elephant exceeds the threshold, it creates an event for the embedded controller through an interrupt.

On reception of the interrupt, the embedded controller sends a warning message in the form of SMS using GSM transceiver unit to the forest officials. The geophones have a wide coverage range of about 120 m^2, when connected as a string of five geophones and are useful in tracking the entire passage of the herds in order to detect their movements. The elephant corridors are identified and these devices are installed to monitor the movement of these herds. This in turn saves both human and elephant lives.

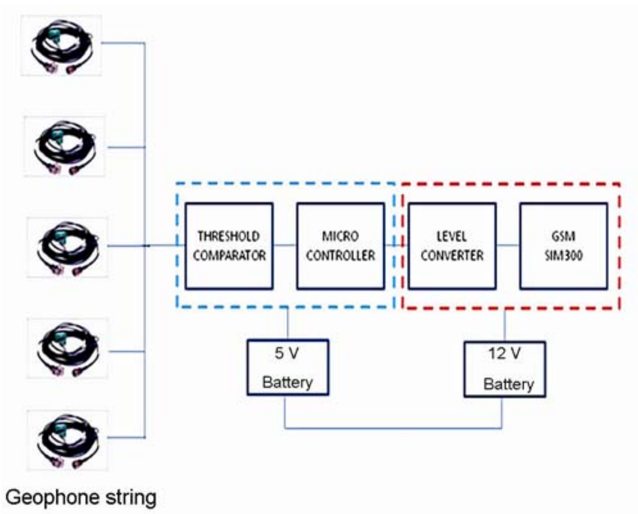

Figure 3. Block diagram of the proposed system model.

Field observations

A field visit was carried out in Kolikombu elephant camp in Topslip, Tamil Nadu. The Environment and Forest (FR.5) Department G.O. (D) No. 181 dated: 02.08.2011 reports, 'The Coimbatore Institute of Technology (CIT) has developed an electronic early warning system using the GPRS technology using the principles of embedded seismic sensor network. It has been demonstrated by the engineers of the institution and working well. It is proposed to install this technology at 10 important locations in Coimbatore Forest division at cost of Rs 7.5 lakhs'[21] (The work was reported in *The Hindu*, 30 July 2010). The geophone detection under actual forest conditions was studied (Figure 5). The procedure was followed for elephants of two different weights – 4 tonne and 570 kg. The

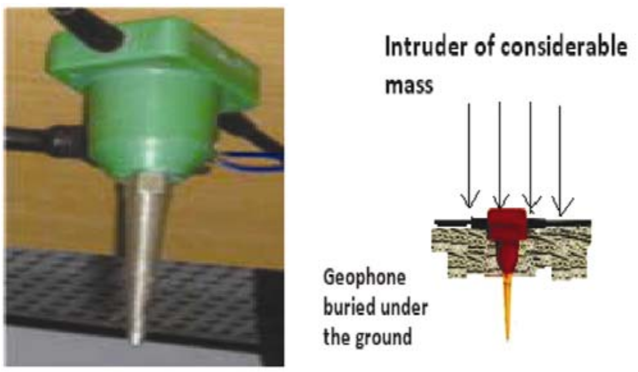

Figure 4. Geophone and buried geophone under the ground.

circle in Figure 5 shows the buried geophone in the ground.

The output of the geophone was of the order of millivolts. The output voltage corresponding to the varying distances from the point of the buried geophone sensor was measured and presented in Table 4.

When an elephant of weight 570 kg is close to the buried geophone, the maximum voltage output of the sensor is observed to be 9.7 mV and at a distance of 15 m the output voltage is 6.8 mV. Similarly, for a bigger elephant of 4 tonne, when it is close to the buried geophone the maximum voltage output of the sensor is observed to be 16.3 mV and at a distance of 15 m the output voltage is 10.8 mV. The voltage generated by the geophone due to vibration resulting from an elephant walk was observed. Response signals were digitized using sound forge software. Each response record is 10,000 samples long. Figure 6 shows the recoded geophone step response. The peak amplitude was obtained when the elephant walked over the buried geophone. Due to the amplitude difference between front and rear footfalls in elephants, only the former are considered. A peak voltage of 16.3 mV was obtained when the elephant walked over the buried geophone and the signal lasted for 0.2 sec.

