A Solution for the Elephant-Human Conflict

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***Abstract* - The Human-Elephant conflict is a serious problem that has existed for decades in Sri Lanka. Although the Department of Wildlife Conservation has implemented several strategies such as electric fencing, translocation and GPS/VHF collars, approximately 150 elephants and 50 humans are killed every year while a lot more are affected. The solution developed through this research incorporates a server and a tracking device. The latter, fixed inside each elephants' collar, consumes an ultra-low idle power of 4.7µW and intelligently decides to transmit location information to the remote server via GSM. This paper discusses how the latest technology has been utilized to dynamically bias harvesting sources to extract as low as 10µW and also how such harvesting methods can be implemented inside a collar. The device built is also able to securely accept over-the-air configurations sent by the Department of Wildlife Conservation aiding remote configuration. The proposed tracker unit, once attached, is able to transmit 12 or more locations a day and with a daily solar generation of 271.8mWh efficiently harvested to a 5000mAh LiPo battery. The device is expected to operate for more than 5 years without any human interaction. The main server accepts and decrypts the location information sent from the tracker device whilst maintaining records. It also operates as a web server. Therefore, a privileged user may securely log in to view all elephants in a map. Moreover, it generates alerts when an elephant intrudes into a human territory and is implemented by adding extra hardware to a low cost embedded Linux computer.**

Keywords — Energy Harvesting, Early Warning, Human-Elephant Conflict, Intrusion Detection, Satellite Navigation Systems, Tracking

I. Introduction

The current population density of Sri Lanka is about 300 humans per km^2, with approximately 750 people added to the population every day [1]. This implies 7500 people every ten days and 22,500 people every month. As more land is required to serve the increase in population, humans have been invading wildlife habitats to keep up with their land requirements. This scenario is primarily the root cause for the aggravation of Human-Elephant conflict (HEC) in Sri Lanka. If the 1.2 million hectares of protected area are managed perfectly, it has the potential to accommodate approximately 1200 elephants. There are about 6000 elephants in Sri Lanka which contribute to 10% of the world elephant population. Similar to the rest of Asia, more than 70% of elephants reside outside protected areas [2]. Since elephants, in due course, lose ground to the human tide, access to their critical resources are blocked by human habitation and fences. Being chased away by humans during day time, the elephants have now evolved to be nocturnal and secretive. It has come to a point where elephants seek food during night and attack humans on hearing their voice. As the Sri Lankan elephant hides in the deep forest during the day, many attacks occur during the night. Due to these sudden attacks by the elephants in rural villages, as well as terrified by such statistics, people who live in such areas do not walk in open spaces at dusk and later. This has directly affected their quality of life and freedom.

According to a study conducted by the Department of Wildlife and Conservation (DWLC), it is found that 65% of Sri Lankan elephant population has fallen since the turn of the 19th Century. Fig. 1, depicts annual statistics of elephant and human fatalities from 2005 - 2012.

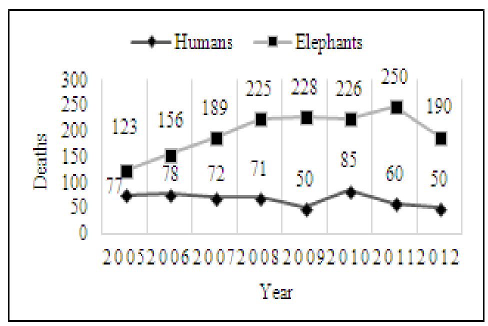

Fig. 1. Annual figures of elephant and human fatalities

Collaring animals is an extensive technique used by scientists worldwide to study animal behavior. The research team believes that this idea can be extended to introduce a solution to the HEC by implementing a special tracker and a web server. The main task of the tracker is to transmit location based information to a remote server which allows all elephants to be visualized in real-time, on a map. Once all elephants are visible on a map, officers of DWLC can avail this benefit of prior knowledge to act and prevent a damage that may otherwise occur.

