The University of Tokyo

# Basic Research in Human-Computer-Biosphere Interaction

（計算機を介した人と生態系のインタラクションに関する基礎研究）

by
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## ABSTRACT

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This thesis presents the author's vision of Human-Computer-Biosphere Interaction (HCBI) to facilitate a sustainable society. HCBI extends the subject of Human Computer Interaction (HCI) from countable people, objects, pets, and plants into an auditory biosphere that is uncountable, complex, and non-linguistic. Utilizing HCBI to experience forest soundscapes can help us feel one with nature, unaffected by physical distance. The goal of HCBI is to achieve ecological interaction between humanity and nature through computer systems without causing environmental destruction.

To accomplish this, information connectivity must be created despite the physical separation between mankind and the environment. This combination also ensures ecological neutrality. This paper presents the concept overview, related work, method and developed interfaces. Using prerecorded animal calls, bio-acoustical feedback from the target wildlife was produced. This thesis focuses primarily on reviews of the design and evaluation of a bio-acoustic interaction system utilizing tracking collars, microphones, speakers, infrared cameras, infrared heat sensors, micro-climate sensors, radio-tracking devices, GPS devices, radio clocks, embedded Linux boards, high capacity batteries and high speed wireless communication devices.

Furthermore, this paper demonstrates that bio-acoustic based food chain information in a biosphere is a potential nonverbal information interface among human beings, computers, and the biosphere and can facilitate interaction with life in ecosystems such as wild animals. Furthermore, the study investigates the potential application of a wildlife presence detection method based on their animal call detection and remotely controllable capacitance sensors for wildlife telemonitoring in ecological studies, which could integrate computer systems into the global ecosystem.

# CONTENTS

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*To my family members*

# Chapter 1

# Introduction

## 1.1 Incompatible Relations between Human Beings and Nature

Human beings seem incapable of peacefully coexisting with nature and the often expressed desire for sustainable relations between man and the environment sometimes appears to be an unobtainable dream. It sometimes seems that the best way to solve all of the world's environmental problems would be to destroy all civilizations. However, since this is not an acceptable choice, might it not be possible to separate humanity more completely from nature? If this could be accomplished, destructive events, such as "roadkills", which are a significant threat to some endangered species, would not occur. It is an ironic truth that the vehicles driven by nature-loving tourists (eco-tourists) are significant threats to wildlife and result in numerous animal deaths.

In ancient times, interactions between nature and human societies were significantly less frequent due to cultural and mythological reasons. Before human beings became capable of leveling mountains with heavy construction vehicles, humanity and nature were physically separated but spiritually and emotionally connected. Japanese farmers prayed to gods in seasonal festivals for the weather conditions needed to ensure successful crop production and the general population was taught to respect the gods that resided in and protected the mountains. Because of this, wild animals and their habitats in the mountains were left undisturbed for the most part and Japan's history and culture evolved in benevolent interaction between nature and humanity. Indeed, society and even business activities paid respect to the traditions and cultural aspects of nature until the human development process known as "urbanization" began spreading. With the advent of urbanization, human society created a paradox in its relationship with nature.

For example, it would be reasonable to ask if we really believe we are protecting the natural environment when developing mountain areas with construction vehicles in order to create "ecologically-friendly" residential areas. If humanity desires to live in ecological harmony with nature, why is it necessary to level mountains and destroy forests?

Recent technological and information advancements, including satellite imaging, have been unable to confirm the presence of mythological creatures in undeveloped natural locations, and very few humans now believe in the existence of gods that control weather or other farming conditions. However, because we no longer embrace the presence of such historical and cultural metaphors in our daily lives, especially in city life, there has been little outcry at the severe devastation of nature brought about by the urbanization process. Furthermore, the increased availability of information on delicate natural habitats provided by environmental movements to promote preservation efforts has ironically increased tourism to such areas, and has thus accelerated the speed of environmental destruction (**Murayama 2006**).

Therefore, to balance human civilization with nature, mankind must transform its relationship with the environment, which is being destroyed by urbanization.One example of how information provided to raise understanding of environmental issues that had a negative impact on wildlife can be found with the Iriomote Cat *(Felis iriomotensis).* This wild feline (**Figure 1.1**), which about the size of a domestic house cat, is found solely on Iriomote island of Okinawa Prefecture, located in the southern Ryukyus of Japan.

The species was discovered by Dr. Imaizumi in 1967 (**Imaizumi 1967**). However, once information on the cat became widely disseminated, the cat also gained significant economic value in terms of tourism, and numerous eco-tourists have visited the island in hopes of seeing the endangered cat before it becomes extinct.

As a result, the most significant threat to that species is now vehicles driven by eco-tourists. As the number of such tourists increases, so too does the number of cars rented and cats killed. Perplexingly, since the news media first reported this ironic fact, the fame of the cats increased further, resulting in even more visits by eco-tourists and Iriomote Cat roadkill deaths. The situation is particularly serious given that fewer than 100 members of the species are thought to exist.

## 1.2 Background

If information technology could be used to provide us with the simulated experience of being close to nature while promoting the necessity of nature conservation, the number of road kills of the endangered species in world heritage areas by eco-tourists might decrease. Even though conservation scientists have actively advocated environmental protection by describing current critical situations and reaching out to everyone with state-of-the-art information technologies, a high-resolution picture of a endangered animal killed by a car, such as that shown in **Figure 1.2**, can never be more than human-computer interaction, and thus will be ineffective at preventing further such deaths.

What is missing is not knowledge and technology, it is an interface by which we can commune with nature, where destruction is occurring at this moment, and experience the current state of incompatible relations existing between human being and the natural environment. Therefore, a methodology that separates human beings from natural environments that require preservation is necessary.


Figure 1.1: The Iriomote Cat (*Felis iriomotensis*) has been listed as an Endangered Species by the International Union for the Conservation of Nature and Natural Resources (IUCN) ©Iriomote Wildlife Conservation Center, http://iwcc.a.la9.jp/img/topimg.jpg

Figure 1.2: An Iriomote Cat killed by an eco-tourist driven car. Vehicles driven by eco-tourists have become a significant threat to the species. [http://eco.nikkei.co.jp/column/yamane_kazuma/article.aspx?id=MMECce004023102007&page=4]

Nevertheless, the sense of belonging to nature is essential for human emotional balance. In Japanese Zen Buddhism, it is taught that the beautiful forest sounds of falling trees, singing birds, buzzing insects, swaying leaves, and trickling implicitly imprint the beauty of nature in our minds. Thus, when we are emotionally stressed, recalling the beauty of nature can help us recover a sense of well-being (**Suzuki 1959**). A reverent attitude towards nature can also provide a starting point for finding a way to mental and physical well-being (**Williams 2001**), while distancing ourselves from the technologies of modern life and evoking the beauty of nature can help us slow down the pace of daily life.

If humanity and nature were physically separated, humans would be unable to cause “roadkill” accidents. Yet, it is also possible that if humans were more thoroughly informed about nature, they would once again give proper respect to historical and cultural metaphors. In this way, we would pay attention to the intangible interactions between nature and human society and restore what was lost during urbanization. These include the biological, cultural and mythological elements that were lost during the process of urbanization.

This thesis presents the author’s vision of Human-Computer-Biosphere Interaction (HCBI) through an introduction of a concept overview and related works as well as a developed interface and related discussion. This vision aims to facilitate interactions among people and remote animals and environments by means of computer systems in a manner that is similar to present day interactions among average people, their pets and their surrounding environment. It also proposes physical and landscape approaches that support the author’s view of future society by incorporating HCBI-based designs and interfaces. It is believed that in this way, we can create intangible but perceivable interactions between nature and human society in a matter similar to the interactions that took place in ancient times.

While not intended to propose a solution to any one single problem, this thesis will proposes new HCBI-based designs and interfaces that are expected to support future society via a multidisciplinary approach.

## 1.3 Motivations

The initial goal was to design HCBI interaction beyond physical and language barriers in order to create a better society. To that end, the author was assisted by the currently ubiquitous and ever expanding computer information technology and mobile computing hardware market, as well as the system downsizing trends that are creating ever more powerful palm-sized devices.

For example, current cell phones are equipped with numerous additional functions and accessories including large liquid crystal displays, large memory storage, infrared sensors and Internet access. The central processing units (CPUs) of such phones now operate at speeds in excess of one GHz, a speed that numerous personal computers still in use cannot match. Thus, it is possible to use such compact high-tech equipment for HCBI. However, the system downsizing trend provides us with a functional smart device in exchange for increasingly complex software and hardware architectures. In short, it is difficult to modify cell phones into wildlife monitoring tools because of the lack of a shared language between humanity and the biosphere. Despite this, using information technologies, it was possible to design a better interaction method that included the following aspects:

### Physical Separation:

Current information technologies enable communication between a caller on a distant planet and a receiver deep on the ocean floor through multiple wireless links. Such technologies allow us to communicate over long distances, in real time, through various networks without direct contact between the caller and the receiver.

### Information Connectivity:

Current information technologies are capable of conveying not only explicit objects, such as text and vocal messages, but also nonverbal messages, even though feelings and moods are often vague and nebulous. Despite limitations, application of new aspects and interfaces are advancing information communication in ways that extend human and biosphere interactions beyond the language barrier.

### Ecological Neutrality:

By combining the two given aspects, physical separation and information connectivity, nonverbal information interaction has been created between human beings and the biosphere. However, these are “virtual” interactions, and their environmental impact never exceeds their virtual impact. This allows us to create virtual impacts on wild animals while never physically interacting with them. In doing so, we can exchange food chain information between human beings and animals in a way that gives eliminates the possibility of damage to the biosphere. For example, it can eliminate the need for road constructions that physically split local biospheres and thus stop the roadkill deaths mentioned previously, even if it cannot restore the animal lives that have been lost.

By combining the three aspects, HCBI was designed and its potential for reducing the degree of incompatibility between human beings and the environment was evaluated.

## 1.4 Thesis Structure

In this section, the author will present an overview of the topics and structures of information discussed in this thesis and describe the research activities that were undertaken over the course of this Ph.D research.

### Chapter 2: Human-Computer-Biosphere Interaction (HCBI)

In this section, the concept of HCBI is introduced from the following perspectives. A literature survey and analysis of Human Computer Interaction (HCI) research was conducted to develop a more cohesive perspective of what the research community refers to as non-verbal interaction among human users. In addition, a literature survey and an analysis of Human Computer Pet Interaction research was conducted to develop a more cohesive perspective of what the research community refers to as non-verbal interaction between human beings and their pets. The author then explores “Human-Computer-Biosphere Interaction” and its relationships to HCI and Human Computer Pet Interaction (HCPI) in order to describe the clear differences among the definitions.

This research is primarily focused on bio-acoustic-based Human-Computer-Biosphere interaction, where a new academic field exploring human-biosphere nonverbal interaction in ambient ways has the potential to emerge. Such technologies should allow users to experience the sense of belonging to nature in ways that minimize environmental destruction. This chapter also proposes methodologies that facilitate information interaction between human and nature through computer systems by means of acoustic ecology. The chapters that follow address the development and evaluation of these proposed methodologies.

## Chapter 3: Experiment to Design Information Connectivity between Human Beings and Biospheres under Physically Separated Conditions

To evaluate the effects of HCBI, it was necessary to develop a system by which human beings could interact with remote biospheres. This chapter focuses on the development of a system that allows us to interact with wildlife through the use of acoustic ecology aspects. This made it possible to ascertain whether humanity could have acceptable interactions with biospheres through computers. To this end, the following two points must be accomplished:

1. Physical separation between human beings and the target biosphere
2. Human-biosphere interaction through a computer system

In this chapter, an evaluation experiment conducted on a target animal equipped with a wearable device is discussed to demonstrate the effectiveness of HCBI on wildlife monitoring applications.

## Chapter 4: Validation of Information Presentation in Biosphere based on food chain relationships

In this chapter, the author examines an intensive experiment performed to evaluate HCBI effects from two directions, from human beings to biosphere interaction and from biosphere interaction to human beings, through computer systems. The experiment was intended to accomplish the following two points:

1. To provide background for more intensive experiments evaluating

Human-Computer-Biosphere interactions.

2. To evaluate biosphere-human interaction through computer systems in order to enhance information connectivity.

In this section, an evaluation experiment was conducted on a target animal equipped with a wearable device to demonstrate the effectiveness of Human-Computer-Biosphere interaction on wildlife monitoring applications.

## Chapter 5: Development of Wildlife Detection System

Prior to installing the HCBI system in the field, it was first necessary to create a methodology that would efficiently detect the presence and arrival of wild animals. In this chapter, the methodologies and development of a system for close- and mid-range wildlife detection are discussed. The system was determined to be capable of detecting approaching wildlife in unpopulated humid environments over long periods of time and at low power consumption

## Chapter 6: Ecological Neutrality

In this chapter, the method by which HCBI could facilitate ecological neutrality is discussed and a comparison with other current environmental preservation methods is performed by reviewing related works on current prevention methodology and by proposing an HCBI application for traffic accidents. Closed and materially closed ecological systems are also reviewed while describing how HCBI could be applied to each.

The point is that are we would be have increased controllability. There is currently no perfect solution to environmental problems, which exist because of environmental imbalances stemming from human society.

## Chapter 7: Conclusions

This thesis will conclude with a review of each preceding chapter.

## Appendix1

This chapter described HCBI based interface design Wearable Forest is a garment that bioacoustically interacts with distant wildlife in a remote forest through a networked remote-controlled speaker and microphone. It expresses the unique bioacoustic beauty of nature and allows users to interact with a forest in real time through a network to acoustically experience a distant forest soundscape, thus merging humans and nature without great environmental impact. This novel interactive sound system can create a sense of unity between users and a remote soundscape, enabling users to feel a sense of belonging to nature even in the midst of a city. This chapter describes the theory of interaction between the Human and the Biosphere through the design process of the Wearable Forest concept.

## Appendix 2

This chapter described HCBI based interface design. Tele Echo Tube is a speaking tube installation that vocally interacts with a remote forest through a networked remote-controlled speaker and microphone through the slightly vibrating lamp-shade like interface. It allows users to interact with Mr.Yambiko, “a mountain Echo” in a forest in real time through an augmented echo sounding experience with the physical vibration over network, experiencing a distant forest soundscape in immersive and ambient ways. This novel interactive multi sensory system can create a sense of unity between users and a remote soundscape, enabling users to feel a sense of belonging to nature even in the midst of a city.

# Chapter 2

# Human-Computer-Biosphere Interaction Concept Proposal

## 2.1 Human-Computer-Biosphere Interaction

The Human-Computer-Biosphere Interaction (HCBI) concept (**Figure 2.1**) proposed by the author is an extension from Human Computer Interaction (HCI) and Human Computer Pet Interaction (HCPI). HCI is described below as:

> *"A discipline concerned with the design, evaluation and implementation of interactive computing systems for human use, and with the study of major phenomena surrounding them"* (**ACM SIGCHI 1996**).

In this research, the author proposes HCBI, which extends HCI and HCPI from countable objects, pets, and plants to their auditory environments, which are uncountable, complex and non-linguistic soundscapes.

Computer supported cooperative work (CSCW) uses computer systems to exchange messages that support task-specific activities. For example, we routinely exchange our ideas, thoughts, theories, and other messages by encoding and decoding words via computer media, cell phones, email, and chat systems. However, in our daily social interactions, we also unconsciously exchange and share a significant quantity of non-verbal cues related to emotion and physical states. This cue information helps us to find appropriate contexts during the verbalization process so that the intended message can be easily received and understood by its intended recipient.

The purpose of "*Tsunagari Communication*" is to foster a feeling of connection between people living apart from each other by exchanging and sharing cue information. One example of this is the "family planter system" (**Figure 2.2**), which uses network and HCI technologies (**Itoh et al. 2002**).

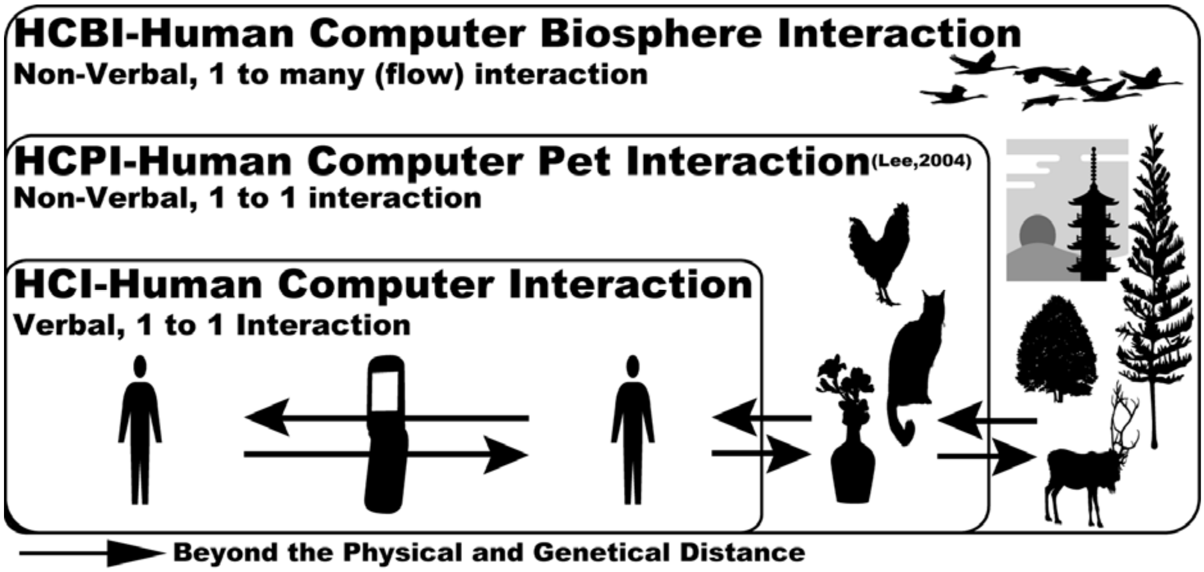


Figure 2.1: Human-computer-biosphere interaction (HCBI) concept, an extension of HCI and HCPI. © 2008 Hiroki Kobayashi and Ryoko Ueoka

Implicit information communication enables a new form of non-linguistic and non-verbal expression and interaction among different species that is unrestrained by physical distance. Lee presented HCPI, a novel type of physical interaction and symbiosis between humans and pets using a computer and the Internet (**Lee et al. 2006**). Ueoka (**Ueoka 2001**) built an interactive communication system on the Internet. This system consists of a remote-control food feeder with position sensing aimed at enhancing the shared relationship between humans and house cats.