Figure 5. Testing carried out in the elephant camp.

Table 4. Sensor output for elephant

Distance from the point of the buried sensor (m)	Sensor output (mV)
570 kg elephant	
15	6.8
10	7.7
05	8.1
00	9.7
4 tonne elephant	
15	10.8
10	13.2
05	14.7
00	16.3

Species classification using feature vectors

We classify footfall signals of four different species using audio signal processing technique. Audio signal processing[22] methods that are applicable for detection and classification purposes consist of extracting relevant features from the sound pattern and using these features to identify and classify them into a class to which the sound is most likely to fit, among a set of classes. Figure 7 shows the process followed in audio classification implemented in this work.

The four types of species used for classification are elephant, lion, gemsbok and human. The signal patterns of geophone output of these four species are generated, converted to an audio wave file and stored. These audio files in the form of .wav are given to classifiers for signal feature extraction from time series audio data recorded. The audio feature vectors chosen in this work are energy entropy, zero crossing rate (ZCR) and spectral centroid[23,24]. For signal classification, Mahalanobis distance method is adopted.

Energy entropy

Every audio signal has a positive and negative peak and the average of the positive and negative peaks is the energy entropy; it is never the same for any two audio signals. It is a measure of abrupt changes in the energy level of an audio signal. It is computed by dividing each

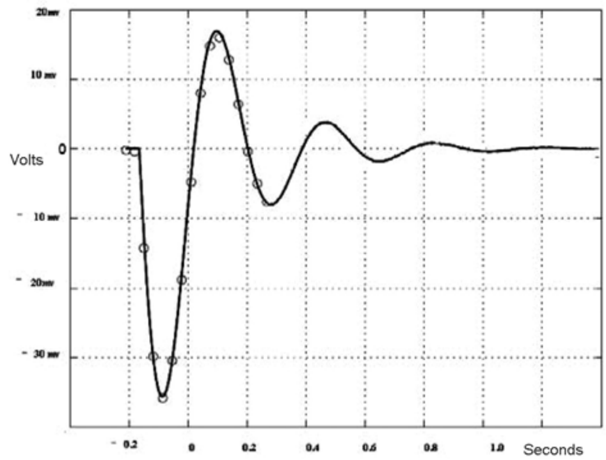

Figure 6. Geophone step response.

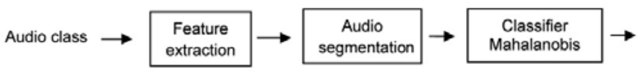

Figure 7. Feature extraction and classification.

audio frame into K sub-windows of fixed duration. For each sub-window K, the normalized energy σ^z is calculated, which is the energy of the sub-window, divided by the energy of the whole frame

$$\sigma^z = \frac{E_{\text{Subframe}}}{E_{\text{Shortframe}}}.$$

Therefore, σ^z is a sequence of normalized sub-frame energy values and it is computed for each frame. Next, the entropy of this sequence is computed[24] using eq. (11). K is chosen to be 80.

$$H = -\sum_{i=0}^{K-1} \sigma^2 \log_2 \sigma^2. \tag{12}$$

Zero crossing rate

This is a measure of how often the sound signal crosses from positive to negative or vice-versa. ZCR would be a good technique for finding the frequency of sign reversals (f_0), since a sinusoid will cross the zero line twice per cycle and hence ZCR should be exactly $2f_0$. It also became clear that ZCR is useful for extracting features other than f_0, such as spectral content and noise content. ZCR is given by

$$\text{ZCR} = \frac{1}{N}\sum_{n=1}^{N-1} \frac{|\operatorname{sgn}[x(n)] - \operatorname{sgn}[x(n-1)]|}{2}, \tag{13}$$

where sgn (.) is the sign function, i.e. $\operatorname{sgn}[x(n)] = +1$ if $x(n) \geq 0$ and -1 if $x(n) < 0$. The average value of the feature sequence was computed as the final feature value.