Existing GPS collars in the world today usually vary in the range of US $ 3000 - 5000 depending on their features and brand. Tracking the location of an

978-1-4673-8922-8/16 $31.00 © 2016 IEEE
DOI 10.1109/TIIEC.2014.35

animal using a collar requires not only the mounting cost, but also indirect costs that are elaborated duly.

However, before fixing such collars, elephants need to be immobilized by using appropriate anesthetics in the correct dosage. While the act of collaring the elephant can be completed as soon as possible, the effect of the anesthetic can be reversed by an anti-dote. The above mentioned task is usually carried out initially, and then repeated as and when the batteries run low, under the supervision of an expert team. Annasiwaththa et al. [3] estimate that there is a 10% failure rate for every collaring operation. He further states that active refurbishing is not routinely conducted as darting and catching an elephant is dangerous to both — elephants and humans. Therefore, a system that demands minimal human interaction seems to be an ideal solution.

Maintaining such human recourses and materials can get very expensive for the government or any non-government organization. Additionally, one more major cost involved is the annual satellite channel per collar which is used to transmit location data through providers such as Globalstar or Iridium. The cost of such links is proportional to the number of transmissions required. This exerts a limitation on the number of fixes that can be demanded from a collar. It is clearly understood through these facts that the existing GPS collar system may not be a viable solution especially in terms of cost. The obligation to purchase highly expensive collars for all elephants including the excessive annual satellite communication costs charged per collar makes such a system unviable for Sri Lanka.

Tracking devices available in the market today, for tracking wild animals, strictly serve as data transmitters and do not incorporate any energy harvesting mechanisms. Such units require additional purchase of expensive high energy-dense battery types to offer longevity while its circuitry itself costs more than 3000 USD. The device built through this research uses a low cost rechargeable Lithium-Polymer battery which eliminates this excessive cost. Moreover, it also allows the user to change or update intervals as well as device settings even after deployment.

Clearly, the problem identified by the research team is that the currently implemented strategies are not effective in bringing down the annual deaths that occur due to the HEC in Sri Lanka. The team has also identified the need for a low cost tracking device that can be fixed into the collar of an elephant.

This paper discusses the development of a tracker that costs only about $80 and consists of superior features. Due to its extremely low cost, it bears the full potential to be used as a feasible solution to obtain GPS coordinates from every elephant in the country.

II. Background

Usage of electric fences and translocation of elephants have been the most common strategies used by the DWLC in Sri Lanka.

Electric fences have been erected on the boundaries of many protected areas in an effort to restrict elephants in such areas. These fences maintain around 6000 - 8000 DC Volts with a minimal current of 4 - 5 mA in the fence wires. The effectiveness of an electric fence and its lifetime is mainly dependent on three factors: location, specification and maintenance. As this creates a requirement for “tailor made” fences, the cost of implementation and maintenance is usually very high.

Translocation of elephants to protected areas is another strategy currently practiced by the wild life officers. However, experts also believe that translocating elephants is futile because such an act may kill the elephant due to stress and hunger. On the other hand, it has also been found that elephants too face social difficulties upon such establishments. Therefore, relying on such a strategy is highly debateable.

The following sections briefly discuss about the present strategies implemented by the DWLC to lessen the Human - Elephant conflict in Sri Lanka with the help of elephant collars. The discussion further extends to state existing commercial products and previous research conducted.

A. GPS Collars

The Global Positioning System (GPS) collar system used today is another approach towards tracking elephants currently used only to identify migration patterns of elephants. The circuit can be pre-programmed to collect a number of locations of the elephant and later transmit the data through a satellite link to a device held elsewhere in the world. This information is later relayed back to Sri Lanka via email after a day or two.

It was found that at the time, more than ten collars are being used in Yala, Udawalawa and Lungumavehera national parks in Southern Sri Lanka and also another three in the North West. These GPS collars cost 3000 to 5000 USD, and have a life span of 2 to 3 years till the next recharge, which is highly dependent on the number of locations transmitted per day.

