TigerCENSE: Wireless Image Sensor Network to Monitor Tiger Movement

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Abstract. Wireless Sensor Network (WSN) in combination with image sensors opens plethora of opportunities in the wildlife tracking. It provides a glimpse into previously unseen, remote and inaccessible world of some of the most endangered species on earth. tigerCENSE [1]is such an attempt to put sensor network technology in conserving one of the rarest and most elusive big cat species. The node, triggered by the Passive Infrared (PIR) sensor, captures the image of tiger using a CMOS image sensor and stores it in an external memory chip. To avoid any disturbance to animal, the node uses an Infrared (IR) flash, instead of white flash, to illuminate the target at night. The stored images get transferred to the base station via radio transceiver. This is transferred to the database server through Internet links for analysis by wildlife researchers. A solar energy harvesting system for recharging node's batteries is being added to avoid frequent human visit to change the batteries, making it highly non-intrusive system.

Keywords: Camera Trap; Wireless Sensor Network; Image Sensor Network; wildlife tracking; Intrusion detection; CMOS camera; IR flash; image sensor.

1 Introduction

Most of the WSN applications have depended on sensors such as light and temperature etc., which produce small amount of data per sample. However, in recent years, technological advances, especially in CMOS, have made it possible to have very small, low powered and cheap image sensors integrated to WSN, enabling us to collect valuable visual information of the target object and its surroundings. These image sensors produce large data per sample based on image size. Due to this Wireless Image Sensor Network (WiSN) has emerged as a new field with its own application areas as well as challenges. One of its most promising applications is monitoring wildlife species.

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Traditional methods of wildlife monitoring are largely based on statistical methods and data collected by ground surveys [1]. Though these methods usually yield extensive data for a given animal and its habitat, they are time consuming, expensive and unauthenticated. Some methods, such as the traditional pugmark census, are not even reliable enough[2]. Above all, most of the endangered or critically endangered species live in remote, arid and inaccessible landscape. Monitoring them, their behavior, their status and distribution becomes life threatening. tigerCENSE is an attempt in this direction to make such tracking more authentic, automated, non-intrusive, less expensive and safe. Under tigerCENSE project we are primarily focusing on collecting images of tigers along with its time/date and location to identify their movement patterns and making it available to the researchers in an easy manner.

Tiger is the largest of all the Asian big cats and one of the most threatened species [3]. Throughout their range in Asia tiger populations are threatened, either directly from poaching, or from habitat and prey loss [4]. Once having the population count above one million is now struggling for its survival with the mere population of 3,402-5,140 across the world [4]. In last few decades number of conservation programs have been proposed by various countries and other international organizations. They have been working on many possible solutions like restoring habitat, monitoring populations, anti-poaching laws etc, and millions of dollars have been invested for the same [5]. But common to all the solutions is monitoring the status and population distribution information of the tigers.

2 Available Technology

The advent of advance camera trap technology has revolutionized conservation plans for wildlife. It helped to uncover invaluable information about rare species and their habitats, which can be shared with local governments when making land-use decisions, anti-poaching activities etc. Most of the available camera traps use independent commercially available camera modules, that may be digital or film-based usually triggered by a motion detector.

In the very old days trip wires and pressure pads were used to trigger cameras [2]. Modern motion detectors are based on infrared and may be active or passive. Active infrared based motion detectors send out an infrared beam to a receptor located some distance away. When any object obstructs this beam's path, the detector triggers and camera captures the photograph. Whereas a PIR sensor tracks heat change in the surrounding. When any infrared emitting object passes in front of the detector, it detects the motion. Also, the modules that aim for night photography usually come equipped with either white or infrared flash. Some of the commercial cameras use almost 64 LEDs making them much bigger and consume lot of power.

These systems usually use strobes and wires to interconnect the motion detector, the independent camera and to setup an automatic image capturing system. This makes their size quite bulky and difficult to camouflage making it highly prone to stealing by people or being damaged by animals. Also, presently most of the commercially available traps do not have a local wireless network link. Although few of the traps do communicate with satellite but because of the leased satellite link, they cost heavily.