Spectral centroid

The spectral centroid is a measure to characterize an audio spectrum. It indicates where the 'centre of mass' of the spectrum is. It is calculated as the weighted mean of the frequencies present in the signal, with their magnitudes as the weight. The spectral centroid C_i, of the ith frame is defined as[24]

$$C_i = \frac{\sum_{k+1}^{N} (k+1) X_i(k)}{\sum_{k+1}^{N} X_i(k)}, \tag{14}$$

where $X_i(k)$, $k = 1\ldots., N$ are the Discrete Fourier Transform (DFT) coefficients of the ith short-term frame and N is the frame length. The process of feature extraction and signal classification[25] is shown in Figure 8.

In classification the aim is to find if there is any important difference between the distributions of two consecutive windows. This is done by measuring the distance between the distributions of a pair of windows at a time. The similarity measure discussed in this work is based on the Mahalanobis distance[26]. The Mahalanobis distance is given by

$$\sqrt{D}_i = \sqrt{(x-\mu_i)^T \sum_i^{-1} (x-\mu_i)}, \tag{15}$$

where

$$\sum_i^{-1} (x-\mu_i)$$

represents the inverse of the covariance matrix of class $\{I\}$. The Mahalanobis distance is a weighted Euclidean distance where the weight is determined by the range of variability of the sample point; expressed by the covariance matrix. The distance measure for features is of critical importance for all classification methods. For K different classes S_w is a measure of the average variance of the features over all classes.

$$s_w = \sum_{k=1}^{K} p(\omega_k) C_k, \tag{16}$$

where C_k is the covariance matrix for class k and $p(\omega_k)$ is the prior probability of the class ω_k, i.e., $p(\omega_k) = N_k/N$, where N_k is the number of samples from class ω_k (of total N samples).

Results and discussion

We have designed, tested and implemented the hardware module for intrusion detection. The placement of the sensors is decided based on the analytical model. The hardware module is implemented such that the sensors at the edge of the sensing field will detect the species once

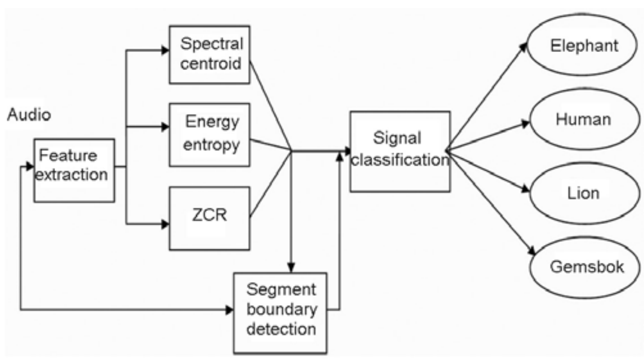

Figure 8. Classification of species.

they enter the sensing range. The sensor output is recorded as an audio signal in the form of a wave file. Figure 9 shows the simulation layout of the sensing field. The dots represent the sensors and the line represents the moving track of the species. A square topology of 50 m × 50 m is considered for simulation. Fifty sensors are randomly placed in the sensing field.

During run time a random species signal is generated and converted to audio signal, and the type of species is determined using the classification process and the classified output is displayed. In Figure 9, the classified output shows that the detected species is an elephant. Similar classification runs are made for all species and tested. The output of the classifier displays the detected species class as an elephant. Simulations are performed for analysing the accuracy percentage of the classifier under actual test conditions. Each class of the footfall signal pattern based on Wood *et al.*[27] was generated using Matlab. Data collection process is carried out for four different species – elephant, lion, gemsbok and human. The footfall signals are processed with the length of the samples taken as 6 sec. The test signals are applied to the classifier and the results are compared against their actual audio signal source to calculate the accuracy percentage. For the feature calculation the signal is divided into K time-windows (frames) of predefined duration S, and for each one of them we calculate the frame-level features. In order to calculate the energy entropy for each sub-window K, the normalized energy is calculated. The energy entropy expresses abrupt changes in the energy level of the audio signal of the four species, as shown in Figure 10. The value of the energy entropy is small for frames with large changes in energy level. We extracted features of species with the signals generated which are characterized by sudden energy transitions in a short time-period.

