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Automated Virtual Elephant Fence Based on Detection, Alarming and Coordinated Repulsion of Wild Elephants

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Abstract

Within the backdrop of almost total failure of the conventional and physical fence with the number of deaths due to human-elephant conflict and elephant-train collision are of at a higher it is well clear that the belief that it is a myth that management of the problem needs novel approaches. The elephant is a giant and intelligent animal, who is observed to be learned through experience may not be confined to an area using a physical barrier, mostly built even not considering the age-old elephant passes. Hence the human habitats including highways should be pre-planned as per an overall strategy so that natural resources strategically assigned for each party so that the natural habitat is least disturbed. Hence envisage the requirement of a virtual elephant fence as a part of the aforesaid carefully designed overall strategy to make the elephant be warned that an area is not appropriate to be or best for the safety of the herd. The present study involved in-depth experimentation of intra-stimuli on real elephants and known elephant responses to such stimuli with anticipation. The proposed is an autonomous system that detects the presence of elephants, alarms the concerned, and coordinatively and tactically repels animals back to safer areas. The resulting insight may perhaps lay the basis for a novel management approach towards the human- elephant conflict and elephant-train collisions.

Introduction

The Human-Elephant conflict (HEC) affects many regions of the world such as South Asia, South East Asia and Africa where the species lives in the wild. The elephants in Asia (Elephas maximus) tend to approach human habitats in search of food and may roam around within villages during dry season, where fresh leaves and fruits are seasonally rare at jungle areas. It was also found that they are also attracted to crops in fields. Furthermore, during wet season elephants tend to use minor or abandoned roads as convenient routes for their movement. As a result, probability of elephant encroachment into villages and resulting damages to humans and property are enormous in such areas. In this context, wildlife managers and the concerned are in need of non-invasive technologies that can repel elephants from human areas. It includes electric fence (Kioko, 2008), relocation (Jarungrattanapong &. Sajjanand, 2012), and sensory stimuli such as sound of bees (Butler, 2016), sound of aerial drones (Duarte, 2018) and tiger growl (Thuppil & Coss, 2016). Infrasonic calls are known to involve in intra-species communication among Asian elephants (Zeppelzauer, & Hensman , 2015) so that carefully selected and exploited infrasonic calls are of paramount important in deterring the species from trespassing.

We endeavored the research within the backdrop of almost total failure of the conventional and physical fence as well as number of deaths due to elephant-train collision are of at a higher rate. Based on the occurrences reported, authors are in the belief that it is a myth that HEC can be totally mitigated merely by a physical fence. The elephant being a giant and intelligent animal, who is

observed to be learnt through experience may not be confined to an area using a physical barrier, mostly built even not considering the age-old elephant passes. Hence authors are in the view that human habitats including highways should be pre-planned as per an overall strategy so that natural resources such as the waterbodies and plant-based resources are strategically assigned for each party so that the natural habitat is not disturbed. At unavoidable circumstances overhead bridges or underways may be accommodated for either party as appropriately to minimize the conflicting conditions. Hence envisage the requirement of a virtual elephant fence as a part of the aforesaid carefully designed overall strategy to make the elephant to be warned that an area is not appropriate to be or best for the safety of the herd. The present study involved in-depth experimentation of intra-stimuli on real elephants and known elephant responses to such stimuli with anticipation. The resulting insight may perhaps lay basis for novel management approach towards the HEC.

Methods

This research was based on the conceptual foundation to utilize elephant own intra-species communication to make them understand of the inappropriateness of an area they may be encroaching into, so that we convince themselves to leave the area. Hence the study was focused on characterizing a virtual elephant fence which is envisaged as an autonomous system that detects the presence of elephants, alarms the concerned and coordinatively and tactically repels animals back to safer areas. The detection is based on image capture by a camera, and image classification utilizing a machine learning algorithm. Alarming is achieved with a global system for mobile (GSM) module controlled by an Arduino based processing platform.

Deterrence is rendered back as directional sound waves from tactically positioned speakers located at carefully selected locations, as per the overall coordinated strategy of repulsion considering the wider area requirements such as elephant passes, habitats and natural resources such as water bodies, which will be determined during the deployment stage. Coordination of aforesaid emitter nodes to direct the elephants back to wilderness is achieved utilizing onboard-mounted radio frequency (RF) modules.