In this paper we are proposing the system, tigerCENSE, which has been able to resolve many of the problems faced by these traditional camera traps. Here we will be discussing the hardware and software design architecture of the tigerCENSE system at the node, base and network levels. In particular, the paper embodies the issues and constraints, which were met during the design and testing of the system.

Section 3 of the paper discusses the design parameters taken into account for tigerCENSE. Overview of the system is described in Section 4 covering the hardware and software aspects of the system. Experience gained, system performance and our field testing results are covered in Section 5. Finally we conclude by enumerating the challenges and experience gained from inception to trials.

3 tigerCENSE

To make an informed decision, researchers need to know the status and distribution pattern of tigers in the area of interest. They collect information using pugmark, DNA technique or through camera traps. As human beings have fingerprints as their unique identity, characteristic stripe patterns on cat's body differ from one individual to another and from one side of the cat's body to the other [6]. In fact, there are no tigers with identical markings. Wildlife researchers are mainly interested in these unique stripes pattern. It allows them to extract potential information on the presence of species, their home range sizes, individual recognition and density estimates, activity cycles, behavior, seasonal variation in movement and abundance and also allows for comparisons to be made between areas [2].

tigerCENSE is an attempt in the similar direction and provides images in an inexpensive, power and time efficient manner. Nodes are setup by researchers along each bifurcation of the tiger trail to help figure out the path taken by tiger. Whenever a tiger gets in the field of view of PIR sensor, an interrupt is generated and the image sensor will capture the photograph. As tiger moves mostly in night, an infrared flash is integrated in the system. The photograph is time stamped and gets stored on a micro-SD card along with node ID. Once the communication with gateway or next hop neighbor is available, it would transfer the image wirelessly using a radio transceiver. As the memory size of the micro-SD card can be increased, the upper limit of photographs that can be saved is adjustable. Also, wireless connectivity and solar recharging for battery, help in minimum anthropogenic disturbance, which otherwise would have been required for data collection and to change the power battery.

Though camera traps technology have been in use for quite long time but still it is not fully explored and suffer some major drawbacks. Besides having all the pros of old traps, tigerCENSE has been designed keeping the following drawbacks, explained further, as its prime design challenges.

Response Time. The time delay between PIR interrupt and capturing the photograph is very critical. Because of large response time of many traditional traps, fast moving animals do not get captured. tigerCENSE system needs to reduce this time to around one second to overcome the said drawback.

Size and Cost. Traditional traps were bulky and costly. Developing a customized system with an integrated image sensor is desirable as this will drastically reduce the size and the cost. Also, presently the number of LEDs used to illuminate the animal is very high. We could make an illuminator with fewer but brighter and more efficient LEDs.

Disturbance to Animals. To allow night photography IR flash is recommended as white flash will startle the animal resulting in the abandonment of the path. Also, mechanical shutter produces a click sound, while taking a photograph. This needs to be avoided as this makes the animal cautious of its surrounding and to behave abnormally.

Automated Data Transmission and Local Storage. A wireless connectivity is required which allows the nodes to be deployed in very remote areas and it will also reduce human visit to the forest to a great extent. Also, to compensate for any link failure due to environment or other failures, the node should have sufficient external memory to store the data for a month.

Remote Configuration. Researchers need to go to the field each time they need to change any parameter, like number of shots in burst mode, delay between two adjacent shots etc. of the traps. Remotely changing of parameter further reduces the visit and labor of researchers.

Fail-Proof against False Interrupts. In spring when many trees shed their leaves in preparation for new foliage, active IR sensor gives lot of false interrupts. Each momentary break in the beam caused by a leaf floating across the path may result in a useless picture being taken. tigerCENSE needs to take care of it as this may consume large amount of power for no good reason.