The current GPS based system incorporates no energy harvesting mechanism and requires a recharge within 2 - 3 years. The recharge process is accomplished after immobilizing the elephant using an anesthetic by an expert team. In addition to the cost of the collar and its mounting , a high recurring cost is incurred for the usage of the satellite link. As this solution is not feasible due to its excessive cost, it can only be used to identify migration patterns of elephants.

B. VHF Collars

This device incorporates a very high frequency (VHF) transmitter inside the elephants’ collar which continuously emits a signal sounds - “beep-beep” - through a receiver. Depending on the position and the direction of the antenna, the received signal strength varies. This method is used to walk up to the elephant and is called “homing in” and works within a range of 3 - 4 km. If the elephant is not in the range, it will have to be manually found. Due to the short lifetime of the device , high man power requirement and short range, it cannot be used to prevent the Human-Elephant Conflict.

C. Existing Commercial Products

Followit, Telonics, Sirtrack, Lotec and Vectronic Aerospace [4], [5] are a list of manufacturers of GPS based collars with a wide variety of functions based on cost. These collars have the ability to communicate over ultra high frequency (UHF), VHF, global system for mobile communication (GSM), and satellite networks such as Globalstar or Iridium. It also has the ability to accept transmission schedules via the same. Through virtual fences, these units are able to maintain a variable number of transmissions in sympathy to the position of the animal. These trackers also incorporate additional circuitry such as proximity sensors, motility sensors to facilitate thorough study of animal behavior. Lotec collars also feature a variety that offer live video streaming. Collars described so far range from 3,000 - 5,000 USD. However, these units do not incorporate any energy harvesting mechanisms therefore the lifetime of these devices mostly depends on the capacity of the non-rechargeable battery pack decided by a user which requires replacement after use.

D. Previous Research

Wanninayake et al. [6] built a software based solution named ICT-RHEC in 2012 to help reduce the HEC in Sri Lanka. ICT-RHEC incorporates a web server, an android application, and a tracker (essentially a mobile phone) that transmits location based information to the web server via Transmission Control Protocol/Internet Protocol (TCP/IP) or SMS. The web server and the android application together offer great features such as visualization of elephants, virtual fencing and temporary hot spots which when enabled, can alert a privileged user the moment an elephant comes too close in the forest. The tracker unit is an android phone fixed inside the elephants’ collar and contains both unwanted peripherals and android software components. Even when all unwanted hardware peripherals and software components are disabled, the mobile phone still consumed idle currents resulting in a considerable wastage of energy. As this device offers a short lifetime, the effectiveness of such a technique is low.

Annasiwaththa et al. [3] have developed a power optimized satellite elephant collar that addresses several issues in the existing collars used for tracking. Communicating over the Iridium satellite network, the device offers over the air programmability and claims to have an operational time of 580 days with 6 locations a day. It has a total build cost of approximately 1359 USD. However, the subject does not incorporate any energy harvesting mechanisms or GSM connectivity. This means that there will also be an additional cost spent to transfer data over the Iridium satellite network.

III. Context of GSM Communication

GSM coverage in a forest is not as high as in urban areas mainly because GSM service providers use directional antennas to limit coverage to only areas of interest. However, due to the side lobes of antenna radiation and other environmental factors, directional antennas cannot limit coverage as expected. In most cases, sufficient coverage is available to send a SMS as transmitting a SMS requires far less coverage as compared to making a 2G call. It is also understood by the research team that a delay in transmission due to lack of coverage in the deep forest will not significantly lower the total effectiveness of the solution. To successfully face such instances where coverage is a problem, the tracker unit incorporates a combination of innovative strategies to maintain transmissions to a schedule.

A. Analysis of GSM Coverage in Elephant Habitats

HEC is mostly affected in human habitat areas. Therefore, it is safe to consider that the part of the forest near such areas will always have sufficient 2G coverage. This does not imply that deep forest will not have enough coverage to send a SMS. Fig. 2, presents a coverage map by one of the leading mobile service providers in Sri Lanka and Fig. 3, presents a map that represents HEC affected areas.