Field Testing

The field testing of the system was conducted at the elephant orphanage, Pinnawala, Sri Lanka, where wild stray elephants are rehabilitated and nurtured pending their returning back to the wild. The facility provided the closest possible opportunity to follow wild elephant responses without prior disturbance due to human presence. Responses of outdoor elephants in groups were monitored upon experimental sensory stimuli emanated from variable distances. Elephant responses considered were, indifference, attention, encounter, and withdrawal following signal perception.

Sound stimuli testing function

The repelling tones may deter Elephants from approaching and in this context the study tested the sounds (Table 1) of airborne drone, Bees and Tiger growl. Elephants communicate through infrasonic waves [6] and effects of infrasonic bursts were also tested. In addition, the sounds emitted by a female elephant leader when it was challenged by the 'mahout' were tested as it

compelled the rest of the herd move towards her. Care was taken not to test the same individual or heard more than once for each sound.

Elephant detection function

The detector node (Figure1) carries out detecting and alarming functions and is integrated in as a single unit. The Detector node carryout the aforesaid functions namely: Image classification using machine learning and Alarming using the GSM module.

The Detector node consists of an IP CCTV which captures the images and transfers it to the processor module for classification. If the classification shows a higher percentage for an Elephant, a pulse will be sent to the alarming unit which sends a series of Short Messages via a GSM module to a mobile number or the Mobile Station International Subscriber Directory Number (MSISDN) of the users. An Infrared (IR) illuminator was utilized to capture images during the dark hours.

Image classification function

Detecting Elephants was achieved using machine learning on Tensorflow. This study used Transfer Learning to retrain an existing image classification model which was trained on the Imagenet. It was trained initially on a Personal Computer (PC). Images of more than 12 categories of wildlife animals were used in addition to elephant's category. This was done to ensure that the detector node can classify between many animals that commonly appear nearby crops such as Bulls.

The camera has a wide-angle image capturing lens but to maximize the range further it was made to rotate 180°. For that purpose, the camera was mounted on a stage which is controlled by a Nema 17stepper motor. In the CCTV camera rotation mechanism, the Nema17 stepper motor is suspended to free from all loads which basically achieved by adding a thrust ball bearing as shown in the figure 2. Here the slight plates can be mounted in any exterior stand which has a base plate. Further the camera rotation limits have been provided externally using the coding. For the protection from weather, aluminum plates have been attached to the stand of the mount with silicon glue pasted on the borders. The Stepper motor is programmed to rotate 180° anticlockwise then 180° Clockwise. 180° angle is divided into 5 sectors and 10 seconds intervals were set between each sector. These intervals were defined to allocate enough time for capturing an image and to classify the captured imaged while the camera's motion is paused. Motor speed was set to 13 rpm for smooth rotation. Since Nema 17 is a bipolar motor, L298n H- bridge module was used to control the stepper motor. 12V output from the solar panel was used to power the motor. 1A constant current was supplied to the motor to achieve the maximum torque possible.

Alarming function

An early warning system was modified alongside the repelling system to warn the relevant authorities about elephant attacks. SIM900 GSM module was used with an Arduino module to send short messages when an elephant is detected. Arduino was connected to the Raspberry Pi which has the image classifier running. SIM900 GSM shield was Communication between the

Arduino and the raspberry pi takes place via the serial Ports. The python script that classifies has been appended with the function of activating the GSM module after an elephant is detected. Arduino was programed to send a particular warning message through the GSM module, and to select the set of mobile numbers it should deliver if it gets a signal from the Raspberry Pi module.

Sound emission function

The emitter node consists of two 8 Ohm 6.5" speakers, two 8 Ohm 4" speakers, modified LA4440 20W amplifier, LA440 amplifier bridge mode 1. The reason to select two speakers is to cater the output impedance of 4 Ohms of the amplifiers. The two speakers are connected parallel and 4 Ohms are achieved. Rather than having a single 4 Ohm speaker the two 8 Ohm speakers increases the omnidirectional range of the sound coverage. When building the emitter node, it was decided to build a speaker box in order to maximize its efficiency for the speaker's specification (Table 2), for that purpose a series of calculations are done according to the following specifications of the speakers.

For the purpose of determining whether the speaker box design should be a sealed or a ported speaker box to Equation (1), was used. If the EBP (Efficiency Bandwidth Product) was less than 50 then a sealed enclosure will be used if above 90 ported enclosure is usually suitable [10].