Health Information of Traps. Presently, once the trap is deployed in the field, there is no way to know about its health and other parameters. The film or the battery might have been exhausted long back but the researchers would not know. Also, the camera might stop working because of some technical problems, it might get stolen or may have been damaged by an animal, but it will remain unknown until someone visits it. This makes the trap highly inefficient as it may loose important information.

Energy Harvesting. Present traps consume enormous power and need the battery replacement at regular interval. This not only leads to frequent visit of the researchers but also the maintenance cost goes up. This requires for an efficient power supply with a recharging mechanism. The Solar recharging system could be an excellent solution to it. With careful energy management policy, supplemented by harvesting, the energy requirements can be met.

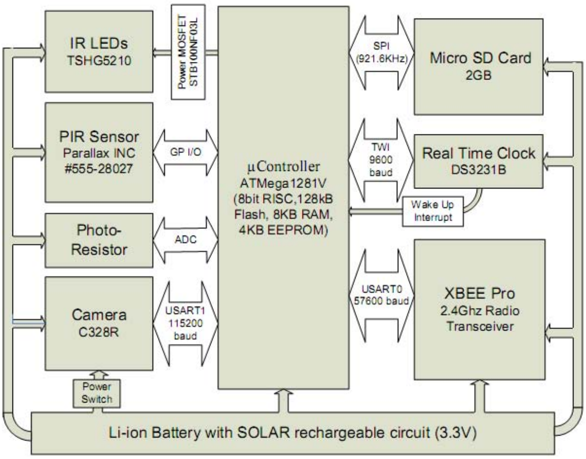

Fig. 1. tigerCENSE Hardware setup depicting various components, their interfacing and power supply

4 System Overview

Broadly the tigerCENSE system is divided like any other traditional WSN in the hardware, related system software and drivers, middle-ware servers with data logging and web hosting services and finally the browser based visualization software. We plan to use radio transceivers capable of communicating over 1.5 km in the free space. The range may get affected due to surroundings but would still be sufficient to allow node to node communication and multihopping of data. Most of the nodes would be in the valley but to provide link to Internet, we would need to use GPRS links using mobile communication infrastructure. As mobile signals would not be available in the valley, we would need to setup a 4-5 km directional link between a gateway in the valley and that on the hills. Using mobile signal available on the hills, we would be able to transfer the data to servers using GPRS. Our focus in this paper is more on the node development and not on the rest of the system, where standard existing technology can be used.

This section describes the platform developed and used for our experiments. Hardware system architecture of tigerCENSE node is as depicted in Figure 1. While describing the hardware used, we will also discuss the flow of the software and the challenges faced during its development.

When the system is in idle state with no movements of animal, all the hardware components will be in power saving or sleep mode except the PIR sensor. When an intrusion is detected PIR sends an interrupt to the micro-controller and the system gets into its active state. The PIR Sensor is a pyro-electric device that detects the motion by measuring changes in the infrared levels emitted by surrounding objects.

PIR. We use Parallax INC #555-28027[8] PIR sensor, which works from 3.3 to 5V and draws less then 100 μA current. Also, it is less prone to false triggers, when compared to active beam interrupted motion detectors. Active beam based system may get triggered by a very small object(e.g. leaves falling of a tree). It has the Fresnel lens with the viewing angle of 90 degree and a range of approximately 20 feet. At start-up the PIR requires a 'warm-up' time in order to learn its environment or in other words creating the heat map of the environment. This start-up time could be anywhere from 10-60 seconds. After this, whenever PIR sensor detects any sudden change in its heat map, in other words it detects an intrusion; it pulls up its output pin giving an interrupt to the micro-controller.

The interrupt from the PIR wakes up the micro-controller and it initializes the image sensor to take the photograph. The initialization of image sensor happens in two steps. In the first step the micro-controller enables the power to the image sensor using a power switch TPS2092 [9]. The power switch is being used to conserve the power which otherwise would be wasted as the quiescent power of the image sensor. In the second step the micro-controller sends commands to the image sensor to customize setting and to capture the image.