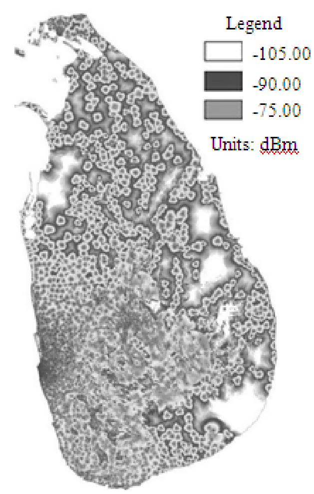

Fig. 2. GSM coverage of Sri Lanka

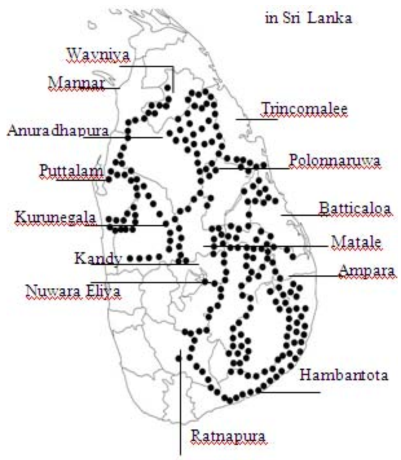

Fig. 3. HEC affected areas in Sri Lanka

The mobile telecommunication industry, similar to the rest of the world, is a competitive business in Sri Lanka. Almost all providers offer excellent coverage and more towers are being added to the existing network to improve its quality and strength.

B. Stratergies Implemented to Overcome Problems caused by Low GSM Coverage

The tracker includes both software strategies and hardware optimizations to best maintain the transmission schedule. If a transmission fails, the system will "Store and Forward" all data whenever a connection is re-established.

The GSM antenna integrated into the collar has a high gain of 5dBi which provides good sensitivity. This external antenna is expected to provide far superior performance than a PCB-integrated patch antenna.

Sri Lanka has five competitive GSM network providers who use their own network transmission and receiving equipment. This leads to an innovative method of greatly decreasing failure rate during transmission even in the deep forest by using a connection that allows roaming within all cellular networks. As there will be variation in the coverage patterns that belong to five different providers, an approach of this sort has enabled a significant improvement in the reliability of the tracker unit.

Another method that can be used is to fix GSM repeaters powered by solar energy at strategic places in the deep forest. Analyzing previously collected migration patterns of elephants, such places can be determined and necessary equipment can be fixed.

IV. Prototype Design and Implementation

A. System Overview

Fig. 4, depicts an overview of the proposed solution. The complete solution consists of two parts: a main server and tracker units.

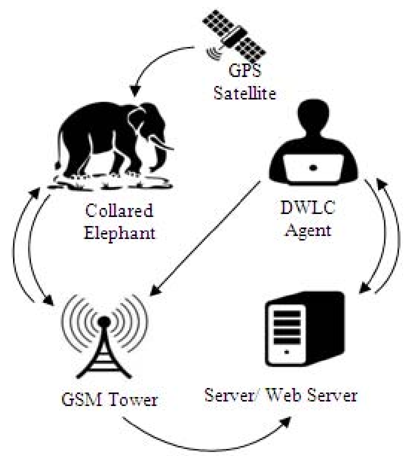

Fig. 4. Overview of the proposed solution

The main server is essentially Beaglebone-Black, an embedded computer which multi-functions as a web server, information processor and a SMS gateway. GSM connectivity is provided to this embedded computer with the help of a SIM908 module connected via the universal asynchronous receiver/transmitter (UART). The Beaglebone-Black maintains records of transmitted locations by each tracker unit in a MySQL database. The same server, if accessed through a web browser on port 80, acts as a web server which can be used to login and view all elephants in real-time. The web server was made with the help of an open source software bundle — Linux, Apache, MySQL and PHP (LAMP) — which added PHP and MySQL functionality on top of Ubuntu - Linux 13.10. Beaglebone-Black clocks a 1GHz AM3359 ARM Cortex-A8 processor with added Ethernet functionality. It also includes a 4GB eMMC flash storage and a 512MB DDR3 RAM.