$EBP = Fs \div Qes$ $EBP = \frac{Fs}{Qes}$

(1)

Where Fs is free air resistance and Qes is driver electrical Q
In order to calculate the EBP values the standard values are used (Table 3)
Therefore,
Mid EBP = 77 / .36 = 213
Woofer EBP = 30 / .26 = 115
Accordingly, a ported enclosure for these speakers is required.

Design Process of Amplifier for the emitter node
When selecting amplifiers off the shelf there exists two forms namely, bridge mode and the stereo mode. Stereo mode amplifiers require two speakers as outputs due to the presence of two channels. In the bridge mode only, a single channel exists, and the power output is high as the resistance is only the effect of the impedance of a single speaker and according to Equation (2), if resistance decreases power increases. Hence a bridge mode amplifier of Power output 20W was selected to emit sounds with a higher intensity.

$$P = \frac{V^2}{R} \quad (2)$$

In this prototype LA4440 is the amplifier element. It has the following significant features [12],

- In-built 2 channels for stereo and mono applications
- Better ripple rejection
- In-built audio muting feature
- At the time of activation, only a small pop noise will occur
- Low distortion (from Low – High frequencies)

Since the Elephants have a hearing range below the human hearing range which is 20Hz, and most of the audio signals were selected from frequencies in infrasonic range (See Table I). Due to these reasons the amplifier should be able to function amplifications even for frequencies below 20Hz. But in its unmodified form the frequency response is as per Figure 5. Fig. 5 shows the amplifier has an effective amplification for low frequencies of 300Hz to 1.5 kHz. However, this does not satisfy the afore mentioned requirements. Furthermore by increasing the capacitance values of (C1, C2), (C3, C4) and (C7,C8) (refer Fig. 4) the frequency response could be shifted to maximize the response for low frequencies. To shift the response the above-mentioned capacitance values were changed and the output signals were monitored utilizing an oscilloscope.
In this case the improvement of 100Hz sinusoidal signal is demonstrated, subjected to the following changes are represented in Fig. 5

- Initial stage: Capacitor values remain as in the Fig. 4.
- Second stage: The capacitors values were increased to C1=1000μf, C2=1000μf.
- Third stage: While keeping C1, C2 values as in second stage the values were increased to C3=1000μf, C4=1000μf.
- Fourth stage: While keeping C3, C4 values as in third stage the values were increased to C7=2000μf, C8=2000μf.
- Fifth stage: While keeping all values as in fourth stage the values were increased to C1=2000μf, C2=2000μf.

The improvement for each frequency was individually monitored via the oscilloscope and it provided clear evidence that the frequency response for low frequency (even 1Hz) response has increased. Hence the amplifier is suitable to amplify sounds in low frequency as much 1 Hz. (refer Fig. 6).

Coordination of the nodes
It has been found out that elephants follow certain paths whist entering areas. Furthermore, the elephants tend to select these paths from elephant corridors and from pocket areas of forests [8]. Therefore, when an elephant or a herd of elephants enter the vicinity of the system, one of main objectives of the study was to direct them towards forest areas or areas where the elephants arrived from (pockets). This is achieved using the coordinated communication between the nodes that was devised from the overall coordinated strategy of repulsion considering the wider area requirements

such as elephant passes, habitats and natural resources such as water bodies, which is purely dependent upon the conditions prevailing at the deployment stage. The RF module nrf24l01 was used to communicate between the nodes.

This detector has a maximum range of 150m therefore, the node is placed at the center of 150m radius half circle to cover an area of 35342.91m2. Average height of an Asian and African elephant is 2.7m and 3.3m [9][11]. Therefore, in this research camera is mounted at a height of 3.5m to capture all height ranges of elephants. Since the maximum range of the detector is 150m, the main emitters must be placed below a distance of 150m. Therefore, main six emitter nodes are placed in 75m distances as shown in Figure where the anticlockwise angle from the center point is 0º, 45º, 90º, 135º and 180º respectively.

The nrf24l01 is a wireless transceiver (transmit and receive) module which is operated in the frequency of 2.4ghz. It is a low cost device with a considerably higher range. The detector provides an output an angle after the detection. Depending on aforesaid result corresponding emitter should be powered on.

Results and Analysis
Statistical analysis of the performance of the tones
The testing was conducted at the Pinnawala Elephant Orphanage, Sri Lanka. The repelling tones and the tones to grasp attention of the elephants were tested on different herds of Elephants to ensure that there is no repetition of the certain tone on the same elephant to avoid the elephant being adhered to it. In general, it was a quantitative study that

involves more than 100 elephants tested as different herds of about 25 elephants in each. The conditions on which the experiments were conducted on day1 and day2 are represented in Table 4, 5 respectively.