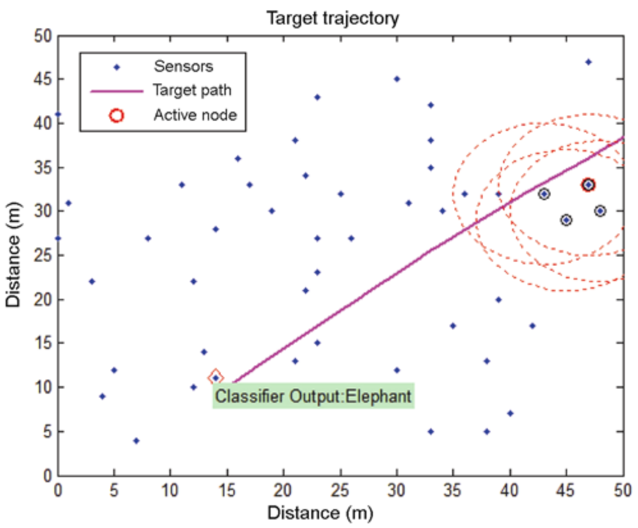

Figure 9. Target and classifier result.

This becomes obvious from Figure 10, where the energy entropy of elephant is high with smaller changes in energy level in a short-time period and the gemsbok produces smaller energy entropy as it shows larger changes in energy level with higher time-period, as presented in eq. (12).

ZCR is calculated by the number of time-domain zero-crossings, divided by the number of samples in the frame. In Figure 11, the ZCR sequences for audio segments of the four species are presented.

It is obvious that the plot justifies that human signal has more ZCR and the elephants have lesser ZCR. ZCR for elephant was in the range 0.2–0.3, whereas for humans it was in the range 1.2–1.4.

The centroid is a measure of the spectral shape and higher centroid values correspond to high frequencies. Higher centroid values are found with gemsbok and human in the range of 0.05 kHz, whereas an elephant has lesser centroid value in the range 0.012 kHz. It is clear that the centroid values for elephants are lesser as their footsteps produce spectra in the lower frequency range. The spectral centroid is computed using eq. (14). The

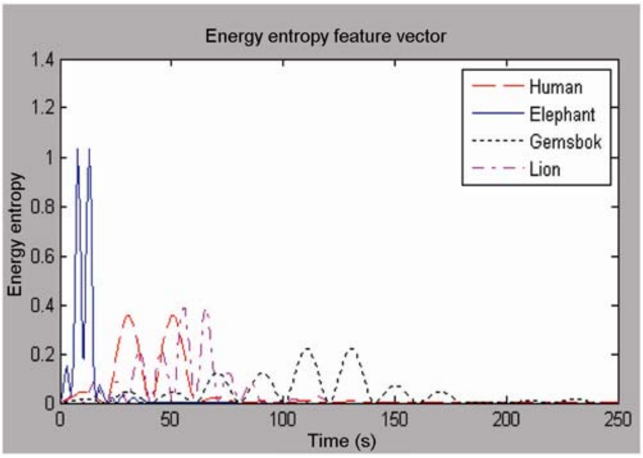

Figure 10. Energy entropy sequences of signals for four species.