The tracker units fitted into the elephant collars transmit location based information to the server by means of SMS messages. It also incorporates special circuitry and techniques to efficiently harvest solar energy and recharge an internal high capacity Lithium Polymer (LiPo) battery whilst providing state-of-the-art facilities to the user.

B. Design of Tracker Unit

The tracker unit consists of three distinct circuitry elements: a main MCU, data acquisition/transmission unit, and an energy harvesting unit. All three units share the same power source. Fig. 5, illustrates a block diagram of how internal peripherals in the tracker unit are interconnected. Fig. 6, illustrates the governing algorithm running inside the main MCU of the tracker unit.

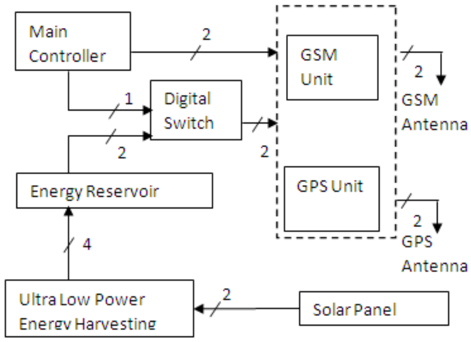

Fig. 5. Block diagram of the tracker unit

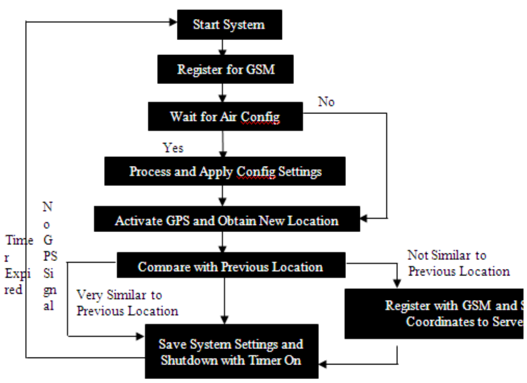

Fig. 6. Implemented algorithm of the tracker

The MSP430 MCU unit communicates with the data acquisition/transmission unit via UART protocol. A slow baud-rate of 9600bps was selected between both to ensure reliable data transfer at all times. This also enabled the MCU to be clocked by an internal very low power oscillator (VLO) which eliminated the need for an external oscillator. During the greater part of the day, the MCU is asleep with the timer on, thus consuming an idle current of only 0.5µA, at 3.6 V. The output of the timer overflow is used to interrupt the MCU to wake up at appropriate intervals. This timer along with another variable are collectively used to offer over-the-air programmability to the tracker unit.

Data acquisition or transmission unit is essentially a SIM908 module. It offers GSM connectivity and GPS positions through the NMEA protocol. However, SIM908 by SIMCom does not offer sleep currents as low as the MCU. Therefore, power to the same was controlled through a MOSFET. SIM908 has a supply voltage range of 3.0V – 4.2V which coincides with the LiPo battery discharge voltage range. As the MCU too is able to operate throughout the same voltage range, it was possible to save both power and cost that would otherwise be spent on a voltage regulator.

The selection of GPS antenna type for the tracker unit is crucial as it directly affects the longevity and accuracy of the tracker unit. As the main module is contorted through a single MOSFET, prolonged acquisition times will contribute towards higher idle energy consumption of sub-modules. Therefore, the GPS Time To First Fix (TTFF) from a cold start was identified to be the bottle neck in reducing the energy requirement for a single transmission.

Helix and Patch antennas are the most widely used types in GPS applications. It was understood that the main lobe of the antenna radiation pattern should direct towards the sky at all times for maximum signal reception. Therefore, the antenna was decided to be fixed in a way that the natural orientation of the collar would result in an optimum antenna orientation. Helix type antennas, due to its omnidirectional radiation pattern, pick up multi-path GPS signals. If such signals are processed, they may result in a prolonged TTFF and erroneous coordinates. Therefore, a bad choice in the GPS antenna will drastically affect the lifetime of the tracker unit.