In previous studies, the author participated in the development of a networked bio-acoustic streaming and recording system, using which, environmental sounds in a subtropical forest on Iriomote Island (**Figure 2.3**), were and are continuously streamed in real time via a networked microphone (**Kobayashi 2000**). The technology behind this networked bio-acoustic streaming and recording system is also used for "*AQUASCAPE: the stethoscope for the Earth's waters*", through which Internet users can listen to aquatic sounds in real time. These include, for example, water movements of a pond in Tokyo, living creatures in a Japanese garden in Kyoto, and a street in Mumbai City, India (**Aquascape 2007**).

Thus, the goal of HCBI interaction is the employment of multisensory devices to facilitate the exchange of information between human beings and wildlife, and in so doing, to influence a target species remotely using multimedia technologies. This study is not merely an attempt to passively monitor, transfer, process and archive information on remote environments using multimedia systems, it also aims to facilitate interactions among people, animals and remote environments in a manner similar to the interactions currently possible between people, their pets and their normal environment.

## 2.2 Review of Related Works

Previously, a number of studies were conducted that explored ways of establishing interactions between computers and wildlife by means of HCI, HCPI and other methods. However, while the technologies used in some of those projects are very similar to those of our research project, our method of interaction between human and wildlife, which allows users to experience nature via computer systems, remains unique.

Botanicalls (**Bray et al. 2006**) was developed to provide a new way for plants and people to interact in order to develop better, longer-lasting relationships that transcend physical and genetic distances. This system allowed computers to become an intermedium among different biosphere species in a way that allows non-linguistic expressions to be perceived and understood by individuals of differing species, something that would appear to violate the rules of linguistic science.

The Botanicalls system allows plants to place phone calls when human help is required. For example, when a plant on a Botanicalls network needs water, it can call a person and ask for exactly what it needs. When people phone the plants, the plants appraise callers of their botanical conditions.

Figure 2.2: “Family Planter” terminals on the Botanicalls network are connected to each other through a network. The system detects human motion and shares it with other terminals in real time. The optical fibers at the top of the terminal illuminate to indicate when a human is detected and then rotate to orient on human motions. These exchanges are designed to blend into the everyday life of the users.

Furthermore, HCI technologies can be employed for wildlife monitoring to remotely observe target animal behavior. Such usage allows every element of a target animal, from its movement pattern to excrement disposal, to be monitored by biology researchers over the course of its life. A normal system incorporates radio tracking and positioning utilizing a VHF signal transmitter collar and receiver, as shown in **Figure 2.4**. In the case of the Iriomote Cat, researchers can use triangulation to estimate the current position of a monitored cat from the signal strength of its radio.

More recently, for audio-visual monitoring, weather-resistant video systems are commonly employed by researchers to monitor animal movements. The author previously studied an audio-based monitoring method that involves recording and analyzing bio-acoustic information obtained from several monitoring sites simultaneously (**Kobayashi 2006**)

Similarly, the Electronic Shepherd (ES) project (**Thorstensen 2004**) at Telenor R&D provides a tracking system for monitoring the movements of grazing sheep. The system, which was originally created to address the needs of sheep and reindeer farmers seeking a way to keep track of their animal during the grazing season, utilizes several wireless devices for positioning and data communication. The main difference between the ES project and this research is that the former tries to trace the movement of a group of sheep via various wireless communication technologies, while this research focuses on interactions with single animals in the wild.

The ZebraNet project (**Juang 2002**) at Princeton University involved the creation of a tracking system for monitoring zebra movements. The system is designed to calculate the latest position of a number of zebras in areas where no cellular service or broadband communications is available. The system utilizes GPS collars, flash memory, wireless transceivers and a small CPU. The primary difference between ZebraNet and the research described in this thesis is the smart device system which includes a GPS tracker, a CPU, battery, and wireless communication device. This device allows the latest positioning information to be calculated and transmitted to remote observers.

**Figure 2.3:** Live sound collected from a subtropical forest on Iriomote Island. A pair of networked microphones (wrapped in a thick black-colored sheet of waterproof sponge and a plastic hard mesh.) is tied to the trunk of a tree. Live sounds from the forest have been streamed to users in real time, 24 hours a day, every day, since 1997. *Photo (right) by SoundBum*

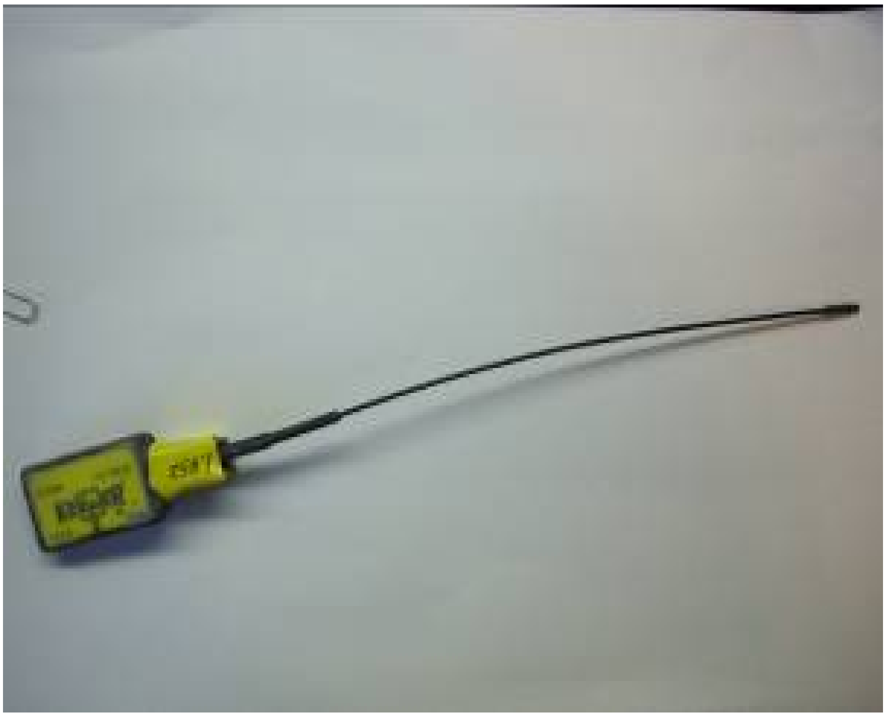

**Figure 2.4:** VHF signal transmitter collar – Positioning system

This non-verbal interaction also increased the efficiency of wildlife monitoring. In comparison to traditional one-way monitoring, acoustically active monitoring is unique and efficient because it actively interacts with the target and acoustically extends the observable period, thus increasing the probability of success by influencing the movement of the target wildlife. This achievement indicates that HCI technologies can facilitate remote interaction between computers and biosphere entities. As a result, it can provide a practical and effective countermeasure against further ecological destruction.

Moreover, these technologies have also been applied to nature education materials. Periscope (**Wilde 2003**), an educational tool, was created to provide information about the forest lifecycles during digitally enhanced children's "field trips" to woodland settings. The system uses a display, network device and a collection of Petri dishes fitted with RFID tags that enable children to conduct experiments with their results shown on the display.

Randell (**Randell et al. 2003**) demonstrated another type of digitally enhanced field trip for schoolchildren, in which pairs of children were equipped with a number of wireless devices and allowed to explore and reflect upon a physical environment that had been prepared in advance with a WiFi network and RF location beacons. While communicating with a remote facilitator by walkie-talkies and handheld PDAs, the children explore, examine and learn from the environment around them as they move through and interact with English woodlands.

However, no matter how advanced the technologies used, these are human centric interactions. We expect some perceivable feedback from others as a response to our inputs before we end an interaction. In contrast, in our daily lives, there are many non-human centric interactions. These include the sounds of birds, insects, swaying leaves, and trickling water in a beautiful forest, all of which can implicitly imprint the beauty of Nature in our minds. When we are emotionally stressed, recalling the beauty of nature can the help us recover a sense of well-being. A crucial factor here is not the means of conveyance, that is, words or language, but the sense that there is "something" hovering around or the atmosphere that we cannot precisely identify (**Suzuki 1959**).

This type of interaction follows the teaching of Zen Buddhism. Zen is one the products of Chinese culture, which developed in the first century A.D. after the culture's exposure to the Indian teachings of Buddhism. Suzuki noted the Japanese love of nature as follows:

> "It consists in paying nature the fullest respect it deserves. By this it is meant that we may treat nature not as an object to conquer and turn wantonly to our human service, but as a friend, as a fellow being, who is destined, like ourselves, for Buddhahood. Zen wants us to meet nature as a friendly, well-meaning agent whose inner being is thoroughly like our own." (**Suzuki 1959**)

Thus, the author proposes HCBI, which extends the range of interaction from countable objects, pets, and plants to auditory environments, which are uncountable, complex, non-linguistic soundscapes, much like Zen elements described above. By realizing HCBI, we can experience the soundscape of a forest, or other natural environment, which are integral to helping us feel one with nature. Furthermore, with HCBI telepresence, we can listen to and experience the global ecological system, integrating all living beings and their relationships, including their interaction with the elements of the biosphere. With HCBI, we can begin to interact with subjects beyond normal physical and genetic distances.

## 2.3 Interaction Design

### 2.3.1 From Bio-acoustic Information

Natural communities contain a wide spectrum of life forms that interact with each other (**Begon 1996**), and it is generally agreed that the essence of ecology is the study of ecological interactions among species in animal communities (**Begon et al. 1996**). In particular, animal communities in tropical forests have extremely complex interactions involving numerous species (**Ricklefs et al. 1993**) (**Leigh et al. 1996**), with the structure of natural sound in rainforests convincingly demonstrating the extraordinary relationships that exist among the many insects, birds, mammals and amphibians that inhabit these environments. If one creature starts vocalizing, others immediately join the chorus (**Bernie 1987**). These bio-acoustic interactions between animals vary depending on the biological diversity of the natural habitat.

This research used bio-acoustical information to develop a wildlife-computer interaction model and to propose a novel cybernetic interface for use as a mobile technology for human-wildlife bio-acoustical interaction.

### 2.3.2 Hypothesis

The author proposes a novel cybernetic interface that uses mobile technology to create human-wildlife bio-acoustical interaction. To establish interaction with wildlife, the monitoring system artificially creates a “prey field” to control the movement of the target wildlife under three conditions; predator-Prey relationship, interspecific communication and interspecific communication in mixed reality.

First, predators hunt for prey in their native habitat (**Figure 2.5**). Bio-acoustical information is one of the signals used by predators to detect the existence of prey. For example, in natural environments real frogs respond to the initial call of virtual frogs and begin singing in chorus. The predator then detects the emergence of a prey field using acoustic cues acquired from the frog chorus before approaching and entering the prey field near the system to hunt. Bio-acoustical interaction has thus been established and a predator hunts prey in its habitat, as shown in **Figure 2.6**. Bio-acoustic information is one of the deterministic factors by which a predator detects the existence of prey in its habitat (**Searcy 2005**), (**Krebs 1993**). A lack of prey indicates the absence of predators from the habitat.

Interspecific communication is considered to be a chorus produced by a group of members of the same species (**Figure 2.7**), similar to the packet Internet grouper (PING) command of the Internet control message protocol between two computers (**Muuss 1984**). A single individual, the caller, begins by calling to other individuals of the same species to confirm their presence (**Kobayashi 2006**). Other members of the same species then randomly respond to the call and thus report their existence to the caller.


Figure 2.5: Interspecific communication

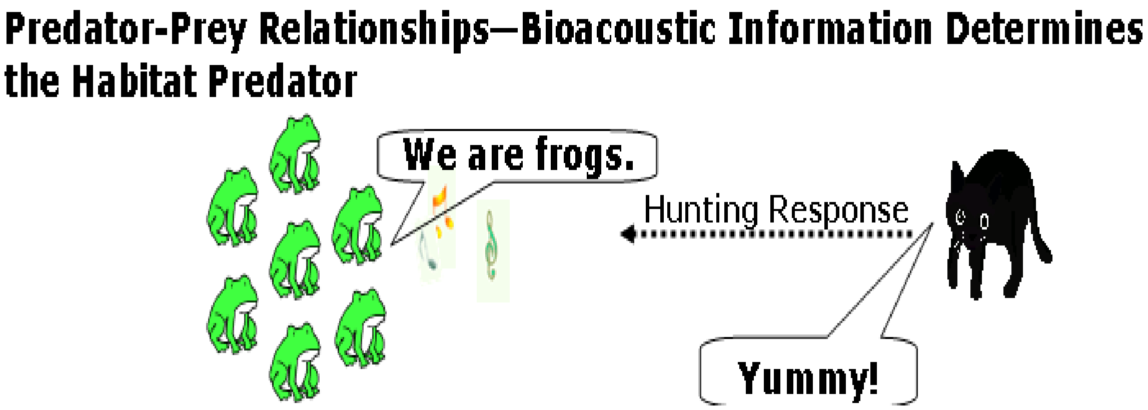


Figure 2.6: Predator-prey relationship

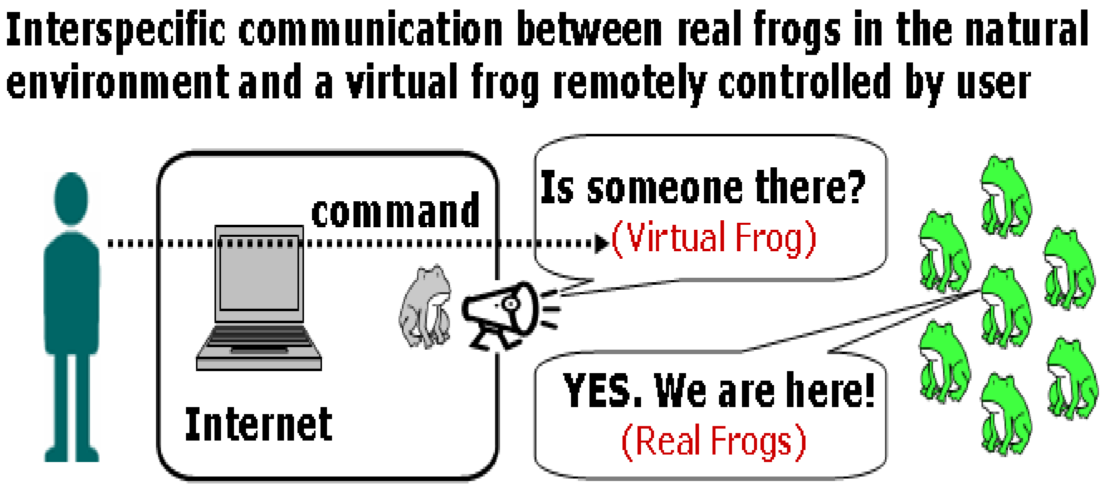


Figure 2.7: Interspecific communication in mixed reality

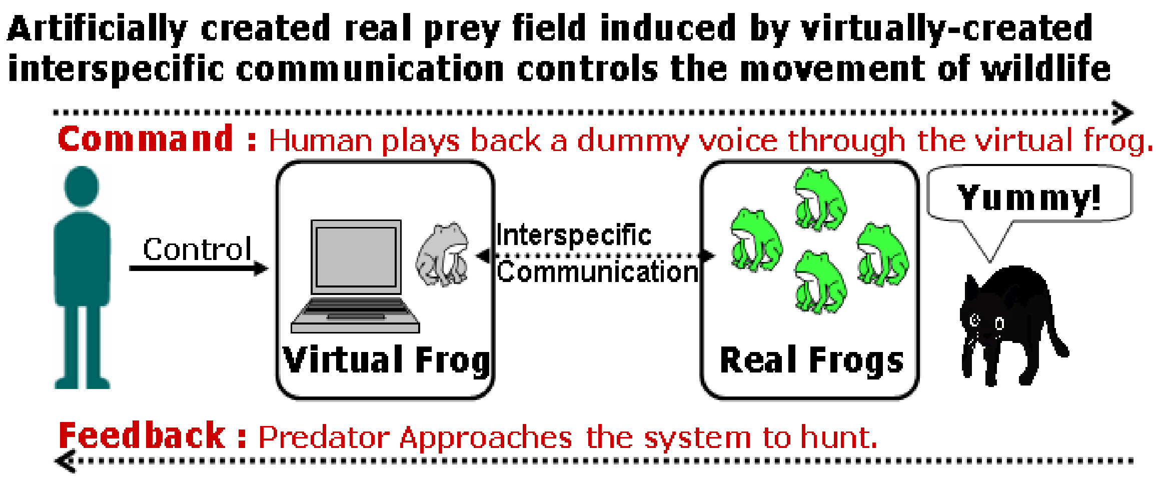


Figure.2.8: Bio-acoustical interaction instigated to control the behavior of a target species

Third, a species can conduct interspecific communication in mixed reality. **Figure 2.7** shows a user playing a prerecorded sound of an initial call from an acoustic speaker. The speaker is placed in the natural environment and remotely controlled by a PC over the Internet (**Kobayashi et al. 2006**). Real frogs answer the initial call and report their existence. The initial call - which is a virtual call broadcast from the speaker - can deceive the real frogs into believing that it was made by another real frog in the area.