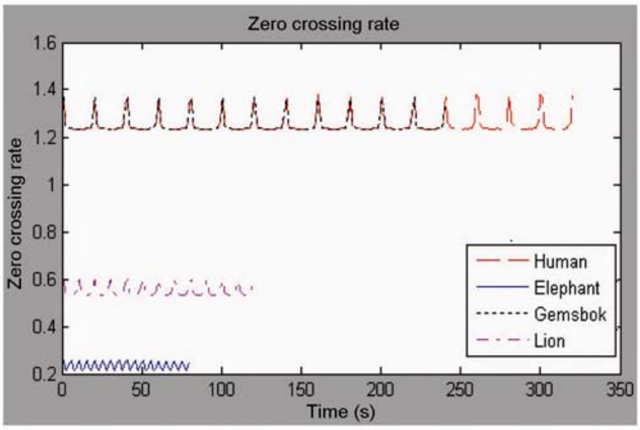

Figure 11. Zero crossing rate of signals for the four species.

spectral centroid for the four classes species is depicted in Figure 12.

A comparison of the feature vectors is presented in Table 5. It shows that all the features of elephant are different and unique. From these results it is clear that the extraction of elephant signals is accurate. The footfall signal pattern can be detected by the system accurately and an SMS about the intrusion of elephants into human habitation can be sent to the forest officials to take necessary action.

Classifier performance analysis

The classification part deals with classifying data based on the statistical information extracted from the signals using Mahalanobis classifier technique[26]. For testing purpose, the test signals are applied to the classifier and the results are compared against their actual audio signal source to calculate the accuracy percentage. The classifier is tested using four test audio signals of each species. Twenty test signals were generated and the classified output was found to be 18 audio samples from the elephant category, 19 from human category, 17 from gemsbok category and 17 from lion category. Table 6 shows the classification output against the actual test signals. The individual accuracy percentage for the four species is shown in Table 6 and total accuracy percentage is found to be 91.25. Thus the classifier will classify the test signals to any of the species based on this pattern.

Computation of the steady-state migration probability

In this work the steady-state probability for the movement of elephants from one region to another along the forest border areas has been determined. Elephant migration between in three villages around the forest border areas was analysed. The daily elephant migration data for 20 years from 1 January 1990 to 31 December 2010 was collected from the Coimbatore forest division. The estimated transition probability matrices for daily migration data are given in Table 7.

The expected number of days of stay in a habitat and migration cycles for the three areas were calculated (Table 8). The results are shown in Figures 13 and 14. From Figure 13 it can be observed that an elephant arriving at Periya Thadagam stays there for 4 days during the wet season and for 5 days during the dry to wet season. An elephant arriving at Nanjundapuram stays for 4 and 2

Table 5. Feature statistics

Feature	Statistics: Elephant	Human	Lion	Gemsbok
Energy entropy	1	0.38	0.4	0.2
Zero crossing rate	0.22/75	1.2/325	0.6/120	1.2/250
Spectral centroid (kHz)	0.012	0.05	0.025	0.05

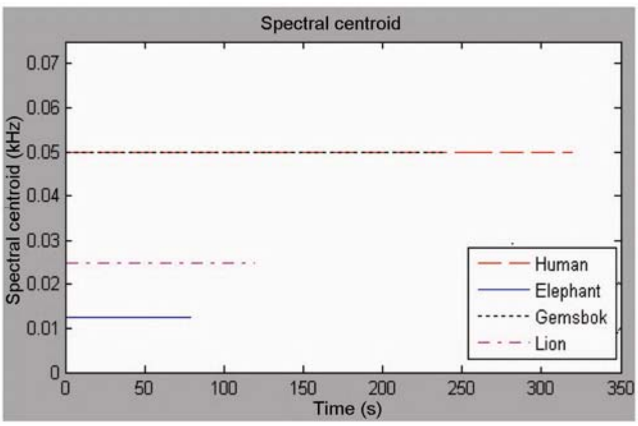

Figure 12. Spectral centroid of signals for the four species.