On the contrary, patch antennas have the tendency to reject such reflected signals as its antenna gain falls off near horizon. Compared to helix antennas, patch antennas also offer higher gain and lower cost. Due to these reasons an active patch antenna was used in the design. The low-noise amplifier (LNA) in the GPS patch antenna offered both amplification of the signal and a reduction in the overall noise figure.

The selection of the active patch antenna was not solely based on its overall gain as low antenna gains cannot be compensated by high LNA gains. Antenna gain (in dBiC), amplifier gain (in dB) and amplifier noise figure were individually considered and the most suitable active patch antenna was chosen.

Prototype PCB was printed on FR4 material using 1 oz of copper. It was tin sprayed and covered with a green solder mask for further protection. PCB traces for all antennae were controlled to be of 50Ω characteristic impedance. This allowed minimal conduction loss of signals from the antennae to the SIM908 module and vice versa. Usage of quad-flat no-lead (QFN) packages for all ICs allowed the PCB to shrink to a small size. Moreover, wherever possible, wide and short PCB traces were used to minimize loss of power dissipated on the PCB tracks. An image of the prototype unit is depicted in Fig. 7.

Fig. 7. Prototype of the tracking device

C. Power Control of Tracker Unit

Unlike the MCU, no other peripheral in the tracker unit is continuously powered. It controls power to the main module through the Texas Instruments P-Channel CSD25402Q3A MOSFET which demonstrated an ultra-low $RDS_{(ON)}$ of 11mΩ at $3.6V_{GS}$.

The main module consists of a GSM unit and a GPS receiver considered as sub-modules. The MCU has the ability to control power to the sub-modules via AT commands which exponentially increases the flexibility of power control. It allows power up of a single sub-module at a time, while keeping all other sub-modules powered down. This sort of an approach offers full control to the MCU to cut off unnecessary power flowing towards modules whenever they are not in use. This technique saves a significant amount of energy which would have otherwise been wasted.

D. Energy Storage

Among all rechargeable Lithium battery types, Lithium Polymer offered ideal characteristics for the application. They were found to have less than 1% self-discharge rate per month and the weight of the 5000mAh battery was only 114g. The battery demonstrated no difficulty in supplying high transient current requirements of SIM908 module required for registration and transmission on the GSM network. The battery was rated to supply a continuous current of more than 100A. LiPo was found to be an ideal choice for its discharge voltage range of 3.3V to 4.2V which coincided with the supply voltage range of the tracker unit. It was also found that a discharge cycle from 3.8V - 3.3V extracts greater than 96% of energy from a LiPo cell. However, the LiPo demonstrated a higher than 1% discharge rate when charged up to 4.2V. Therefore, the operating voltage range of the battery was limited from 3.8V to 3.3V.

To ensure the protection of the elephants, the battery was enclosed in a heat and pressure tolerant enclosure designed to stop the damage that may occur from an explosion. This strategy is also expected to improve the thermal performance of the LiPo cell. Other battery types such as Li-Ion, $LiSO_4$ and Li/MnO_2 were considered. However, LiPo was seen to be more suitable for the application.

E. Implementation of Efficient Solar Harvesting

Raghunathan et al. [7] suggest that voltage and current outputs of a solar cell are closely related, and once plotted, maintains almost identical shapes for different light intensities. This effect is illustrated in Fig. 8.