Finally, to establish the wildlife computer interaction, the author proposes an interface that artificially creates an actual prey field to influence the movement of the target wildlife, as shown in **Figure 2.8**, under the three conditions mentioned above. The interaction method is designed to proceed as follows:

1. A user remotely controls the PC to initiate interspecific communication with real frogs by broadcasting an initial call through a speaker placed in the natural environment.
2. Real frogs in the natural environment respond to the initial call. The virtual and real frogs start singing in chorus.
3. The predator acoustically detects the emergence of the prey field through the frog chorus.
4. The predator then enters and stays in the prey field near the system to hunt, thus establishing bio-acoustical interaction.

To evaluate this hypothesis, the author participated in the construction of a system designed to evaluate the bio-acoustic interaction system using a networked remote sensing embedded system. In the evaluation system, instead of a user controlling the system to initiate interspecific communication, the system monitors the movement of the target wildlife remotely target wildlife remotely.

The challenge currently faced by conservation managers is the development of a behavior-control system for wild animal species whose positions and movement patterns are both unknown and unpredictable in a natural environment. An HCI system of this type needs to be small enough to be carried in the field by researchers, capable of being controlled remotely by system engineers, and “smart” enough to interact with wildlife nonverbally. Furthermore, the system must be capable of operating under the extreme conditions found in hot and humid subtropical forest environments until such time as the target wildlife species arrives at a monitoring site. This requires the use of weather resistant, energy efficient and highly stable equipment.

# Chapter 3

## Experiment to design Information Connectivity between Human beings and Biospheres under physically separated conditions

## 3.1 Objective

To evaluate HCBI effects, it was first necessary to develop a system that would allow humans beings to interact with a remote biosphere. This chapter focuses on development of a system that allows users to interact with remote wildlife through the use of acoustic ecology aspects. In this manner, it was possible to ascertain whether practical human-biosphere interaction using computers is possible.

## 3.2 System Background and Overview

Wildlife monitoring is the function of observing animal behaviors. From their movement patterns to excrement behaviors, biology researchers observe all elements of an animal's life using various tools. To accomplish this, three major observation tools are commonly used. They are, radio tracking for estimating locations, an automated analog camera system for visual monitoring, and an automated analog video system for animal movement monitoring.

The radio tracking system consists of a VHF signal transmitter collar and receiver as shown in **Figure 3.1.** In the Iriomote Cat study, the animals researchers desired to observe most were equipped with VHF signal transmitters. Observers could then use radio signal strength triangulation to estimate the animals' positions. Before commencing development of an appropriate new monitoring system, it is necessary to review the technologies, methodologies and weather issues related to current wildlife monitoring.

## 3.2.1 Technical Limitations

A radio-tracking system usually consists of a VHF signal-transmitter collar and receiver, as shown in **Figure 3.1**. With our system, a cat that researchers want to observe in its habitat is first fitted with a VHF signal transmitter. Observers can then use triangulation to estimate the cat's position from the transmitted signal. The VHF transmitter is equipped with an analog circuit that generates a radio signal and a small lithium battery that lasts between two and three years. However, due to characteristics of the analog circuit, there are slight frequency changes that could occur after several months. As a result, it can become increasingly difficult to estimate the position of a target animal by triangulation. To tune a receiver to the desired signal, the observer must first estimate the most likely frequency it will be found on, which may have shifted from the one that was originally specified.

As a result, in studies employing this methodology, it was found that positioning accuracy decreased toward the end of the transmitter's life. While using a global positioning system (GPS) tracking collar would appear to be an effective solution to this problem, Iriomote Cats are too small and light to carry the high-capacity battery conventional GPS devices require. Use of small, lightweight batteries that only last for a short periods would require frequent recaptures of the target animal for battery replacement, which could cause a variety of undesirable anthropogenic effects such as stress-induced illnesses and would be contrary to the aims of nature conservation.

Furthermore, employing GPS technology to the monitoring such a small terrestrial mammal is not practical because of interference to the GPS satellite signal by vegetation before it reaches the collar. Consequently, during this study, analog VHF transmitter collars were used, accepting the trade-off involved between the difficulties involved in estimating the peak frequency signal and the need to disrupt the target species as little as possible.

Automatic analog still and movie cameras were set up by researchers in numerous locations to capture images of the cats (**Figure 3.2**). However, there are several drawbacks associated with the use of analog equipment, particularly the fact that still cameras only have 36 photographs on a roll of film and the analog movie cameras have very high power consumption. These factors required observers to trek to the monitoring sites regularly to replace film or batteries and make it difficult to conduct long-term observations in locations that are difficult to visit regularly.

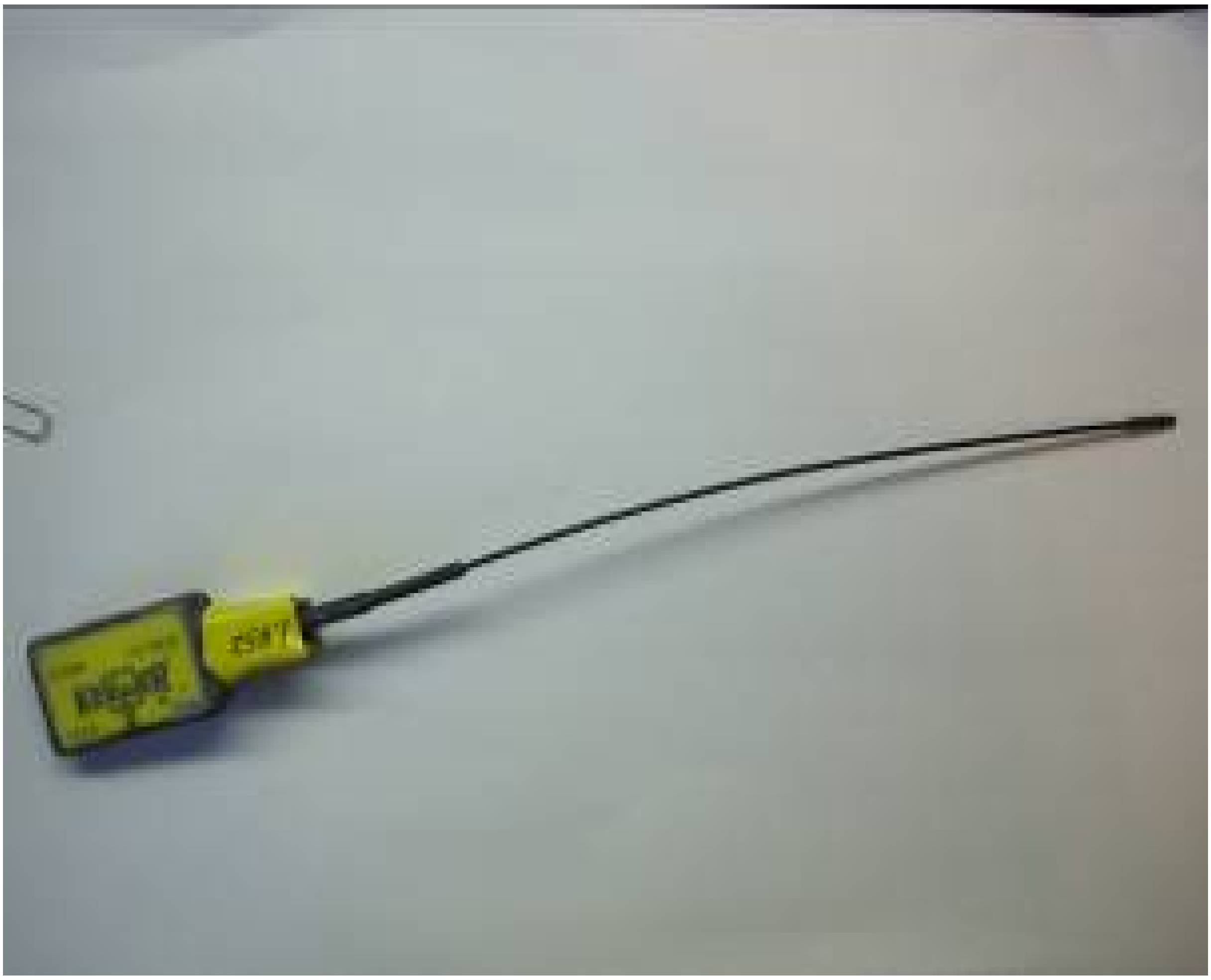

Figure 3.1: VHF signal transmitter collar – Positioning system

Figure 3.2: Automated photograph system with IR sensor

Furthermore, the gradual shift in the transmissions frequency over time, which reduces positioning accuracy, is also problematic. While a newer positioning system would solve the accuracy problem, battery weight and radio disturbance remain critical problems. Likewise, using automatic analog still and video cameras limits recording time because of limited data storage and battery capacity. Thus, it was not possible to simply apply available current technologies to the HCBI evaluation of this study and it will be necessary to develop a more efficient system that combines digital and analog tools in the future.

### 3.2.2 Methodological Limitations

In addition to the aforementioned technological problems regarding analog systems, another critical methodological problem existed. That is, the various observation tools mentioned above are all one-way observation systems and there was no appropriate method to facilitate two-way interaction between a computer and wildlife.

As a result, observations only occurred under the following conditions. First, the monitoring system has to be set up at an observation site and a researcher has to activate the power supply. The active system then waits until an animal happens to come within range. Then, if the animal moves in front of the system, its body will be detected via sensors (e.g., body heat, infrared trigger beam, pressure-sensitive pads etc.). As soon as the sensor stimulus is detected, the system response is triggered (e.g., the automated analog camera system takes a photograph of the animal). Ultimately, the animal leaves the monitoring site and the system ceases making observations. If the animal subsequently returns to the site, the abovementioned steps will be repeated.

Even if the current methodology is improved by adding additional functions, it remains inefficient. First, there is no guarantee that the sensor will correctly detect the animal. In fact, insolation heat often triggers IR-activated systems, resulting in photographs that show nothing but the location itself. Generally, the likelihood of the system taking a good photograph of a target animal facing the camera is very low. For example, of the 60 monitoring sites on Iriomote Island that are fitted with automated analog camera systems, each of which is visited at two-week intervals by researchers to replace batteries and film, the probability that just one of these sites will produce a usable photograph of a single animal averages one per month.

This indicated it was also necessary to design a methodology that facilitates two-way interaction between computers and animals as well as methodology to detect the animals more effectively.

### 3.2.3 Weather Durability

Excessive humidity is a very important consideration in the system design process. Iriomote Island is too humid to allow a system to be operated continuously. According to data obtained from the Japan Meteorological Agency, the average annual humidity in the Tokyo area from 1961 to 2006 was less than 70%. In comparison, the average annual humidity on Iriomote Island during the same period was approximately 80%. As a result, any system designed to work at humidity levels typical of the Tokyo area could not be guaranteed to work on Iriomote Island, especially since the island’s humidity often exceeds 90%.

In short, sensitive digital devices do not work well outdoors on the island (**Figures 3.3, 3.4 and 3.5**). An AXIS 2411 video server was first used to capture and digitize infrared images. According to the product specifications of the video server, the server was designed to operate under humidity conditions of 20-80%. During the system design process in Tokyo, which was conducted at average humidity levels of less than 80%, the video server worked perfectly.

However, during the second stage of the development, when the author transported the system to the island, it was found that the video server malfunctioned often due to the excessively humid island environment. Furthermore, there were no tools on the island with which to repair the sensitive digital device, so it was not possible to resolve the situation. Therefore, subsequent development efforts undertaken in Tokyo paid careful consideration to the effects of high humidity. However, since fully waterproof equipment is very expensive, it was decided to use normal equipment housed in an extra case for weatherproofing.

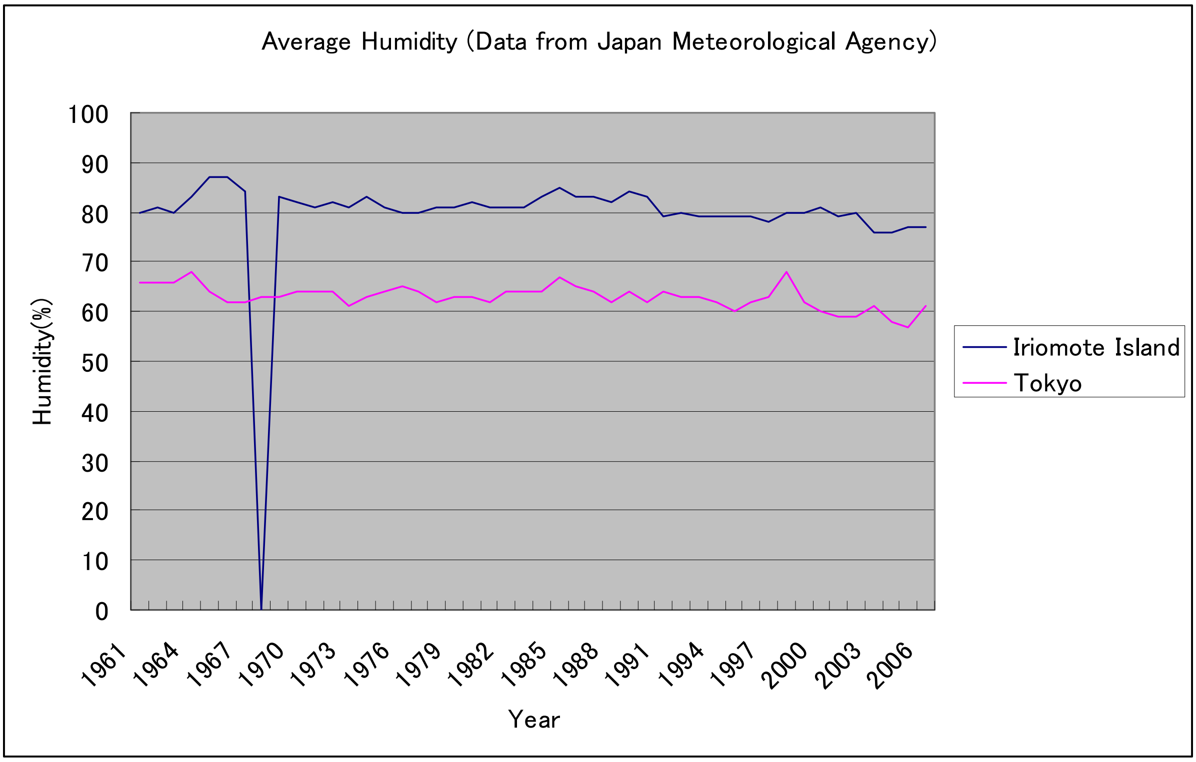


Figure 3.3: Yearly average humidity on Iriomote Island (blue) and Tokyo (red) in Japan from 1961 to 2006 [Japan Meteorological Agency] 1970 Data from Iriomote Station was unavailable.