The data obtained were based on reactions shown by elephants under an controlled experiment of emissions of audio frequencies rated to, drone sound, tiger growl, bee sound and the low frequency burst. The testing includes four main criteria of reaction that could possibly be shown by the test subjects them being Indifference, Attention, Encounter, and Withdrawal. These criteria were made using observations based on common sense. Indifference is when the elephant shows no reaction to the signal and continues on being in its idle behavior. Attention is the criteria that gets satisfied when the elephant shows some sort of attention due to the signal (this condition was further clarified during the testing by the feedback obtained from the “mahout” or elephant caretakers). Withdrawal is the criteria that is met when the test subject initially shows some fear and backs itself off once the signal is emitted and refrain in approaching. Encounter is when the test subject refrains in withdrawing and tends to approach towards the direction of the signal source.

There was a series of intensity levels emitted throughput the testing for each sound. But it has been omitted here since there was no considerable significant observation between the reactions of the elephants and the sound intensity levels. In the controlled setup it was observed that there was no significant encounter and withdrawal shown by test subjects as the elephants in Pinnawala

orphanage are well adopted to the presence of humans around them. But there was an attention given by a considerable number of elephants. 31 elephants in total 15 showed attention while 16 showed indifference. The sound of the drone had most of the test subjects withdraw and some elephants larger in size to encounter. As per the elephant experts in Pinnawala, this is a result of the larger elephants trying to defend the rest of the herd from the deterrence present. 29 elephants in total, 3 showed attention 15 encounter, 11 withdrawal. The observation for the tiger growl was interesting because at the time the signal was emitted the herd was comparatively far from the source of sound. Once the sound started to be emitted the herd withdrew few feet and huddled up in fear. Once the tiger growl sound was stopped being emitted the whole herd moved towards the emitter node in a mode of encounter. 20 Elephants in total, 3 showed attention, 2 indifference ,5 showed an encounter while 10 showed withdrawal. For the low frequency burst some of the elephants withdrew from that area but in a calm manner and not as frenzy as it happened to be in the above two situations. Rest of the elephants paid good attention towards the emitter node. 18 Elephants in total, 2 showed attention, 11 showed indifference, 3 showed encounter, 2 showed withdrawal. The sound of bees has a similar effect as in the low frequency burst.

In this research Chi-Square method and Odds ratio methods were used to evaluate the tones statistically by analyzing the ability to cause deterrence to the elephants. The Table 6 represents the statistical results obtained. From Tables 6 and 7 it is evident that both odds ratio and Chi- square values are favorable as per the research objectives that means it says that the sound of the drone and the sound of tiger growls can cause a severe deterrence to the elephants. The accuracy of this conclusion is high because the number of test samples in the control experiment which is 31 is almost near to the number of test samples in the experimented by emitting the sound of the drone. The sound of bees and the low frequency burst has a similar result in terms of encounter and withdrawal, but its accuracy is comparatively low as the number of test samples are less compared to the control experiment. These results may vary favorably if this test was conducted on wild Elephants rather than the Elephants in Pinnawala Elephant Orphanage since wild elephants are more attentive to the changes around them than the captive elephants.

Analysis of the performance in the detector node

To demonstrate the performance of the detector node as an illustration. The false alarm rate of images captured under different conditions such as Long distance, perspective, light conditions (Day only), Visibility, occlusion were subjected to classification:

$False\ alarm\ rate$ =
According to Equation (3),

$Total\ number\ of\ accurately\ detected\ images$

$Total\ number\ of\ sample\ images$

× 100 (3)

General False Alarm Rate = (87/98) * 100 = 88.78%.