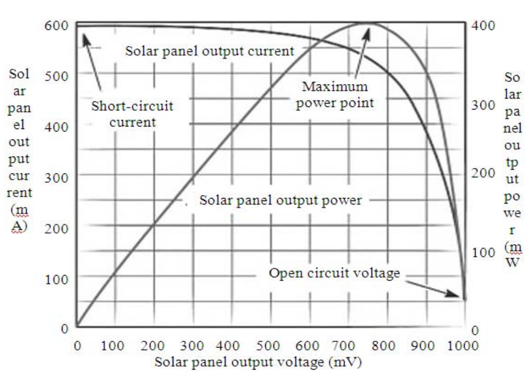

Fig. 8. Solar panel output voltage, current and power

The biasing point at which maximum power can be extracted from a solar panel is defined as the **maximum power point**. It is defined as a percentage of voltage or current that a panel should be biased into in terms of its open circuit voltage (V_{OC}) or closed circuit current (I_{SC}). A solar panel *forced* to operate at this point, delivers the highest power than at any other operating point. It was found to be the best to define maximum power point as a percentage of V_{OC} or I_{SC}. Most solar panels tested were found to have maximum power points close to 80% of V_{OC} at all sunshine intensities. Therefore, it was concluded that biasing a solar panel to 80% V_{OC} at all times is one way of maximum power point tracking (MPPT). Since V_{OC} and I_{SC} are highly dependent on sunshine intensity, proper MPPT action demands frequent checking of V_{OC} and dynamic assigning of V_{BIAS} at constant time intervals. This tracker unit incorporates dynamic allocation of V_{BIAS} by seeking for a new V_{OC} value from the panel, every 16 seconds. This task was accomplished through correct configuration of Texas Instruments BQ25504 energy harvesting IC. The IC was able to efficiently acquire and manage microwatts to milliwatts of power generated through the solar panel.

The same IC multi-functions as a buck-boost converter and runs an algorithm to charge the LiPo battery. All capacitors that function as temporary energy reservoirs in the design were chosen to be of extremely low leakage polypropylene capacitors. The 22μH inductor used in the design had a maximum series resistance of 0.33Ω. Such considerations ensured higher efficiency in transferring energy from the solar cell to the LiPo battery.

F. Solar Panel Selection, Mounting and Performance

Solar harvesting on top of an elephant's collar can be challenging as panels are prone to damage due to stress and accumulation of mud or dust, which in turn decreases received sunlight intensity. A structure made of tempered glass was used directly on top of a fully flexible solar panel to create a solution that is able to absorb shock. This setup is illustrated in Fig. 9.

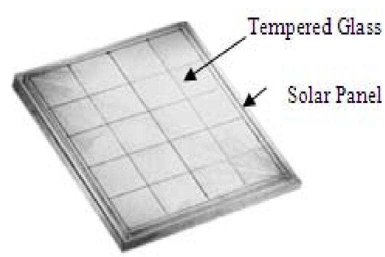

Fig. 9. Solar panel arrangement

It also addresses the second issue of accumulation of dust or mud. As elephants often submerge themselves in rivers and tanks in the forest, dust or mud accumulated on top of the glass is expected to be washed away.

All elephants around the world do not have a similar behavior and it is believed that the Sri Lankan elephant prefers low sunlight as compared to the African elephant. To obtain an estimation of the amount of energy that can be harvested through the panel, statistical data specific to the Sri Lankan elephants are needed. This data must include daily exposure of the elephant to sunlight and its traveling patterns. Since such data were not found, a minimal value of 2.5 hours of sunlight exposure per day was assumed. It should be noted that actual statistics may offer higher duration of sunlight exposure.

The solar cell chosen is dye-sensitized. It is special not only for its flexibility but also for its high efficiency at very low-lux conditions making it an ideal choice for the Sri Lankan elephants. TABLE I describes the properties of the solar panel used. 10,000 lux represents a situation when the elephant is under low light condition and 100,000 represents when the elephant is exposed to direct sunlight in an open area.