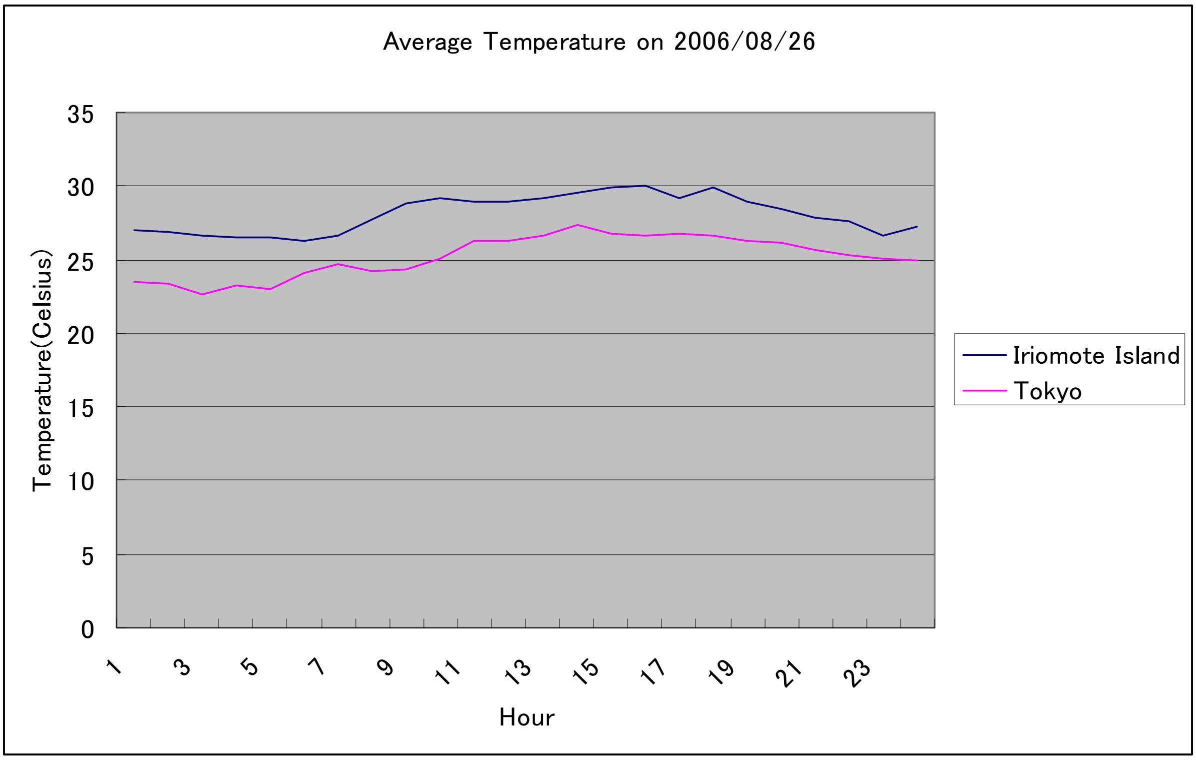


Figure 3.4: Average temperature on 2006/08/29 in the Iriomote Island (blue) and Tokyo (red) in Japan on 2006/08/29 [Japan Meteorological Agency]

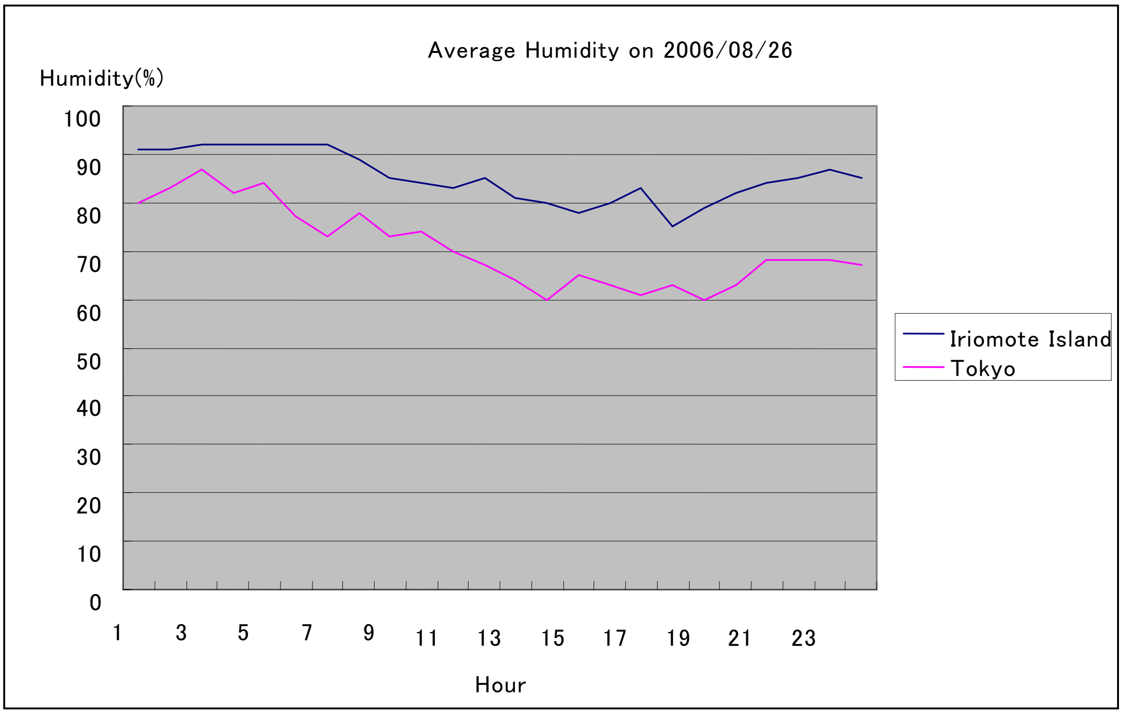


Figure 3.5: Average humidity in the Iriomote Island (blue) and Tokyo (red) in Japan on 2006/08/29 – [Japan Meteorological Agency]

## 3.3 Hardware Description

After considering this background, the author developed a networked, remote, embedded system for evaluating bio-acoustic interaction. The system utilizes a portable, networked, embedded Linux system with multifunctional sensors designed for efficient observation of endangered species. **Figure 3.6** shows a picture of the system carried by the author, and **Figure 3.7** shows an overview of the equipment.

### 3.3.1 Sensory Devices

The system is equipped with eight different devices: a weatherproof microphone, a weatherproof speaker, infrared camera, a VHF signal receiver, and temperature, humidity, GPS, and infrared sensors. The weatherproof microphone is used to record bio-acoustic signals in the field, while the speaker is used to play audio recordings. The microphone and speaker combination is designed to act as a sound trap for monitoring the biological behavior of wild animals.

The infrared camera controlled by an infrared sensor is designed to capture digital images of animals passing in front of the monitoring system at any time, day or night. The VHF signal receiver monitors signals broadcast from the small transmitters affixed around the neck of the target animals. The GPS and radio clock sensors were used to calculate the exact location and precise times the wild animal images were recorded. The temperature and humidity sensors continuously logged temperature and humidity in the field. See **Figures 3.6**, **3.7** and **Table 3.8** for details.

### 3.3.2 Data capture, processing and system description

The data capture/processing system (DCPS) captures and processes signals obtained from the sensors, and saves and transfers data through the data communication system (DCS) (**Figure 3.7**). The DCPS consists of nine subunits: an analog-to-digital converter, an audio encode/record, data storage, power control, VHF

Digital Signal Processor (DSP), system information, remote control, and system-control timer units. The analog-to-digital converter converts analog signals from the microphone, infrared camera, signal receivers, and temperature and humidity sensors into digital-format files. It also converts digital signals and audio data into analog signals that can be played as sound files through the speaker. All captured and preloaded data are stored on a compact flash card.

Figure 3.6: Main and Battery Units – The author carries the main unit (gray colored box) and battery (black colored box) units

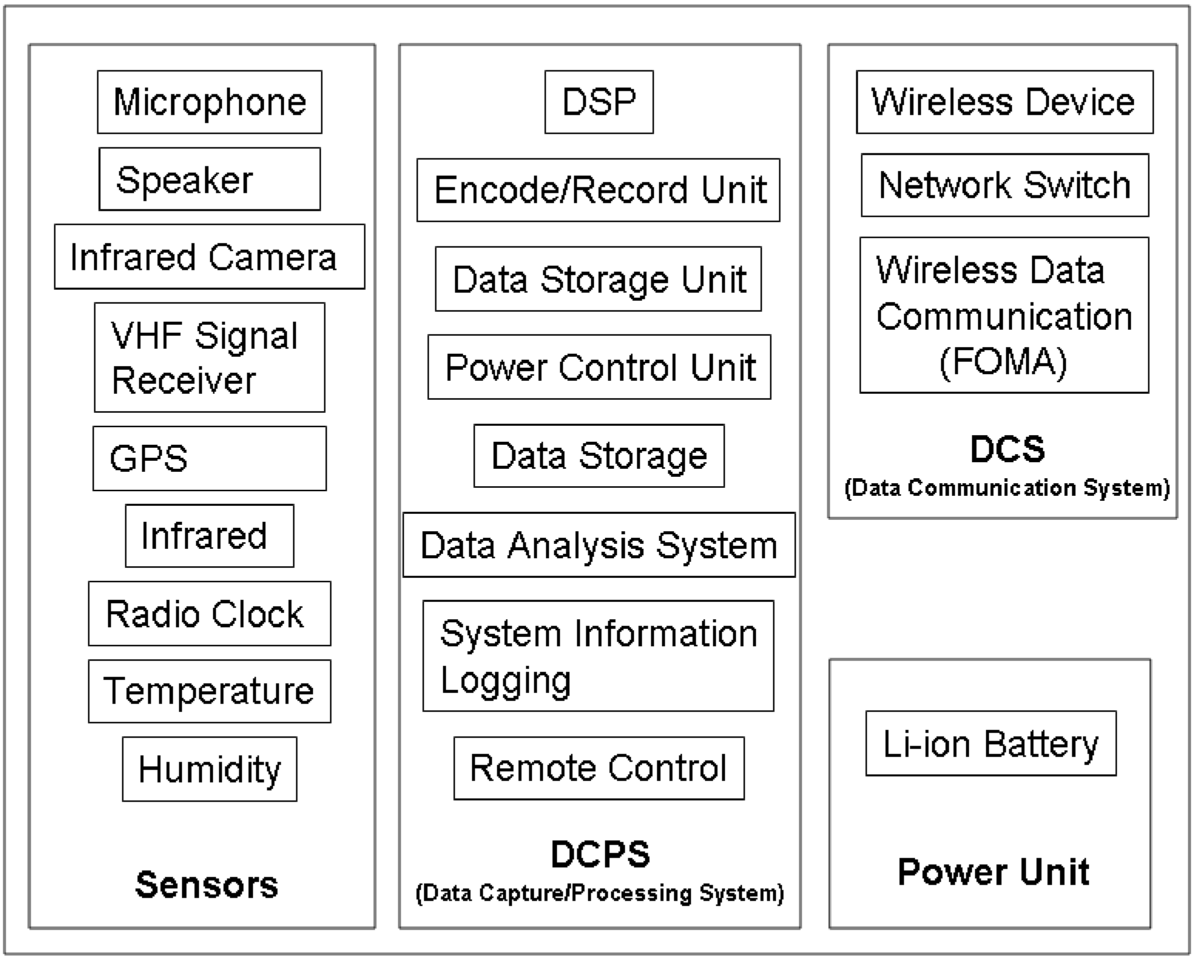


Figure 3.7: System components

To reduce power consumption, the power control units automatically regulate power usage by turning the subunits on or off as required. The VHF DSP unit monitors radio-tracking signals from receivers to estimate the location of animals wearing the small radio signal transmitters. When the animals approach the vicinity of the monitoring system, the VHF DSP unit sends a request to the power control unit instructing it to turn on the other units. Data can be analyzed by open source software running on a Linux-based embedded system.

All units and their subsystems are remotely controllable through a character user interface (CUI), such as one of the various shell programs. A timer equipped with a radio clock and GPS-based correction controls the power circuits through an operation scheduler, which controls the time intervals of the observation period.

### 3.3.3 Data communication system and power unit

The DCS provides a 100 Mbps Ethernet connection with a network switch for all DCPS units (**Figure 3.7**). It also provides an Internet connection to the DCPS units through a wireless freedom of mobile multimedia access (FOMA) data communication card developed by NTT DoCoMo, Inc. (**Kodama 2003**). The Internet data communication line runs at 384 kbps and provides monitoring capability from remote locations. In the future, an additional wireless data communication device will be built into the DCS so that the observed data can be shared among the mobile kits at other locations. The power unit is housed in a separate weatherproof case and provides more than one month of electric power. It connects to the system via a weatherproof power cable. The power units are rechargeable Lithium-ion batteries, and recharging takes a maximum of eight hours.

This hardware system was designed to facilitate bio-acoustic interaction between remote users and wildlife via a computer network. Using prerecorded animal calls, the system produces bio-acoustic feedback that induces reactions from members of the target wildlife species and affects the behavior of wild target species members in remote locations.

| | |
|---|---|
| **Audio, Storage and Communication CPU** | Intel XScale Processors 400 MHz, 64 MB SDRAM |
| **Video Unit CPU** | ETRAX 100 LX 100 MHz, 64 MB SDRAM |
| **Power Control and Signal Detection Unit CPU** | ETRAX MCM 100 MHz, 16 MB SDRAM |
| **Storage Unit** | Compact Flash Interface |
| **Communication Unit** | 10/100 Base-T Ethernet<br>FOMA 384 Kbps<br>Bluetooth 2.0<br>Wireless LAN IEEE 802.11/b/g<br>GPS (DGPS, WAAS, EGNOS and MSAS)<br>Radio Clock (JJY, NIST) |
| **Sensors Unit** | Infrared Camera (4 ch)<br>Microphone<br>Speaker 150~20000 Hz, 85 dB 1W/1m<br>Temperature<br>Humidity 5 to 95% +-5<br>Radio Tracking (2 ch) 0.1～1299.99995 MHz<br>Heat Sensor |
| **Electrical and environmental requirements** | Line Voltage: DC 12 V<br>Operating Temperature: to 70°C<br>Relative Humidity: 0% to 100% |
| **Size and Weight** | Main Unit: 51.7 × 39.2 × 22.9 cm, 15 Kg<br>Battery: 34.2 × 29.5 × 15.3 cm, 3.8 Kg |

Table 3.8: Hardware specifications

The interaction steps are shown in **Figure 3.9**. The system is unique in that people can observe the reactions of the target wildlife species when the system detects the approach of wildlife by VHR radio-tracking and heat detection. Observers are alerted to the presence of the target wildlife species via email.

## 3.4 Software Design and Method

The system uses Linux kernel 2.6 in flash and customized software. The advantage of Linux kernel 2.6 in flash is its simplicity and small size and that it does not require any specific operating environment for custom software. Since the time spent on software implementation was the most important constraint on the author's time, extensive use was made of BusyBox commands **(Busy Box, 1999)** to code the custom software in the shortest possible time.

### 3.4.1 Embedded Linux Operating System

Embedded Linux is a Linux-based operating system used in cell phones, PDAs, media player handsets and other consumer electronic devices. Combining the Linux kernel with a small set of free software utilities offered a workable alternative to the – usually proprietary – bespoke assembler or C software widely used in other embedded developments.

Compared to other embedded operating systems, the advantages of this approach are as follows:

- the source code can be modified and redistributed with ease
- it has a relatively small footprint – a typical installation may require less than 2 MB of memory
- it incurs no royalty or licensing costs
- it is mature and stable
- it has a large support base
-

In addition, at less than 20 seconds, boot-up time is very short, which is a major advantage for wildlife monitoring.

On the other hand, software complexity is the primary factor influencing programming times because programmers must select the required code, compile it, and evaluate the program’s stability for long-term operation from scratch. No written manuals exist because everything used all the products used were open source.

### 3.4.2 Software Functions

Because Linux kernel 2.6 is an operating system, it was necessary to develop customized software for controlling the entire monitoring system. After an extensive literature review, the software was written using a combination of different programming languages, including C, C++ and BusyBox commands (**Fork et al. 1998, Budd 1998, Murdocca et al. 2000, Patterson et al. 1998, Silberschatz 2004, Aho 1988, Josuttis 1998, Smith 1994, Arikan 2006, Levoy 1995, Hollenback 2005**). The final software supports the following three management functions.

The boot function shown in **Figure 3.10** is a second-stage program loaded and executed after a call by the onboard power time module. Depending on the detection of a VHF radio-tracking signal from the target wildlife species, this function decides whether the system should employ the observation sequence function or standby mode.

The observation sequence function shown in **Figure 3.11** is a second-stage program loaded and executed after a call is received from the boot function. This function actually turns on the power circuits of all the subsystems, performs pre-transactions, calls the main bio-acoustic interaction function and turns off all power circuits when the interaction is complete.

The bio-acoustic interaction function shown in **Figure 3.12** is responsible for initiating the sound interaction following VHF signal detection. The signal detection module then performs another scan to detect the radio signal one final time before executing the sound interaction. This is done to ensure that an animal equipped with a radio collar is still within 20 meters of the system when the interaction takes place.

**Mode ()**

```
{
  While (always true)
    Check the VHF signal from the wildlife animals for 30 sec

      IF VHF signal is detected,

            IF battery voltage is higher than safe level
                  Reset Power Timer module
                  Go to Observation Sequence ()

            Else

                  Send "Battery low" messages to observer

      Else

            Sleep 60 sec // move to standby mode

  Done
}
```

Figure 3.10: Pseudocode for the boot function

**Observation Sequence ()**

```
{
    //Initialization Process
    Turn on all subsystems
    Wait until all systems ready

    If any subsystem boots up faster than others,
    Capture all data from sensors and store in temporary buffer

    //Preparation Process
    Sync with GPS and radio clock
    Adjust internal clock timer
    Calculate absolute timestamp when system booted

    //Pre-transaction Process
    Transfer all precaptured date into storage unit.
    Process precaptured data with time stamp information.
    Save precaptured data into Data Storage Unit

    //Main Observation Part
    Call Bioacoustic Interaction ()

    //Running Control part
    IF total running time reaches maximum running time,
        Turn off all power circuits
    Else
        Go back to main observation part

    Done
}
```

Figure 3.11: Pseudocode for the observation sequence function

**Bioacoustic Interaction ()**

```
{
   //Signal Detection part
   At each scan for radio-tracking signal
   IF tracking signal is detected
   Send "signal detection" message to observer
      //Sound Interaction part
      While body temperature is being detected
            Capture environmental data
            Play back voice of prey animal
            Take and send infrared pictures to observer
            Save data in Data Storage Unit
      Done
   Else
   Done
}
```

Figure 3.12: Pseudocode for the Bioacoustic Interaction function – producing the sound interaction after VHF signal detection.