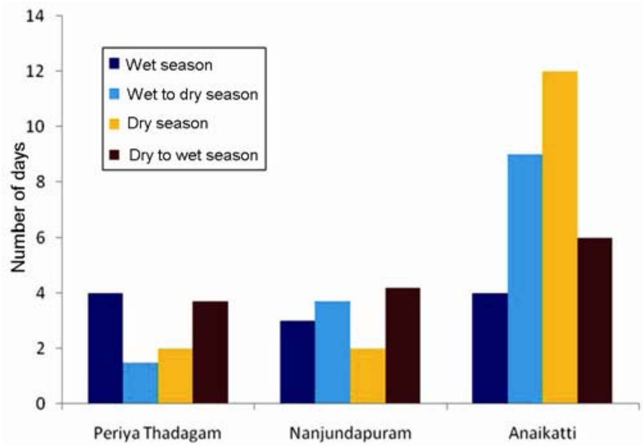

Figure 13. Expected number of days of stay in a habitat.

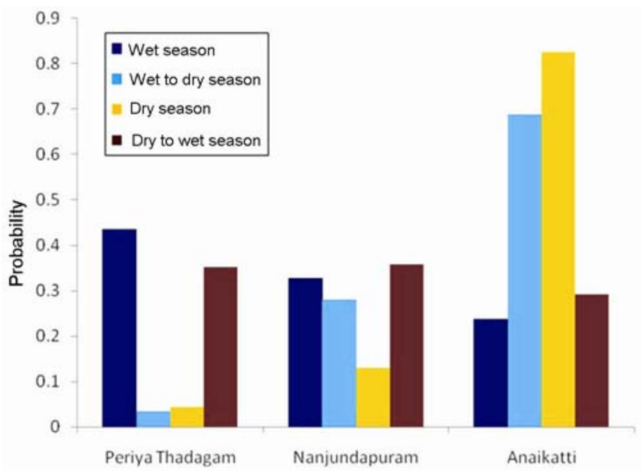

Figure 14. Probability of staying in a habitat.

Table 6. Classification accuracy percentage

Classified output versus actual test signal	Actual test signal: Elephant	Human	Gemsbok	Lion
Classification output				
Elephant	19/20	2/20	4/20	1/20
Human	3/20	19/20	2/20	1/20
Gemsbok	1/20	2/20	17/20	2/20
Lion	4/20	2/20	4/20	18/20
Individual accuracy percentage	95	95	85	90
Total accuracy percentage		91.25		

Table 7. Migration probability during different seasons

P_{ij}	Transition probability matrix: *P*	*N*	*A*
Dry to wet season			
P	0.2550	0.4540	0.2910
N	0.0297	0.7195	0.2508
A	0.0240	0.0920	0.8840
Dry season			
P	0.7510	0.1438	0.1053
N	0.2592	0.6592	0.0815
A	0.0984	0.2073	0.6944
Wet season			
P	0.4686	0.2804	0.2509
N	0.0387	0.5089	0.4523
A	0.0220	0.0621	0.9159
Wet to dry season			
P	0.7383	0.1593	0.1024
N	0.1837	0.7624	0.0539
A	0.0900	0.0991	0.8108

days during the wet to dry and at dry season respectively. Elephants migrate to another fragment within 3 and 2 days during the wet and dry to wet seasons respectively. An elephant arriving at Anaikatti stays for 8 days during the wet to dry season and 12 days during the dry season. Elephants migrate to another fragment within 4 days in the wet season and 5 days in the dry to wet season. From Figure 14, we observe that elephants prefer to stay in Periya Thadagam and Nanjundapuram during wet and dry to wet seasons only. During the dry and wet to dry seasons, they prefer to migrate to Nanjundapuram and Anaikatti. Elephants were observed in Periya Thadagam in the dry and dry to wet seasons.

Based on daily migration data, equilibrium state probabilities π_1, π_2, π_3 and the number of days of habituating at Periya Thadagam, Anaikatti or Nanjundapuram are given in Table 8. On the basis of these values obtained, it is observed that:

(1) On an average when an elephant stays in Periya Thadagam for one day, the number of days it stays at Anaikatti for the four seasons are 1, 11, 18 and 1 days respectively. Similarly, the number of days it stays at Nanjundapuram are 1, 5, 3 and 1 respectively.