Parameter of the Solar Panel	Value
Total Active Area	36 cm²
Power Density at 10,000 lux	200 µW/cm²
Power Density at 100,000 lux	2500 µW/cm²

TABLE I
Solar Panel Parameters

The following calculations describe the least amount of energy that can be harvested on top of an elephant during a typical day. The photovoltaic power generated per day is denoted by P_{GEN_total}. It has been assumed here that the elephant stays 6.5 hours in the forest and only 2.5 hours under direct sunlight. A nominal cell voltage of 3.55V has been assumed throughout the calculations.

$$P_{GEN\_TOTAL} = P_{GEN\_PEAK} + P_{GEN\_AMBIENT} \quad (1)$$
$$= 2500\mu W/cm^2 \text{ X } 36 \text{ cm}^2 \text{ X } 2.5h$$
$$= 225mWh/day$$
$$P_{GEN\_AMBIENT} = 200\mu W/cm^2 \text{ X } 36 \text{ cm}^2 \text{ X } 6.5h \quad (2)$$
$$= 46.8mWh/day$$
Thus, $P_{GEN\_TOTAL} = 271.8mWh/day = 76.56mAh$ (3)

V. Expected Performance and Financial Analysis of the Tracker Unit

The following chapter presents an analysis on the performance of the tracker unit through observations and results. Using such conclusions, the lifetime of the device is predicted as well as financial analysis of the design is revealed.

A. Energy Consumption of Peripherals in the Tracker Unit

TABLE II contains numerical values of energy consumed by different peripherals of the tracker unit evaluated for a single transmission. Calculation is conducted for the worst case scenario assuming the TTFF of the GPS is 45 seconds. Miscellaneous figure accounts to communication and switching energy.

Peripheral	mAh val.
MSP430 in active mode for 45sec	0.046
GPS location acquisition from cold start	1.188
Registration with GSM network	1.280
Transmission of a SMS	1.280
Miscellaneous usage	1.500
Total milliwatt hours required	5.294

TABLE II
Energy Consumption

Therefore, a total number of 14 transmissions per day are earned through efficient solar energy harvesting.

B. Financial Analysis of the Tacker Unit

TABLE III presents a detailed view of the amount spent on a single tracker unit. Minor amount spent on capacitors, resistors etc., have been accounted under miscellaneous.

Peripheral	Cost (US $)
TI MSP430G2553	0.9
SIMCom SIM908	12
GSM Antenna	3.7
GPS Antenna	5.2
LiPo Battery	9
TI BQ25504	2.1
Coilcraft Inductor	0.6
Solar panel	35
Tempered glass	1.5
PCB printing	4
Miscellaneous	9.5
Total Cost of Tracker Unit	$ 83.5

TABLE III
Cost Analysis of the Tracker Unit

VI. Conclusion

This research has developed a low cost solution that has the full potential to solve a serious problem in Sri Lanka. As the solution costs far less than any other commercially available tracker unit, even a moderately wealthy organization or a government body may take the initiative to implement the said solution. It is proven through results that the tracker unit offers superior electrical specifications and state-of-the-art facilities for the user such as over the air configurations. Its ability to efficiently harvest microwatts to miliwatts of solar energy is a unique feature that extends its expected lifetime over 5 years. It is also possible to use the same solution to gather migration patterns of elephants for research purposes.

Moreover, with minor modifications, the work done can be easily extended to build a device that can track other types of animals.

VII. Future Enhancements

The tracker unit developed so far is able to harvest only solar energy. Future research is directed to exploit the methods of harvesting electrical energy from the motion of the elephant, as well as thermal energy from the environment.

The GPS module is expected to be replaced in the future to enable extended reception from both Global Navigational Satellite System (GLONASS) and Global Positioning System (GPS) to enable 15 seconds TTFF from cold starts. This is expected to further enhance its lifetime and ensure that the functionality of the tracker unit is not disturbed even in the absence of one satellite system.

Value line series MSP430 microcontroller is expected to be replaced with a Texas Instruments FRAM series MSP430 microcontroller which incorporates ferromagnetic RAM technology. This microcontroller is expected to drastically improve the longevity of the tracker unit as it consumes 250 times less power than any flash based microcontroller, when run at an equal speed.

Acknowledgment

The research was funded by the Sri Lanka Institute of Information Technology in Sri Lanka. The authors would like to thank Stanford Magnets, USA for partially sponsoring components for the experiment.

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