## 3.5 Results

In February 2007, a two week evaluation was conducted in the northern part of Iriomote Island (24°20’N, 123°55’E).During the evaluation period, the system was set up in the northern part of the island with all functions fully operational. The evaluation was started at 16:30 on Feb 16, 2007. A VHF signal receiver was set to monitor the signal from one of Iriomote Cats fitted with a radio transmitter collar. The previously recorded call of a White-breasted Waterhen (*amaurornis phoenicurus*) was used for the interaction lure to obtain feedback from the target. At 18:36:11, the IR sensor detected a heat source. DCPS then generated and sent a notification email to the observer, which was received at 18:36:40, 30 seconds after the heat source detection. However, it is possible that the infrared image digitizing system was still in the process of booting at that time as no image was captured for this event. At 18:52:49, the system detected the VHF signal and body heat at the same time. An infrared image was successfully captured and is shown in image ① one of **Figure 3.13**. At 18:52:50, the speaker started to play the pre-recorded sound when the target appeared on the right side bottom on of image ②. At 18:52:54, shown in image ④, the target reacted to the sound by looking back toward the system, which was the call of White-breasted Waterhen. The target kept looking at the system until 18:52:58, as seen in image ⑧ and **in Figure 3.15.**

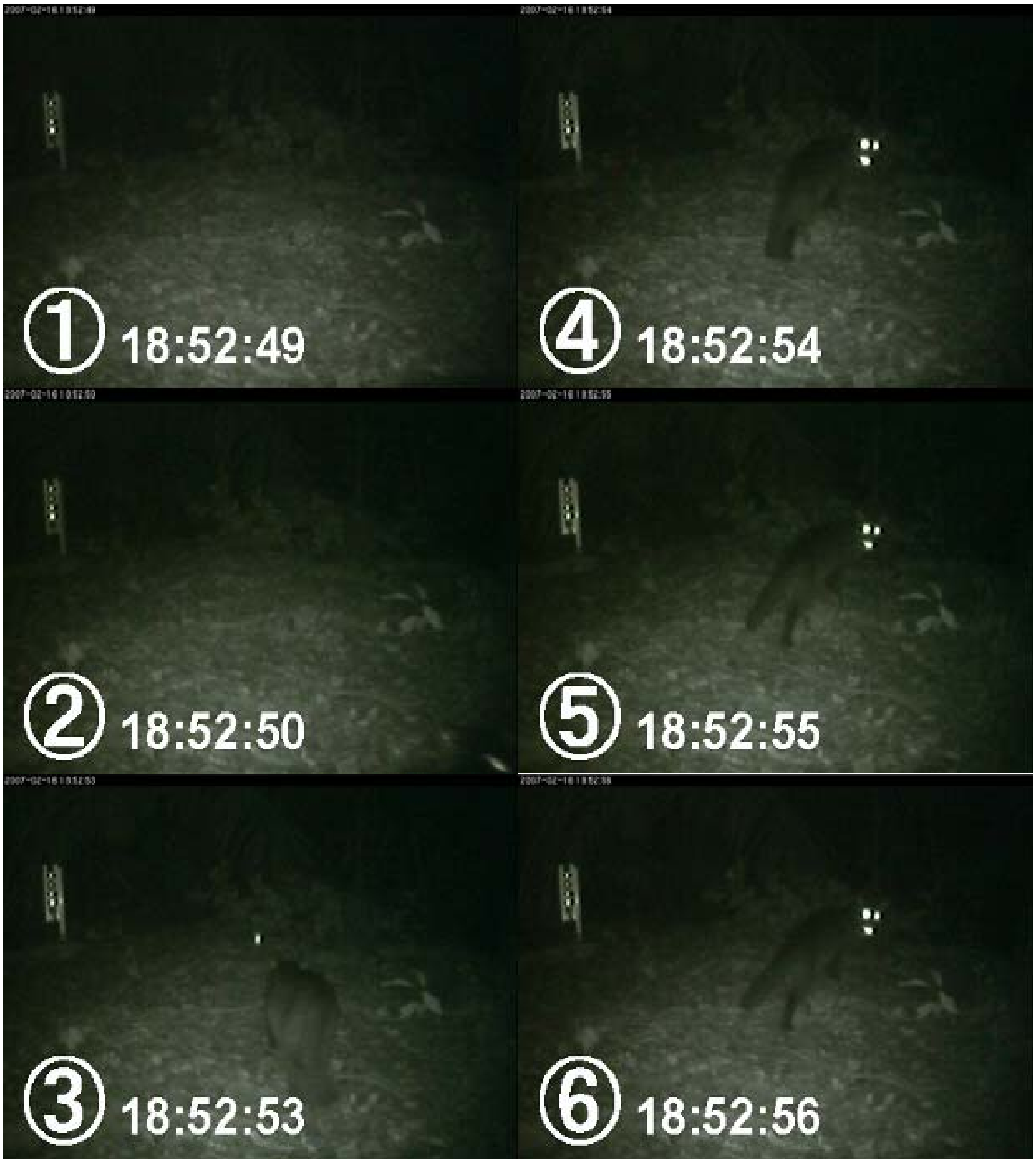


Figure 3.13: Infrared pictures taken by system (1~6)

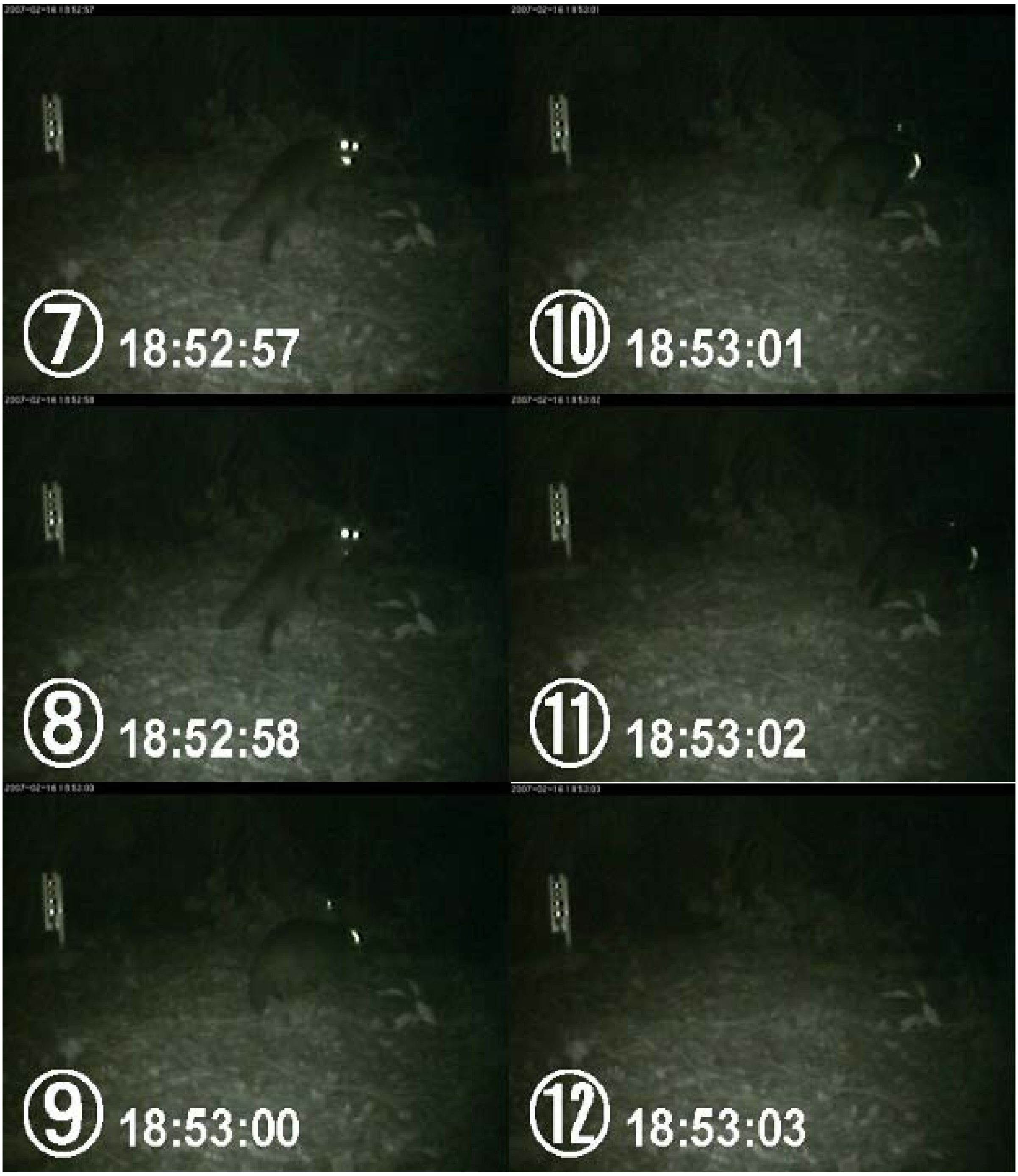


Figure 3.14: Infrared pictures taken by system (7~12)

| Date | Time | Cat | VHF | Heat | Pictures | Interaction | E-mail |
|---|---|---|---|---|---|---|---|
| 2007/2/16 | 18:52:49 | Approach | Detected | Detected | 1 | | |
| 2007/2/16 | 18:52:50 | Approach | Detected | Detected | 2 | | |
| 2007/2/16 | 18:52:53 | Approach | Detected | Detected | 3 | Effective | |
| 2007/2/16 | 18:52:54 | Response | Detected | Detected | 4 | Effective | |
| 2007/2/16 | 18:52:55 | Response | Detected | Detected | 5 | Effective | |
| 2007/2/16 | 18:52:56 | Response | Detected | Detected | 6 | Effective | |
| 2007/2/16 | 18:52:57 | Response | Detected | Detected | 7 | Effective | |
| 2007/2/16 | 18:52:58 | Response | Detected | Detected | 8 | Effective | |
| 2007/2/16 | 18:53:00 | Move | Detected | Detected | 9 | Effective | |
| 2007/2/16 | 18:53:01 | Move | Detected | Detected | 10 | Effective | |
| 2007/2/16 | 18:53:02 | Move | Detected | Detected | 11 | Effective | |
| 2007/2/16 | 18:53:03 | Move | Detected | Detected | 12 | Effective | Sent |

Figure 3.15: Record of Interaction – time series of captured data

## 3.6 Discussions

Bio-acoustic interaction between a wildlife species and human beings was successfully demonstrated. The target animal responded to a prerecorded call by looking back toward the system as if it were an actual prey animal. Furthermore, the cat's behavior was captured and transmitted in real time to a person living in a city. The person received emails from the system each time the cat responded to the prerecorded call. However, it will be necessary to conduct a longer experiment fully confirm the HCBI effect.

During the system performance and sound interaction evaluation, the radio-tracking system often failed to work properly due to frequency fluctuations from the VHF radio-signal transmitter. It is believed that this is a result of mechanical degradation of the analog transmitter circuit over time. The transmitters are designed to transmit an analog signal at a specific frequency set at the time the target animal is fitted with a collar. However, frequency fluctuations due to mechanical degradation are known to occur after the animals fitted with collars are released.

Since it is impossible to recapture the animal and measure the most recent peak frequency being emitted from the collar, observers must estimate this shift by adjusting the frequency dial of a portable signal receiver. Unfortunately, this estimation method is often complicated due to interference from geographical features, weather conditions, and proximity to power lines. As a result, the radio-tracking system will eventually cease detecting the signal from the target animal because the detection system remains set to the original frequency. This indicates that it will be necessary to develop a system that more effectively detects target animals.

The impact of behavioral modification of an endangered wildlife species living in its natural habitat through bio-acoustic interaction has the potential to offer an effective way of preventing animal deaths from motor vehicles. The system enables observers in remote locations to influence the movements of target wildlife species in real-time and can encourage target animals to focus their attention on the system by manipulating hunting or prey detection behaviors. If a wild animal is on a road and a car is approaching the area, the system can lure the animal off the road by means of bio-acoustic interaction.

That is, the endangered animal walking along a road would detect the emergence of a prey field induced by the system and move off the road to a safer area. Thus, the application of micro-miniature computer hardware technologies has considerable potential for use in numerous multidisciplinary applications (**Hirose 2002**) and it is clear that information technologies can extend our capacity to interact with other species in a way that transcends physical and even taxonomic interactive capability beyond physical and inter-species barriers. In the second phase of development, those involved with this research plan to develop an HCI interface for practical teachware in human-environment interactions from the perspective of soundscape and acoustic ecology defined by Schafer (**Schafer 1977**).

## 3.7 Conclusions

A networked, remote sensing embedded system for evaluating bio-acoustic interaction between wildlife and human beings in a remote location was developed. The Linux-based monitoring system was capable of generating virtual bio-acoustic interactions between the system and a target animal species using a tracking collar, microphone, speaker, infrared camera, infrared heat sensor, microclimate sensor, radio-tracking, GPS, radio clock, high capacity battery, and high-speed wireless communication device. The system captured and stored environmental data from the wildlife habitat, and transferred the data via a high-speed wireless connection to an observer.

Virtual bio-acoustic interaction is a two-way interactive process used to influence the behavior of wildlife. In this study, a prerecorded call of a prey animal was played and the response of the target species to the virtual call was established. To ensure that such interactions take place, the choice of the prerecorded call requires careful consideration of the prey species or interspecific social interactions of the target wildlife species in its natural habitat. An incorrect choice of prey would result in no feedback from the target wildlife species. Tests successfully demonstrated bio-acoustic interaction between wildlife (an endangered species of wild cat) and human beings via a computer system, thus validating the HCBI concept. It is believed that implementation of the system could make a significant contribution to nature conservation. Development of the system involved the combination of a variety of technologies and opens up a range of possible applications for engineers and researchers around the world.

# Chapter 4

# Validation of Information Presentation in Biospheres based on food chain relationships

## 4.1 Objective

In the previous chapter, this study determined that human beings can interact with wildlife through a computer while remaining physically separated. Information interaction was confirmed between a specific wildlife species member and a computer utilizing the recorded call of a prey animal. However, it is necessary to determine whether the food chain information is an appropriate intermedium between the biosphere and the computer. In this chapter, an experiment examining (1) human to biosphere and (2) biosphere to human interaction via a computer system is carried out in shown in **Figure 4.1**.If information interactions in the two conditions could be confirmed, food chain information will be verified as an appropriate intermedium interface in HCBI.

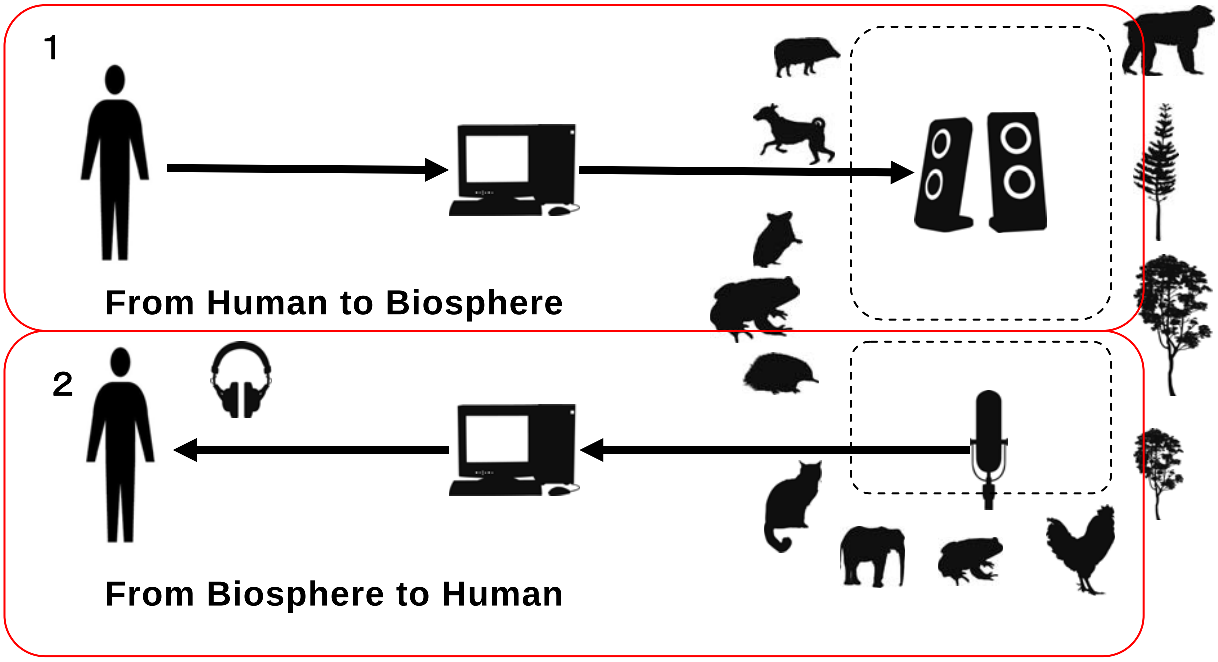


Figure 4.1: Evaluation overview of food chain based interaction from human to biosphere (top) and from biosphere to human (bottom).