Image Sensor. COMedia Ltd.'s C328R [10] image sensor module is used, which performs as a JPEG compressed, low cost, low powered still camera. It interfaces with the micro-controller using the serial communication. It works on 3.3V with 60mA of current. As we are using IR flash to illuminate the object, we use a lens without IR filter. CMOS image sensors are typically sensitive to 1000 nm and use of IR LED in 850 nm to 950 nm range to illuminate the target is possible. The lens configuration can also be altered to vary the Field of View (FOV) of the camera [11]. Currently, we are using the lens with FOV of 60 degree.

Before taking the photograph the micro-controller reads the output of a photoresistor, interfaced to its ADC pin, to sense whether the ambient light is sufficient for the image or if flash is required. Depending on the need, micro-controller switches on the high intensity Infra-Red Flash using a power MOSFET.

All the photographs need to be time stamped along with the node ID. To keep track of time on the node, we are using a Real Time Clock (RTC). When the node is powered on for the first time, it needs to be in the range of a base station to synchronize with the system time. Once the time is set, the battery backed RTC keeps the timing information for years and corrects any drift each time node communicates with the base.

Real Time Clock (RTC). We use DS3231[12] as RTC, which is one of the industry's most accurate RTC. Its power consumption is 110 μA at 3.3V. It has integrated temperature compensated crystal oscillator (TCXO) and I^2C interfacing.

A radio transceiver has been used to transfer the collected photographs and other data/health information of the node to the gateway/base station for onward transmission to the server.

Radio-Transceiver. Communication module XBee Pro[13] from Digi-Key is used, which is based on ZigBee/IEEE 802.15.4 standard. It operates at 2.4 GHz (only freely available ISM band in India), providing a range of more than a kilometer. Its RF data rate is 250 Kbps. While using this frequency results in higher power consumption for same range compared to 900 MHz, we gain in terms of much higher data rate and smaller compact antenna. Low cost, low power and ease of use are among the other advantages. It also provides five sleep modes to meet various needs of different applications. We use lowest power sleep mode as it is not a time but power critical system. Recently introduced, XBee Pro 2.5 version supports multihop transfer of data.

The image can be transferred using multihop facility provided by XBee Pro 2.5. But there are chances, because of bad weather or some other technical problem, establishing a communication link is not always possible for a sensor node especially those deployed in remote areas. So the captured image needs to be stored in some storage device. Typically the size of a photograph is 60KB. So we cannot use an internal memory and need an external storage.

Micro-SD Card. We have used micro Secure Digital (SD)[14] card, commonly used in mobile phones, which can be interfaced with micro-controller using SPI bus. The card can be manually removed and the images can be transferred into a computer, phone or even a digital camera for viewing. The conventional method of writing data into external flash memory restricts the user from viewing the images with such ease. The storage capacity of the micro-SD card is adjustable depending on the activity of the animal at the location. Currently we are using a 2GB card.

All the decision making and controlling of components on the node is done centrally by the micro-controller.

Micro-controller. ATMega1281V [15], with 128K bytes program memory, is the core processing unit of our design. It has 4K bytes of EEPROM and 8K bytes of SRAM. The availability of 2 USART ports enables independent communication of Camera and Radio transceiver with the core processing unit. The internal resonator is not accurate enough for serial communication, so an external crystal of 1.83728 MHz is used. (Limiting baud error to zero percent [15]).

An efficient energy power supply and management policy has been designed to achieve true non-intrusive nature of tigerCENSE. Energy efficiency is achieved by using very low loss DC/DC converter and other components such as power switch to switch off all the devices, whose sleep mode power consumption is not sufficiently low. All the peripherals are switched off or kept in sleeping mode, except PIR sensor, in normal mode. The system is powered by a re-chargeable Li-poly battery. Solar energy harvesting is being added to further enhance the node life. The battery's capacity should be sufficient enough to power the node for at least one month. We are carrying out tests to determine node's actual life time in working environment.

Battery. We are using a 6AH Li-poly battery[16]. These are very slim, extremely light weight batteries based on the new Polymer Lithium Ion chemistry. Its output voltage is 3.7V with 2.7V cut-off voltage. Also it has 2C discharge rate.