The performance (refer Table 8) of the detector node was calculated as a result of the False Alarm Rate which is mentioned as above. This was done under certain criteria’s as follows,

- Distance = Images were tested with the distance
- Perspective = Images were tested with different viewing angles of the Elephants for the

calculation of FAR

- Light condition (Day) = Images were tested at different times in a day
- Visibility = Images were verified with certain blur effects
- Occlusion = Images were tested with different outlooks (parts of the physique) of the Elephants

Accordingly, a General False Alarm Rate was taken to get a perfect representation of the performance in the Detector node and as shown there possibility of a false alarm is , Possibility of false alarm= 100% - 88.78% = 11.22%

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TABLE 1 FREQUENCY RANGES AND DURATIONS OF THE SOUND FILES

Audio	Frequency Range (Hz)	Duration of the Clip (min)
Drone	35-16,200	1:07
Bees	25-15,000	1:01
Tiger growl	45-14,300	1:57
Low frequency burst	1-350	0:59
Female threat-response 1	1-16,800	0:05
Female threat-response 2	1-16,800	0:07
Female threat-response 3	1-16,800	0:05
Female threat-response 4	1-17,980	0:10

TABLE 2 SPEAKER SPECIFICATIONS

Speaker	Model	Size (Inches)	Frequency Range (Hz)	Impedance (Ohms)	Sensitivity (db SPL)	Xmax (mm)
Mild	13M/BS16E2	1:07	200-400	8	88	8
Woofer	30W/MAS	0:10	35-3200	8	89	8

TABLE 3 EXPERIMENTAL CONDITIONS

	Day 1	Day 2
Date	24.10.2018	20.10.2018
Time	0900h	1000h
Venue	Elephant Orphanage Center, Pinnawala	Elephant Orphanage Center, Pinnawala
Temperature	27ºc Average	28ºc Average
Wind Speed	5km/h (South)	5km/h (East South)
Pressure	1002.09hpa	1002.08hpa
Altitude	190.14m	190.14m
Humidity	70%	72%
Precipitation	35%	24%
Frequency Tones	Tiger Growl, Bee sound	Drone, Low frequency Burst

TABLE 6 ACCURACY OF THE DETECTION NODE

Property	Values	Accuracy (%)
Distance (m)	2	100
	5	100
	10	100
	25	100
	50	100
	100	100
	150	94.14
	200	89.88
	300	85.66
Detector node angle (X°)	0	100
	45	100
	90	100
	135	100
	180	100
Light ambient (Day)	Low	100
	Mid	100
	High	100
Visibility (%)	25	0.00
	50	52.65
	75	100
	100	100
Occlusion (%)	25	57.33
	50	86.44
	75	100
	100	100

FIGURE 1 FINAL OUTLOOK OF THE DETECTOR NODE

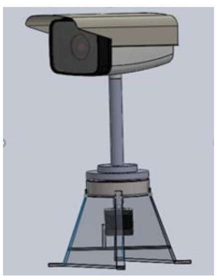

FIGURE 2 DETECTOR NODE WITH THE MOTOR FOR ROTATION

FIGURE 3 LA4440 SINGLE MODE (BRIDGE) AMPLIFIER CIRCUIT [CITE]

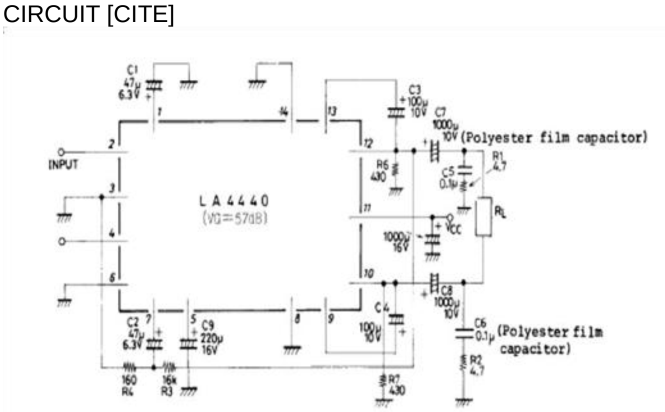

FIGURE 4 VARIATION OF THE MAXIMUM OUTPUT VOLTAGE WITH THE CHANGE

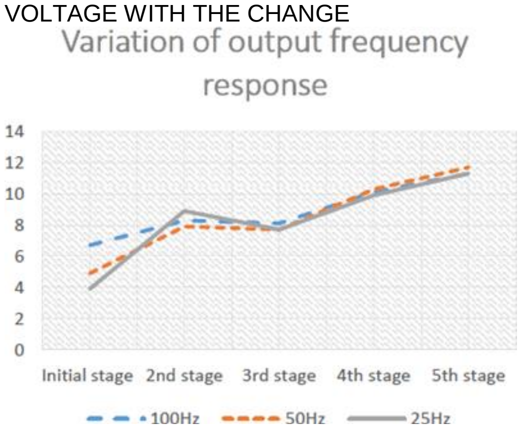

FIGURE 5 PLACEMENT OF THE DETECTOR NODE