## 4.2 Background

Continuing with this study while building on the conclusions of the previous chapter, it is noted that more intensive experiments between human beings and the biosphere are necessary. However, human beings and the biosphere do not share a common set of explicit interactions. Wild animals cannot be surveyed via questionnaires, a beautiful sky does not send messages promoting its beauty and cute kittens do not promote themselves by sending messages stating that they are cute -- even through wild animals in subtropical forests do exchange bio-acoustical information with each other. Therefore, it was necessary to develop new methodologies for observing reactions from humans and biosphere members regarding information presented through the computer.

Again, as described in Chapter 2, ecosystems naturally contain a wide spectrum of wildlife species that interact with each other (**Begon 1996**), and it is generally agreed that the essence of ecology is the study of interactions among species in animal communities (**Begon et al. 1996**). In particular, animal communities in tropical forests have extremely complex interactions involving numerous species (**Ricklefs et al. 1993**) (**Leigh et al. 1996**), with the structure of natural sound in rainforests convincingly demonstrating the extraordinary relationships that exist among the many insects, birds, mammals and amphibians that inhabit these environments. If one creature starts vocalizing, others immediately join the chorus (**Bernie 1987**).

In Chapter 2, it was confirmed that the target species of a biosphere could be motivated to respond to presented bio-acoustic information. This indicates that an equal or greater numbers of responses could be received from the biosphere if such observations were extended, which indicates that bio-acoustic information could be employed as an intermedium interface between human beings and biospheres.

In the “biosphere to human” experiment stage, data posted on a BBS system will be collected and subjected to data mining. This process was intended to determine which types of bio-acoustic information were most interesting to listeners. If users were found to pay the most attention to the bio-acoustic information present in natural sounds, it would indicate that the bio-acoustic information could be an acceptable intermedium interface between biospheres and human beings.

If both the biospheres and human beings respond to bio-acoustic information transmitted via a computer system, it can be concluded that bio-acoustic information was the non-verbal intermedium between them.

## 4.3 System Overview

This system consists of (1) a speaker triggered by infrared sensors and (2) an acoustic live streaming and feedback system. Both systems were installed at a remote location on Iriomote Island.

### 4.3.1 Human to Biosphere Information Presentation through Computer

This subsystem consists of following four components:

1) Infrared sensors
2) Speaker
3) Data capture and processing system
4) Data communication system

The system architecture is shown in **Figure 4.2**. Infrared sensors are placed by the infrared cameras and set to activate when wild animals pass in front of them. Once the body heat of the animals is detected, detection signals are sent to the data capture and processing system (DCPS) with time stamp information. Simultaneously, bio-acoustic feedback is played from the speaker based on a programmed sequence. A data communication system (DCS) was employed to monitor the observations.

DCPS captures analog signals from the sensors. To avoid temporary blackouts this system was equipped with a UPS system that provides electric power during a blackout.

Observations were conducted using the following three day sequence:

1. ***For the first three days, when an animal was detected by infrared sensor, the time information was saved and recorded sounds were played.***

2. ***For the next three days, when an animal was detected by infrared sensor, the time information was saved.***

Using this procedure, the system could ascertain whether the number of detection increased when bio-acoustic feedback was introduced to animals approaching the monitoring site. The three day cycle, which was used in a previous study (**Watanabe and Kobayashi 2006**), was adopted because the battery capacity of portable recording systems limit their observation time to two or three days at most.

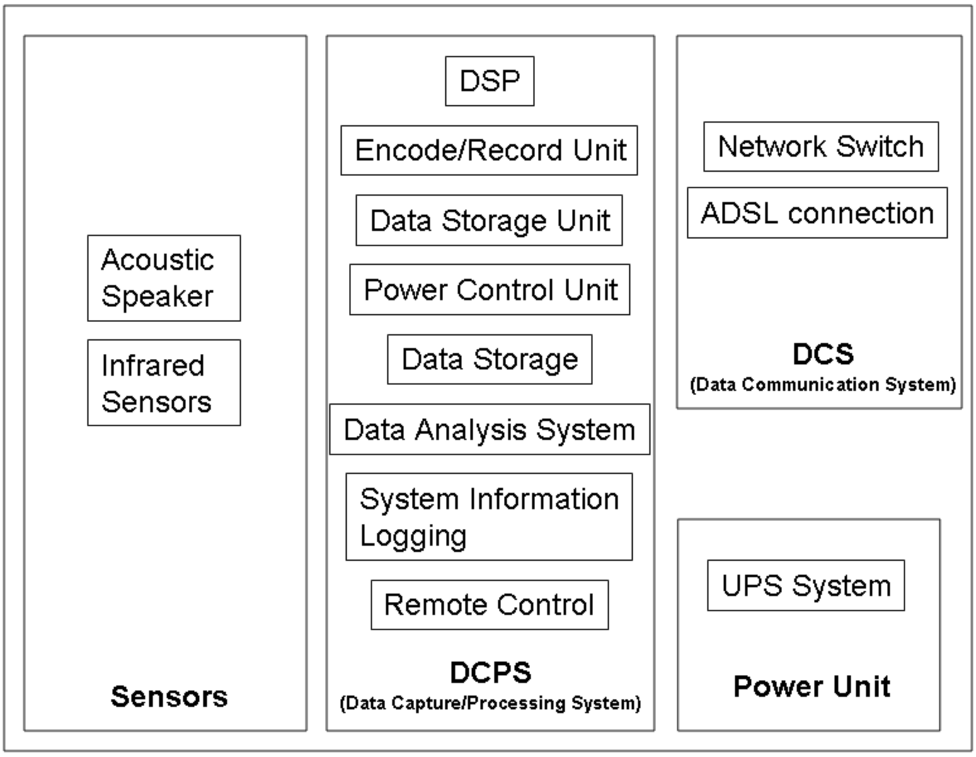


Figure 4.2: System diagram blocks – Abstract block diagram of the hardware

### 4.3.2 Biosphere to Human Information Presentation via Computer

This sub system consists of following four components:

1) Microphone
2) Data capture and processing system
3) Speaker
4) Data mining system

Based on the design, construction and operating experiences of the first developments, a new observation tool for monitoring and processing feedback from users was created. The system enables users to listen to live stream audio and collect the feedback in real time. Furthermore, the system can separate individual words from collected data, categorize them, and count their usage frequency. The system diagram is shown in **Figure 4.3**, while the Web interface is shown in **Figure 4.4**.

The system architecture is shown in **Figure 4.3**. A weatherproof microphone placed within the ecosystem collects environmental sounds 24 hours a day, 365 days a year. This part of the audio digitization system (ADS) converts the analog audio signal from the microphone to a digital audio signal, and transfers the signal to recoding system with extremely low noise. The weatherproof microphone setup consists of a non-directional microphone wrapped by a sheet of thick waterproof sponge and a plastic hard mesh. The microphone and cable joint are covered with waterproof putty and tape to protect it from moisture. Microphones were attached in pairs to trees with elastic bands, as shown in **Figure 4.5**. Digitized signals are then sent to the DCPS.

The digital signal cable can be extended up to 10 kilometers without incurring digital distortion. Next, the digital audio signal is connected to the audio processing system. This audio signal is digitally processed to enhance its quality by remotely controllable real time audio processing software. The processed audio signal is sent to the encoding/recording system shown in **Figure 4.6**, encoded into MP3 live stream, and recorded as WAVE sound format files. The MP3 live stream is sent to a stream server at the data archive system directly through the Internet and is played on various MP3 based audio software formats at different locations simultaneously around the world. The storage/analysis system stores WAVE sound format files which are sent from audio encoding/recording system into its hard disks. The system is capable of storing a full year of continuously recorded audio files on one TB capacity hard drives.

The DCPS provides an internal computer network in the audio digitizing/streaming/recording system, and also provides Internet accessibility to/from the system. Thus, all systems are remotely controllable through Internet. Furthermore, a remotely placed local system monitors all system information through SYSLOG and SNMP software continuously. This management capability allows operators to monitor all the system information, from the input level on the microphone to data traffic delay, using the Internet connection from DCS.

DCS also provides the live sound stream from the DSPC on Iriomote Island to users over the Internet. Users can listen to the MP3 live sound from the island through the SoundBum interface. With Apache HTTPD, PHP and PostgreSQL severs, a bulletin boards receive and collect feedback from users. Each comment is logged with a user defined name, location and saved with a time stamp. The collected data is processed and analyzed by KH_Coder to determine the word appearance frequency in comments submitted from the users. Based on these comments, feedback from users on the bio-acoustic information could be collected, and thus it was possible to evaluate what sounds users pay most attention to.

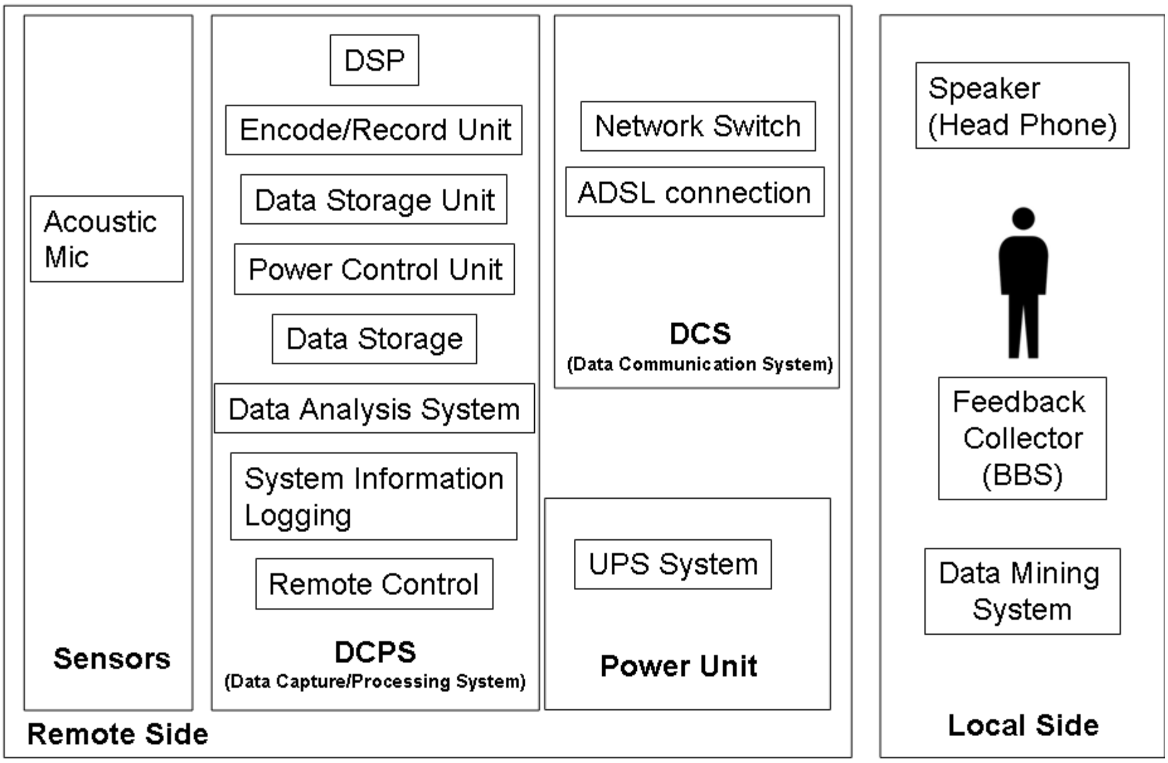


Figure 4.3: System diagram blocks – Abstract block diagram of the hardware

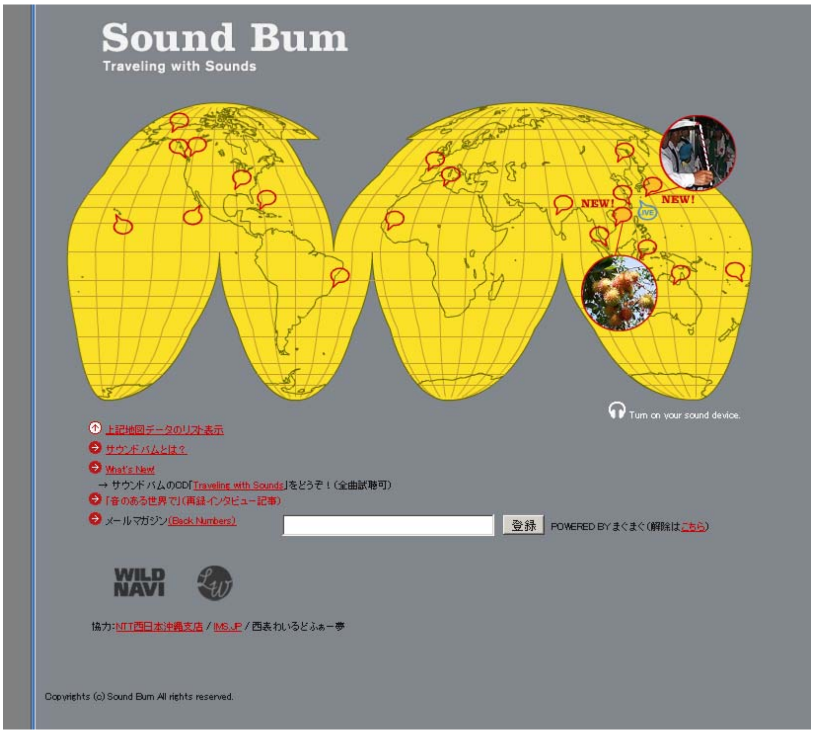


Figure 4.4: Web Interface for live sounds from Iriomote Island

Figure 4.5: Audio digitize system: A remote microphone system installed on Iriomote Island

Figure 4.6: Recording system and data communication system installed on Iriomote Island

# 4.4 Results

## From Human to Biosphere through Computer experiment

The field trial of the second development stage was conducted on the southern and northern regions of Iriomote Island from October to November, 2008 using the previously described sequence. From **Figure 4.7** and **4.8**, it can be seen that the number of detections had actually increased since October 17. However this increment was not in linear form for the observation sequence **“A”** indicates the Step 1 while **“B’** indicates Step 2. Ultimately, the infrared sensor was eaten by an animal and stopped working on November 2. This incident was confirmed visually after the experiment. **Figure 4.8** indicates the average amount of rain. This allowed us to confirm that the sensors were eaten by the arriving animal while heavy rain occurred at the site.

## From Biosphere to Human through Computer experiment

The field trial for the third development stage was conducted in the northern part of Iriomote Island from April 1, 2000 to April 1, 2010. During the 11 years observation period, feedback from user reactions were collected and archived and a total of 2831 comments were recorded through WEB interface in **Figure 4.9**. To analyze the semantic content of the comments, a kh_coder was employed to process the data and subtract “nouns”, as shown in **Figure 4.10.** We successfully subtracted and analyzed the posted comments from the users shown in figure. The most frequently appeared words were “animal voices” – not any specific name of animals or plants, or any sounds of falling trees, wind or ocean tides.