Designing a simple power supply for such complex system was a challenge. All components and sensors were carefully selected to have low energy consumption profile and almost similar input supply range with 3.3V as the common voltage. The decision of using a common voltage (3.3V) not only made the power supply for the node simple but also saved energy, which otherwise, would have been wasted in regulating it for different voltages. With time the battery voltage will reduce from 3.7V to 2.7V. But the node needs a constant voltage supply of 3.3V so we need a buck-boost DC converter to regulate the battery voltage.

Buck Boost Converter. To utilize the battery power to the maximum, a DC/DC converter, TPS63001[17] buck boost converter from Texas Instruments, is used. It provides a constant 3.3V output with a maximum of 1.8A of current; being rated up to 96% efficient.

The same battery will be used to power the IR LEDs. These LEDs will be used in pulse mode with high time of 30ms. To get high intensity rays, we need to supply very large current (approx. 3.0 A) for this pulse duration . As a battery may not supply such large current, we need buffer storage of electric charge in between. Super-capacitor is the best option for this task. We are using two super-capacitors in series to get the required voltage.

Super-Capacitor. Super-capacitor TS12S-R[18] is used, which is highly compact and high density capacitor with capacity of 10F at 2.5V. Its self discharge rate is very low and can supply maximum of 4.5A of current.

To switch on the LEDs for such a short time, we need a Power MOSFET with very small ON time resistance. ON time resistance is of particular importance as we are drawing very high current of 2.5A. Even few milliohms of ON resistance can result in significant voltage drop across LEDs, which will reduce its intensity severely.

Power MOSFET. The Power MOSFET STB100NF03L[19] from ST Microelectronics has been used for the said task. Its ON-resistance is less than 3.2 $m\Omega$ with Gate threshold voltage is as low as 1.7V.

Tigers mostly move in night time and to illuminate the animal, we are using IR LEDs. But since the size of the trap is of much concern, we need to use least no. of LEDs possible. This requires very high radiant intensity, low forward voltage LEDs.

IR LED. We use TSHG5210[20], which is the strongest high intensity IR LED available in the market from Vishay Semiconductors. This is an infrared, 850nm emitting diode with forward voltage of 1.5V. In pulse mode its radiant power is 2300mW/sr. Its angle of half intensity is +/- 10 degree. However, one may need wider beam angle than what this provides.

Right now the system uses 12 LEDs in parallel. We are working on the ways to reduce the number of LEDs to about 5-6 by improving the charge buffer system. We selected parallel configuration as it is easy to provide a large current instead of high voltage. Also, in such configuration each LED is independent of the other and failure of one LED does not disturb the function of whole flash.

Learning from the experience for wildCENSE[21] project the node has been designed employing numerous noise reduction techniques. To reduce the ADC noise, a LC filter (L=10mH and C=$0.1\mu F$) has been added to the ADC pins of the micro-controller. Also, the AVcc is connected to the main power supply

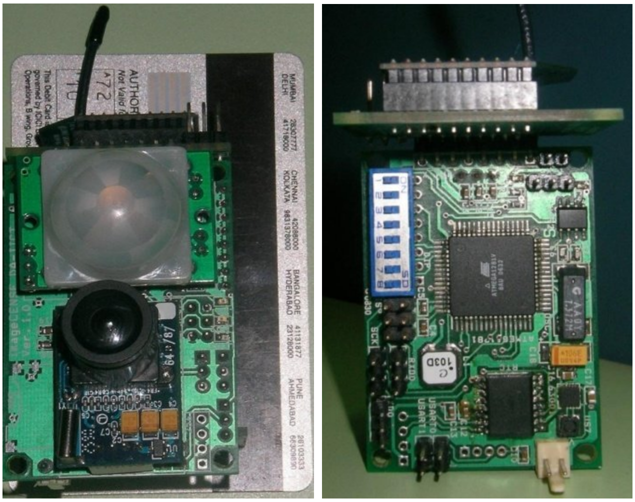

Fig. 2. tigerCENSE node, Front and Rear view

without any in between fan out lines, to reduce noise [22]. The whole PCB has copper pouring to keep the noise at a minimum level as also to dissipate any heat generated by the node. Figure 2 depicts the PCB made for the node. The size of the populated PCB is 3.8 x 5.6 x 3.1cm^3, weighing only 43 gms excluding power supply and enclosure.