(2) On an average when an elephant stays in Nanjundapuram for one day, the number of days it stays at Anaikatti for the four seasons are 1, 3, 1 and 1 respectively. Similarly, the number of days it stays at Periya Thadagam are 2, 1, 7 and 1 respectively.

(3) On an average when an elephant stays in Anaikatti for one day, the number of days it stays at Periya Thadagam for the four seasons are 2, 1, 1 and 2 respectively. Similarly, the number of days it stays at Nanjundapuram are 2, 1, 1 and 2 respectively.

Conclusion

An analytical model has been developed to study the behaviour of elephants along forest border areas. In this study, the elephant migration in three villages around the forest border areas is analysed. The daily elephant migration data for 20 years from 1 January 1990 to 31 December 2010 were collected from the Coimbatore forest division. The observed data were analysed and the maximum number of days the elephants stay in Anaikatti during the dry season was observed to be 12. It was also observed that the elephants prefer to stay in Anaikatti during all seasons than in the other areas. The lowest habituating area was found to be Periya Thadagam and this area is used for migration between seasons. Therefore, the developed warning system should be used more in Anaikatti area and early warning SMS can be sent to the forest officials to take necessary action to prevent human–elephant conflicts. The early warning system is a solution to detect elephant movement without affecting the ecological conditions to overcome human–elephant conflict. The unpredictability of time and location of elephant arrival into the villages are considered the major issues that is resolved in this work. Field observations show that the proposed method can be used as an accurate multi-class classification scheme to detect elephants in the forest border areas, even in the presence of different animal species. The overall performance of the multiclass classification system was found to be 91.25%. This is a

Table 8. Probability, expected length of different spells, migration cycle (MC) and equilibrium state

Season	π_1	π_2	π_3	Periya Thadagam run	Nanjundapuram run	Anaikatti run	MC	*N*
Dry	0.4349	0.3278	0.2373	5	3	4	11	22
Dry to wet	0.0333	0.2793	0.6874	2	4	9	14	21
Wet	0.0437	0.1295	0.8268	2	3	12	16	15
Wet to dry	0.3510	0.3572	0.2918	4	5	6	14	25

N, The number of days to reach equilibrium state.

high classification performance, taking into account the number of classes and the fact that some classes are quite similar. This system has been rigorously tested throughout various phases of the project and was found to be efficient.