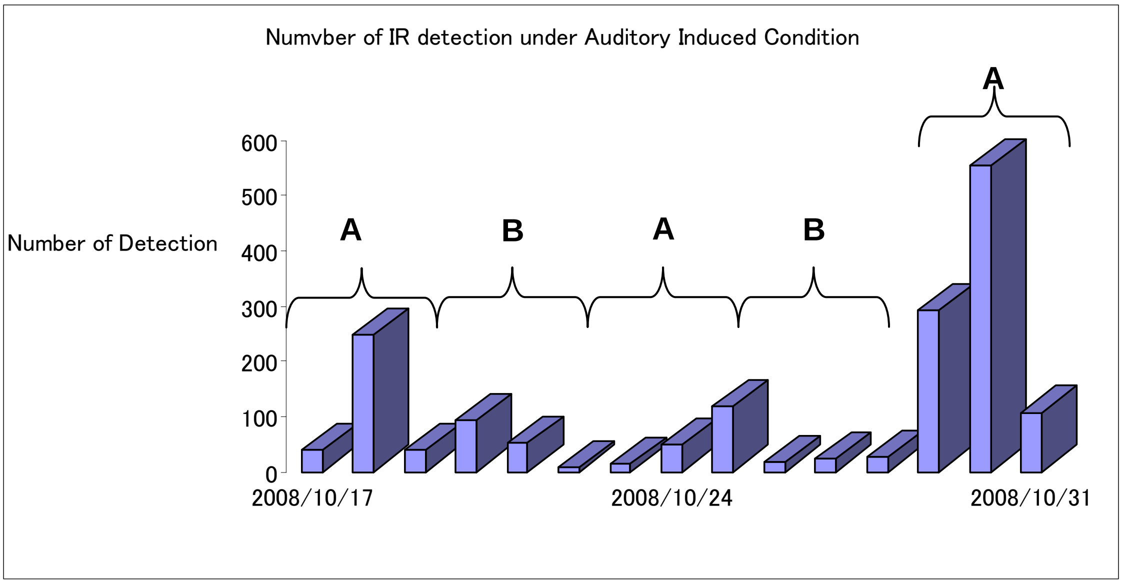


Figure 4.7: Number of infrared sensor detections. (Number detection versus time)

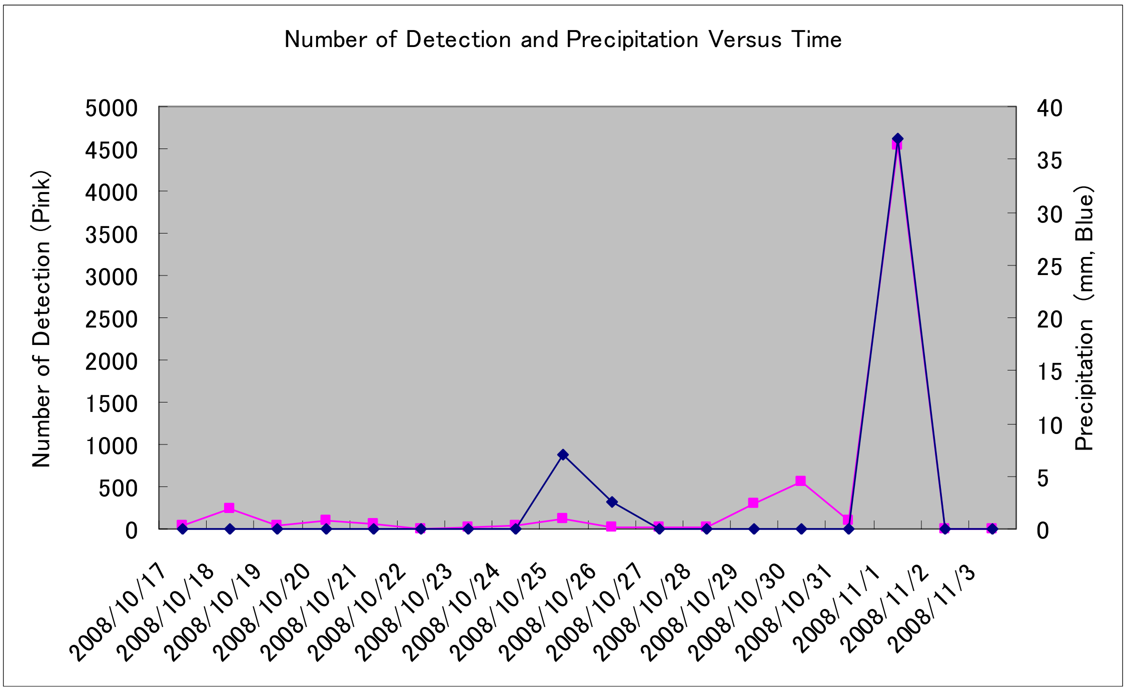


Figure 4.8: Number of infrared sensor detections (pink) with amount of rainfall (blue)


Figure 4.9: Web interface used to collect feedback from users (in Japanese)

| 名詞<br>(Noun) | 出現回数<br>(number of appearances) | 頻度/frequency(%) |
|---|---|---|
| 鳴き声(singing voice) | 89 | 7.44 |
| カエル(frog) | 42 | 3.51 |
| マイク(microphone) | 37 | 3.09 |
| 台風(typhoon) | 33 | 2.76 |
| スタッフ(staff) | 26 | 2.17 |
| 鈴虫(bell cricket) | 25 | 2.09 |
| 感じ(feeling) | 20 | 1.67 |
| セミ(cicada) | 19 | 1.59 |
| 久しぶり(a long time) | 17 | 1.42 |
| ヒヨドリ(brown-earned bulbul) | 14 | 1.17 |
| ノイズ(noise) | 13 | 1.09 |
| メンテナンス(maintenance) | 13 | 1.09 |
| 動物(animal) | 13 | 1.09 |
| 飛行機(airplane) | 13 | 1.09 |
| 音楽(music) | 12 | 1.00 |
| カラス(crow) | 10 | 0.84 |
| 気配(a sign of presence) | 10 | 0.84 |
| 種類(kind) | 10 | 0.84 |

Figure 4.10: frequency of words in feedback comments

## 4.5 Discussions

It was confirmed that food chain information transmitted through a computer system could be used as an intermedium between (1) human beings to biospheres and (2) biospheres to human interactions.

The results of experiments on human to biosphere interactions conducted through computers indicate a possible relationship between the precipitation rate and the number of infrared sensor detections. It is possible that the incremental increase was caused by reduced food availability during rain conditions. If less bio-acoustic information is available during rain conditions, prey sounds played from the speaker became more significant to animals around the site. This could be a possible reason why the sensor itself was broken by the animals afterward.

The results of experiments on biosphere to human interactions conducted through computers indicate that users also respond to bio-acoustic information. From the standpoint of informatics, the amount and duration of bio-acoustic information contained in sounds are small when compared to other continuously present environmental sounds such as wind and running water. In contrast, bird and animal calls are only a small fraction of the total soundscape. This result indicates that listeners only pay attention to a small faction of the total soundscape, and not the dominant part.

Based on the experiment conducted under the abovementioned two conditions bio-acoustic food chain information in subtropical forests was successfully used as the intermedium among human beings, computers and a biosphere and remote interaction between them was established.

Keeping the system in operation with high quality streaming sound 24 hours a day over entire years required advanced computer engineering knowledge. The quality of the digital signal processed by the real-time audio processing software decreased as the recording system ran over extended periods. In most of the cases, the processed signal contained numerous “clipping” sounds. These “clipping” sounds were caused by reduced computation power experienced by the CPU located on the motherboard of the recording system.

Generally, computation power slowdowns are caused by heat and memory leakage. The heat is generated by the recoding system itself because it must operate in the extremely high moisture and temperature environment of a subtropical forest. The memory leakage, defined as losing necessary memory blocks for a computation process, occurs in the recording system because it must operate continuously. This problem is especially serious for programs that operate for extended periods of time and which consume increasingly large amounts of memory over time.

Therefore, to solve the heat and memory-leakage problems, it was necessary to set up two identical recording systems and configure them to operate separately in 12 hour shifts. When one system is in operation, the second system is offline. By following this time shift scheme, the CPU temperatures of the two systems decreased and the memory leakage problem was resolved. However, it was extremely difficult to configure the hardware switching mechanism to operate reliably under unmanned conditions. Specifically, the system shutdown process on one system had to be followed by the startup process of the second system every 12 hours, yet it was not easy to set up the second system to reliably detect the shutdown of the first system unsupervised. Because this system shutdown process (and need for switchover) might also be caused by factors other than the 12 hour shift change, such as power cuts, etc., software errors could occur in addition to hardware problems.

Therefore, in order to operate all systems over long periods under unmanned conditions, an intelligent autonomous control system had to be designed and incorporated. All system components were upgraded several times over the last nine years of the experiment until system stability was achieved.

To develop ecological bio-acoustic information hardware, the collection node (i) was set up in a subtropical forest on Iriomote Island and connected via ADSL to the transmission node (ii) installed on the same island. Over extended periods in an unattended environment, this information system continuously records and transmits (via the Internet) bio-acoustic sound from the subtropical forest on the northern coast of the island where the temperature and moisture levels are high.

Through continued technical improvements focusing on the development of a stable information system, a system that could operate continuously was developed and around-the-clock operation was realized. The system has been hosted by Yoshihiro Kawasaki's SoundBum (**Kobayashi et al. 2000**) since 1997 and environmental real-time sounds of Iriomote Island sub-tropical forests have been monitored by a networked microphone and transmitted through an Internet website as "Live-Sound from Iriomote Island" 24 hours a day, 365 days a year, since that time. The real-time streaming system has been upgraded several times over the years to improve long-period stability under unmanned operating conditions.

## 4.6 Conclusions

This chapter ascertained whether bio-acoustic information could be used as the intermedium between human and biosphere interaction using computer systems. Therefore, the study focused on the development of a system that could be used to evaluate interaction scheduled for examination via experiment, which were (1) human to biosphere and (2) biosphere to human interactions through a computer system. It was confirmed that food chain information could be the intermedium interface information for interactions in both conditions.

# Chapter 5

# Development of Wildlife Detection System

## 5.1 Objective

Prior to installing the HCBI system in the field, it was first necessary to develop a methodology for efficiently detecting the presence and arrival of wild animals while using minimal resources to monitor them in areas where their behavior and appearance are unpredictable. This chapter describes the methodologies and development of a system for close- and mid-range detection and monitoring. It describes how the HCBI system can detect approaching wild animals in uninhabited and humid environments over long periods of time with low power consumption.

These requirements meant that technologies currently on the market, most of which were designed to use indoor city usage, could not be readily applied. In order to operate an HCBI system in the field, the following requirements must first be considered:

1) Electric power limitation
2) Meteorological factors
3) Thermolytic effect on environment.
4) Fluctuating insolation conditions

Accordingly, in this chapter the development of a system that could be applied to the detection of wild animals using (1) presence detection at close-range distances using a capacitance-based organism detection system and (2) presence detection at mid-range distances based on sonographic vocal detection (**Figure 5.1**) is described.

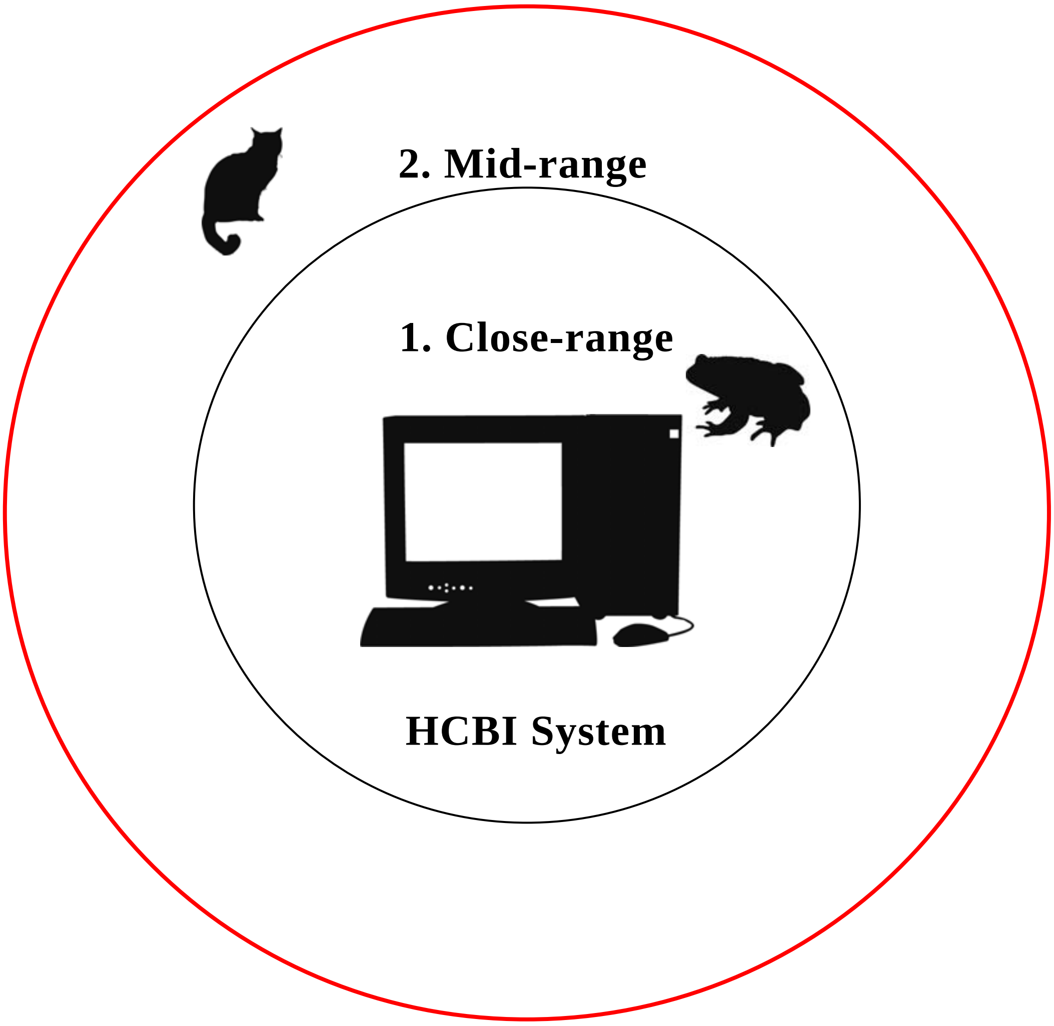


Figure 5.1: The HCBI system uses a two-layer detection system. Close-range detection is done by capacitor sensors. Mid-range sensing is accomplished by sonographical vocal information. Range sensitivity depends on the specification of the microphones used

## 5.2 Background

Ecological monitoring of wild animals involves the analysis of information related to target animals, such as data related to their location and prey preferences in actual environments, as well as data related to meteorological conditions. Using ubiquitous and wearable technologies, it is generally considered likely that species inhabiting environments near urban areas (human settlements) can be monitored effectively given the relatively close proximity of these environments and the availability of electric power, information infrastructures and information systems such as those associated with cellular phones (**Lee et al. 2006, Ueoka 2001**).

However, in more remote areas, such as the home range of the Iriomote Cat, the availability of electric power and information infrastructures for monitoring wild animals is either limited or nonexistent. This is primarily because the profitability generated by infrastructure-based services is usually low in areas such as wildlife refuges where the number of users is small.

Furthermore, in areas where there are no infrastructure networks, predicting the behaviors of species with extensive home ranges (on the scale of several kilometers) is difficult. Although field surveys of such species are conducted periodically, monitoring target species in environments such as the hot and humid subtropical forests inhabited by the Iriomote Cat can impose considerable burdens on observers. Thus, it was necessary to develop methods and techniques that maximize monitoring performance while using the fewest possible resources.

To date, these existing infrastructure restrictions have meant that the following two methods are typically employed to monitor wildlife: (a) a close-range sensor approach, employing an automatic photographic device consisting of a camera, thermal sensor and food lure (**Figure 5.2A**), and (b) a long-range sensor approach, such as a telemetry system that employs signals from a radio transmitter attached to a target animal to estimate its position (**Figures 5.2B and 5.2C**).


Figure 5.2: A) Automated photograph system with IR sensor B) Iriomote Cat with telemetry collar, C) Telemetry system, D) A missed shot due to shutter control failure, © Yamaneko Research Group, University of the Ryukyus

Close-range sensor systems sometimes employ food to attract, and thermal sensors to detect, target animals, and then photograph those detected animals using a water-proof analog camera. Currently on Iriomote Island, 70 to 80 such systems have been deployed and are operated by the Ministry of the Environment, the Forestry Agency and the University of the Ryukyus. However, the maintenance of such equipment and the replacement of 36-exposure film rolls in the hot and wet subtropical forests of the island requires considerable effort, is very labor intensive, and places field workers in danger.

In addition, frequent thermal sensor malfunctions due to insolation variations result in inconsistent image capture rates, and the actual maintenance of the cameras themselves is becoming increasingly difficult as spare parts for waterproof analog cameras become harder to procure. Although use of IR sensor, waterproof digital cameras could be considered, the time delays associated with focusing and shutter release is problematic and often means that the target has moved out of the frame when the picture is taken (**Figure 5.2D**).

In the long-range sensor approach, observers use a portable receiver to estimate the current location of a target animal by measuring the strength and direction of radio signals transmitted from animals that have been fitted with radio collars. At present, several Iriomote Cats are being observed using this method. However, since the unique geographical features of the island interfere with the reception of the transmitted radio signals, using this technique requires considerable experience and skill on behalf of the observer. Furthermore, since surveys are, by nature, conducted on a periodic basis, accurately recording long-term changes in seasonal habitat preferences can be difficult. In addition to the constraints conferred on the size and weight of transmitter devices by the animal’s body size, the aforementioned factors can constrain the use of long-range sensor methods in certain species and environments (**Figure 5.3**).