5 Experimental Results

Based on the expected speed of movement and width of walkways(assumed 10 feet) and distance of node from walkway to be 10 feet, a delay of 1.8 sec is kept

Fig. 3. Prototype box used for testing

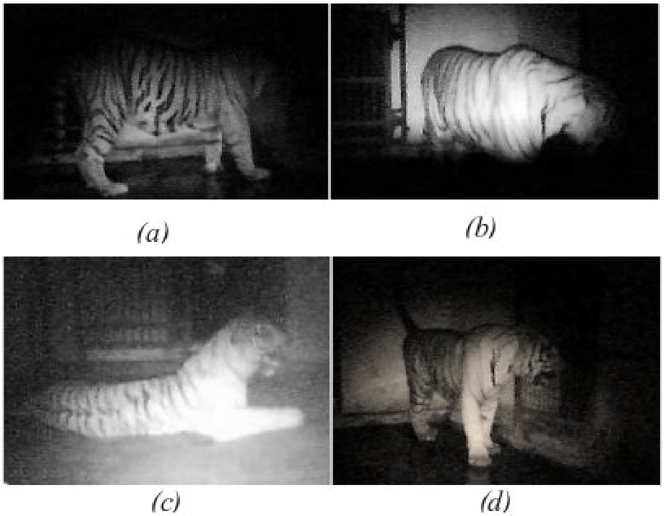
(a) (b) (c) (d)

Fig. 4. Photograph clicked using IR Flash in dark night

between the PIR interrupt and capturing a photograph of the object. Minimum delay achievable seems to be 250 ms. It is extremely small time as compared to the response time of traditional traps which ranges into few seconds. Also, minimum delay between two continuous shots has been found out to be 1s. It is dictated by the time to transfer the data from Image Sensor to Micro-SD card and can be reduced by buffering it in a fast memory, if one needs to collect a burst of images.

To find out the minimum suitable ON time for the IR flash to capture the stripes clearly on its body, we deployed a prototype box, as shown in Figure 3, near the cage of a tiger in Kankaria Zoo, Ahmedabad, Gujarat. We programmed the node to take pictures with increasing ON time starting from 10ms to 70ms with an increment of 10ms. Figure 4 shows some of the photographs taken by the node in the dark using an IR Flash. From the experiments we concluded that an ON time of 30ms is sufficient to get a reasonable quality image with clear stripes. We need flash time to be as low as possible to reduce blur due to motion. Some commercial digital cameras use 125 ms flash time, which leads to significant blare to the extent of image being useless.

6 Conclusion

This paper presents an operational prototype for wildlife monitoring using WiSN. tigerCENSE is compact, non-intrusive, energy efficient and reliable sensing device. It not only has all the capabilities of traditional traps but has also addressed most of the drawbacks of them. Integrated development has led to minimum delay of 250 ms. The software protocols and the hardware implementation have all been carefully crafted to optimize the systems energy requirement. Further, utilizing the solar recharging mechanism, node lifetime would be enhanced.

In future, we can also add some micro-climatic sensors in order to collect ambiance information. Also, to reduce the amount of wireless data transfer, we can deploy in-situ digital signal processing technique. This will help us save both power and time which is highly crucial for the success of the system.

tigerCENSE has been mainly developed to help in the research and conserving tigers. Besides the use for conducting a census, camera traps can be very useful for many management tasks. It can be used for human surveillance as well. In the past, traps have photographed poaching parties. Although due to latency in collecting the photograph target animal prey were not saved but it eventually led to the arrest and conviction of known offenders.

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