1. Lenin, Janaki and Sukumar, R., Action plan for the mitigation of elephant–human conflict in India. Asian Nature Conservation Foundation, Indian Institute of Science, Bangalore, March 2011.
2. Fernando, P., Ananda Kumar, M., Christy Williams, A., Wikramanayake, E., Aziz, T. and Singh, S. M., Review of human–elephant conflict mitigation measures practiced in South Asia. (AREAS technical support document submitted to World Bank), WWF-World Wide Fund for Nature, 2008.
3. King, L. E., Lawrence, A., Douglas-Hamilton, I. and Vollrath, F., Beehive fence deters crop-raiding elephants. *Afr. J. Ecol*., 2009, **47**, 131–137.
4. Singh, A. P. and Chalisgaonkar, R., Restoration of corridors to facilitate the movement of wild Asian elephants in Rajaji–Corbett elephant range, Irrigation Department, India, May 2006.
5. Loarie, S. R., Van Aarde, R. J. and Pimm, S. L., Fences and artificial water affect African savannah elephant movement patterns. *Biol. Conserv*., 2009, **142**, 3086–3098.
6. Venkataraman, A. B., Saandeep, R., Baskaran, N., Roy, M., Madhivanan, A. and Sukumar, R., Using satellite telemetry to mitigate elephant–human conflict: an experiment in northern West Bengal, India. *Curr. Sci.*, 2005, **88**, 1827–1831.
7. Wijesinghe, L. *et al*., Electric fence intrusion alert system (eleAlert). In Global Humanitarian Technology Conference, IEEE Conference, Seattle, WA, 2011, pp. 46–50.
8. Hao, Q., Brady, J., Guenther, B. D., Burchett, J. B., Shankar, M. and Feller, S., Human tracking with wireless distributed pyro electric sensors. *IEEE Sensors J.*, 2006, **6**, 1683–1696.
9. Mainwaring, A. and Polastre, J., Wireless sensor networks for habitat monitoring. In WSNA'02, Atlanta, Georgia, USA, 28 September 2002.
10. Juang, P., Oki, H., Wang, Y., Martonosi, M., Peh, L. and Rubenstei, D., Energy-efficient computing for wildlife tracking: design trade-offs and early experiences with ZebraNet. In Special Issue: Proceedings of the 10th Annual Conference on Architectural Support for Programming Languages and Operating Systems, San Jose, CA, December 2002, vol. 30.
11. Graham, M. D., Adams, W. M. and Kahiro, G. N., Mobile phone communication in effective human–elephant conflict management in Laikipia County, Kenya. *Oryx*, 2012, **46**, 137–144.
12. http://www.coimbatoreforests.org
13. Graham, M. D., Notter, B., Adams, W. M., Lee, P. C. and Ochieng, T. N., Patterns of crop-raiding by elephants, *Loxodonta africana*, in Laikipia, Kenya, and the management of human–elephant conflict. *Syst. Biodiver.*, 2010, **8**, 435–445.
14. Hedges, S. and Gunaryadi, D., Reducing human–elephant conflict: do chillies help deter elephants from entering crop fields? *Oryx – Int. J. Conserv.*, 2009, **44**, 139–146.
15. www.humanelephantconflict.com
16. Holt, K., An application of Markov chains. In Mathematics Senior Seminar 4901, University of Minnesota, Morris Spring, USA, 2010.
17. Dastidar, A. G., Ghosh, D., Dasgupta, S. and De, U. K., Higher order Markov chain models for monsoon rainfall over West Bengal, India. *Indian J. Radio Space Phys*., 2010, **39**, 39–44.
18. Garg, V. K. and Singh, J. B., Three-state Markov chain approach on the behaviour of rainfall. *N. Y. Sci. J*., 2010, **3**, 76–81.
19. Hons, M., Stewart, R., Lawton, D. and Bertram, M., Ground motion through geophones and MEMS accelerometers: sensor comparison in theory, modelling and field data. CREWES Project, Society of Exploration Geophysicists, University of Calgary, 2007.
20. Chandler, G. J., Izmirli, O., O'Connell-Rodwell, C. and Wood, J., Elephant Censusing via Geophone Arrays: A Visual Approach for Linear Arrays, In Proceedings of Asilomar Conference on Signals, Systems and Computers, California, USA, 2009, pp. 1159–1163.
21. http://www.tn.gov.in/gosdb/gorders/eandf/eandf_e_181_2011_D.pdf.
22. Gerhard, D., Audio signal segmentation, School of Computing, Simon Fraser University, Canada, February 2000, pp. 28–40.
23. Breebaart, J. and McKinney, M. F., Features for audio classification. In Algorithms Ambient Intelligence, Springer, Netherlands, 2004, pp. 113–129.
24. Omar, A. H., Audio segmentation and classification, Master's thesis, Technical University of Denmark, DTU, Kogens Lyngby, February 2005, pp. 42–48.
25. Lu, L., Zhang, H.-J. and Jiang, H., Content analysis for audio classification and segmentation. *IEEE Trans. Speech Audio Process.*, 2002, **10**, 504–516.
26. Wölfel, M. and Ekenel, H. K., Feature weighted Mahalanobis distance: improved robustness for Gaussian classifiers. In 13th European Signal Processing Conference, Antalya, Turkey, 2005.
27. Wood, J. D., O'Connell-Rodwell, C. E. and Klemperer, S., Using seismic sensors to detect elephants and other large mammals: a potential census technique. *J. Appl. Ecol*., 2005, **42**, 587–594.

ACKNOWLEDGEMENTS. We thank Tamil Nadu Forest Department and Mr I. Anwardeen, DFO for providing permission to visit forest and sponsoring the work.

Received 18 July 2012; revised accepted 21 March 2013