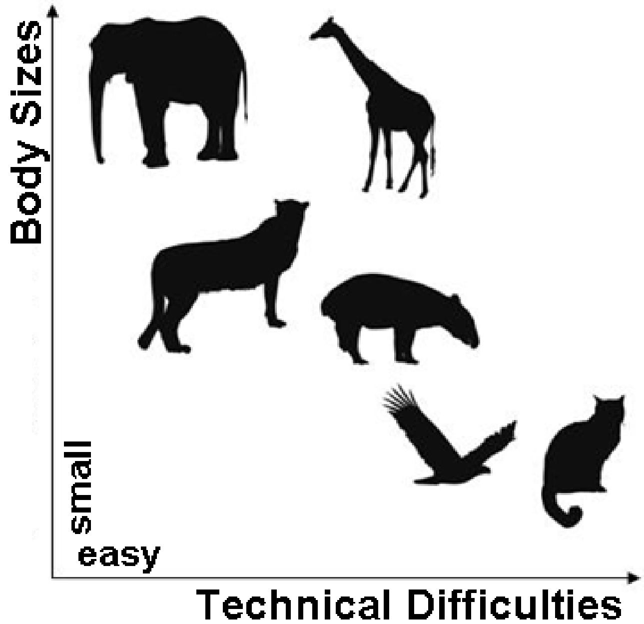


Figure 5.3: Relationship between technical difficulties and body sizes of target species in wildlife monitoring applications

Figure 5.4: (Top) Eagle equipped with stereo cameras, (Bottom) Black duck equipped with VHF System

More specifically, the total mass of a transmitter system that can comfortably be borne by an animal is limited to 2% or less of the animal's body weight. Consequently, large animals like elephants can wear systems weighing up to 100 kg and mid-sized animals (e.g., the size of a small cow) can bear loads of up to 6 kg. Consequently, while there has been considerable interest in research and development of ubiquitous sensor systems for monitoring large- and medium-sized terrestrial mammals, including systems based on wireless LAN (**Juang et al. 2002, Thorstensen et al. 2004**), ZigBee (**Nadimi et al. 2008**), infrared sensors (**Kobayashi et al. 2006**), motion control using actuators (**Wark 2007**), virtual fencing with GPS-based electric stimuli (**Bishop et al. 2007**), and so forth, small mammals and birds are usually only capable of carrying loads of ≤ 75 g or ≤ 30 g, respectively (**Figure 5.4**). Furthermore, in the case of wild animals, it is not usually possible to recapture a collared animal every two or three years for battery replacement (e.g. GPS-based studies for elucidating the migration routes of migratory birds (**Argos System 2007**).

In addition to body size, environmental factors may also restrict the use of long-range sensors (**Kobayashi et al. 2006**). The extensive vegetation cover that characterizes subtropical forest environments inhabited by small terrestrial mammals makes it difficult for positioning signals from satellites to reach any sensors those animals may be carrying.

As no other information infrastructure is in place, analog radio signal transmitting collars (**Saeki and Waseda, 2006**), which transmit VHF signals used to estimate a target animal's current position by triangulation, are still widely used today. However, the diffuse scattering of radio signals caused by geographical features and degradation of transmission circuitry (frequency fluctuations) over long operation periods interferes with efforts to accurately determine the location of target animals.

In subtropical environments such as those found on Iriomote Island, even ubiquitous sensors may not be viable. For example, many of the close-range IR sensors that have been set up on the island often detect and react to thermal sources other than the target animals. Frequently these thermal sources occur as a result of unpredictable seasonal and climatic variations in isolation, which makes a workaround to this problem difficult. The average temperature and relative humidity (RH) on Iriomote

Island in August 2009 were 31.5°C and 85%, respectively (**Japan Meteorological Agency, 2009**), which is outside the operating conditions specified for most household communications devices (0 to 40°C and 15 to 80% RH) (**Yamaha 2006**).

Although a combination of wide-angle, waterproof cameras and OpenCV systems may appear to be well suited for recording wild animals, such an approach would require an extensive network of cameras to be deployed throughout the target area in order to increase the likelihood of capturing images of the target species. In terms of power consumption, such an approach would be impractical in an outdoor environment where power infrastructure is limited. Furthermore, even if sufficient power sources could be made available, the wiring and other hardware components would also be vulnerable to the elements. For example, the maximum instantaneous wind velocity during a typhoon on September 16, 2006, was 69.9 m/s (**Japan Meteorological Agency, 2009**) which is strong enough to blow down trees and damage cables, which in turn would interrupt continuous observation.

Thus, the primary problem associated with using minimal resources to monitor animals in areas where their behavior and appearance are unpredictable is primarily related to the extreme conditions of these natural environments, and because the power and information infrastructures in these areas are typically limited. Specifically, other than using wearable devices, infrared sensors and camera traps, no other systems can be used for monitoring approaching animals. This chapter, therefore, describes the development of a system consisting of (1) presence detection at close-range distances using a capacitance-based organism detection system, and (2) presence detection at mid-range distances based on sonographic vocal detection. Using these methods, the HCBI system can detect approaching animals and control other system components, depending on needs and circumstances.

To achieve these aims, a remote acoustic information acquisition device outdoors was constructed and emplaced. In addition, a method for detecting living organisms using a musical instrument called a Theremin (**Skeldon et al. 1998**) that utilizes indoor capacitance was designed, and problems associated with this method were clarified.

## 5.3 System Overview

This system consists of two subsystems, (1) presence detection at close-range distances using a capacitance-based organism detection system, and (2) presence detection at mid-range distances based on sonographic vocal detection.

### 5.3.1 Presence detection in close range distance using capacitance-based organism detection system

In **Figure 5.5**, multiple capacitance sensors were evenly distributed on a planar surface to simulate an environment where wild animals move horizontally. Each Theremin sensor node (**Skeldon et al. 1998**) has a 360° horizontal detection. A Theremin is an electronic musical instrument invented by Professor Lev Sergeyevich Termenin in 1919 (**Figure 5.6**). The instrument is unique in that Theremin players, “living organisms” position their hands in the air and control both pitch and volume without physical contact with the instrument. It was considered that the characteristics of the instrument could be applied to the detection of animal bodies in its vicinity.

A Theremin converts the “beat tone” generated between two oscillators with different frequencies into sound. The oscillating frequencies vary depending on the capacitance associated with variations in the distance between the hand and the antennas. Music from the instrument results from subtle changes in capacitance introduced by the musician as well as capacitance variations that are inherent in performance conditions, the physical characteristics of the performer, his or her movements, clothing and other factors. Thus, fine tuning the instrument before a performance is imperative (**Figure 5.7**).

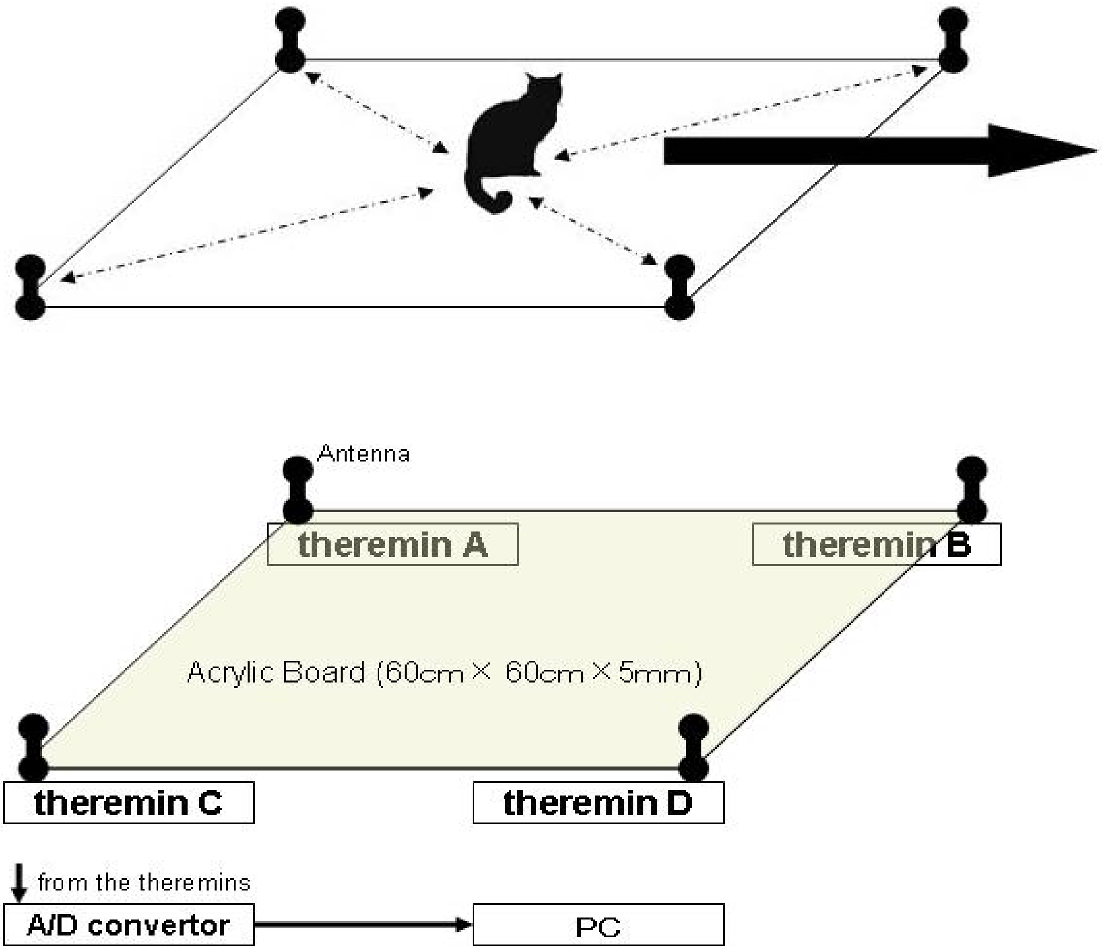


Figure 5.5: System concept (Top), System diagram (bottom)

In the case of detecting wild animals outdoors, performance conditions, or in this case conditions related to weather, vegetation, insolation and terrain vary significantly. In situations where multiple units are deployed throughout a remote area and operated for extended periods, power expenditures must be carefully controlled. However, since the careful regulation of numerous units is unfeasible, developing a robust method for monitoring power supplies was considered essential. In this study, this problem was addressed by deriving the heterodyne value of the Theremin relative to a body in motion using **Equation (1)** below:

$$(1)\Delta F_x = F_{base} - F_x \tag{1}$$

where $F_{base}$ is the base frequency when the hand is placed within a 50 cm radius of the antenna. The value was measured ten times by changing variable $X$ at 5 cm intervals from 5 to 50 cm, which means that $\Delta F_x$ is the arithmetic mean of ten measurements. However, this implies that the $F_{base}$ value varies with the performance environment each time the power is turned on, and is not reproducible given that differences arise between multiple Theremin units. Detection using a specific frequency as a threshold at the time an animal approaches was considered too difficult. In contrast, since the heterodyne value $\Delta F_x$ is always constant against distance $F_x$, even among different Theremins, and even if $F_{base}$ is varies markedly, the distance can still be measured (**Figure 5.8**)

In our experiment, four Theremins (Theremin Premium, Science for Grownups, Gakken, Japan) were installed at the corners of a thin acrylic board, as shown in **Figure 5.11 top** and connected to an A/D converter (US-1641; TASCAM, Japan). Real-time processing was performed on a PC (MAX/MSP; MacBook Pro, Apple Computer, USA) connected via USB. In terms of software processing, the initial frequency of the Theremin in each node was measured using an approximate expression derived from Equation 1. Based on the obtained measurements, a map depicting the estimated positions was drawn in arcs.

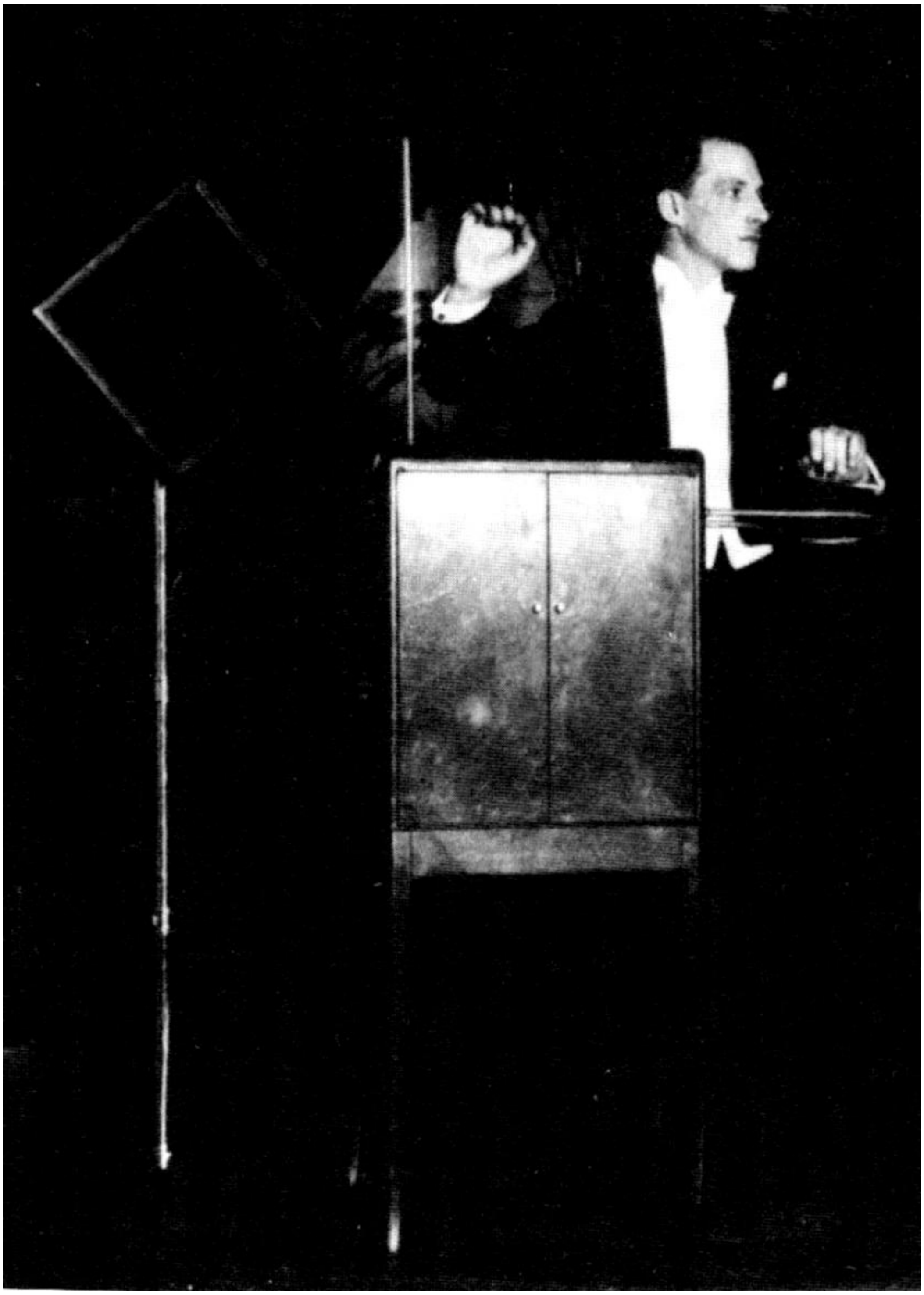

Figure 5.6: Lev Sergeyevich Termene plays a Theremin, a musical instrument he invented.

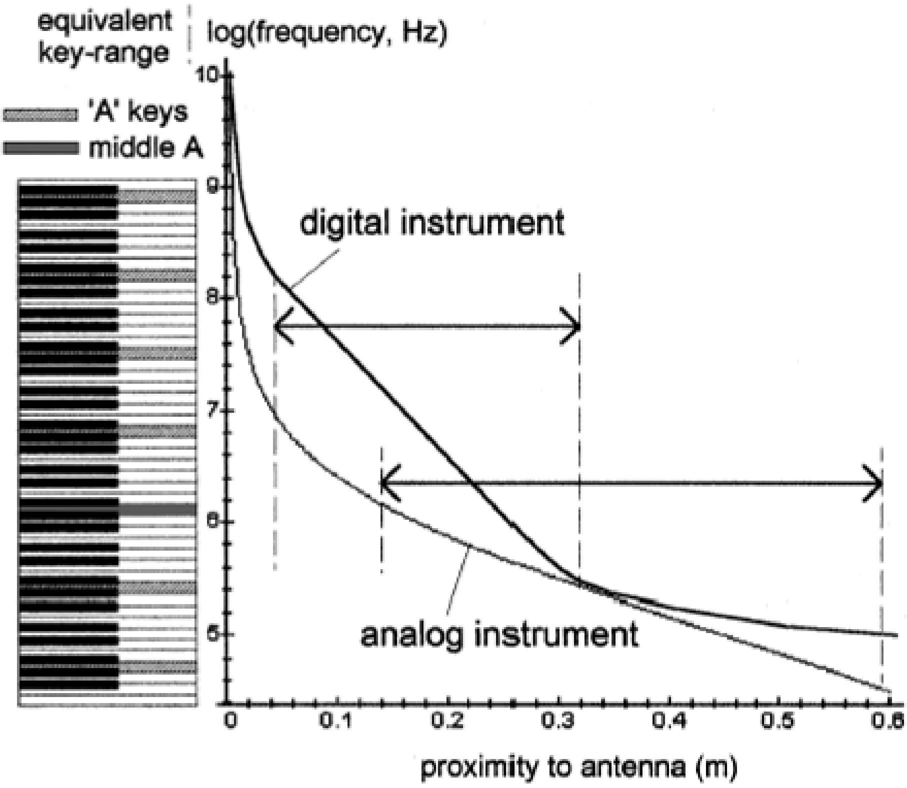


Figure 5.7: Plots of the logarithm of frequency (equivalent to a piano key range) against proximity to the pitch antenna of each instrument. *"The broad linewidth of the oscillators in an analog Theremin design permits a large drift of running frequency, influenced, for example, by thermal drifts in component values. The instrument can often require tuning when switched on and possibly fine adjustment thereafter." (Skeldon et al. 1998)*

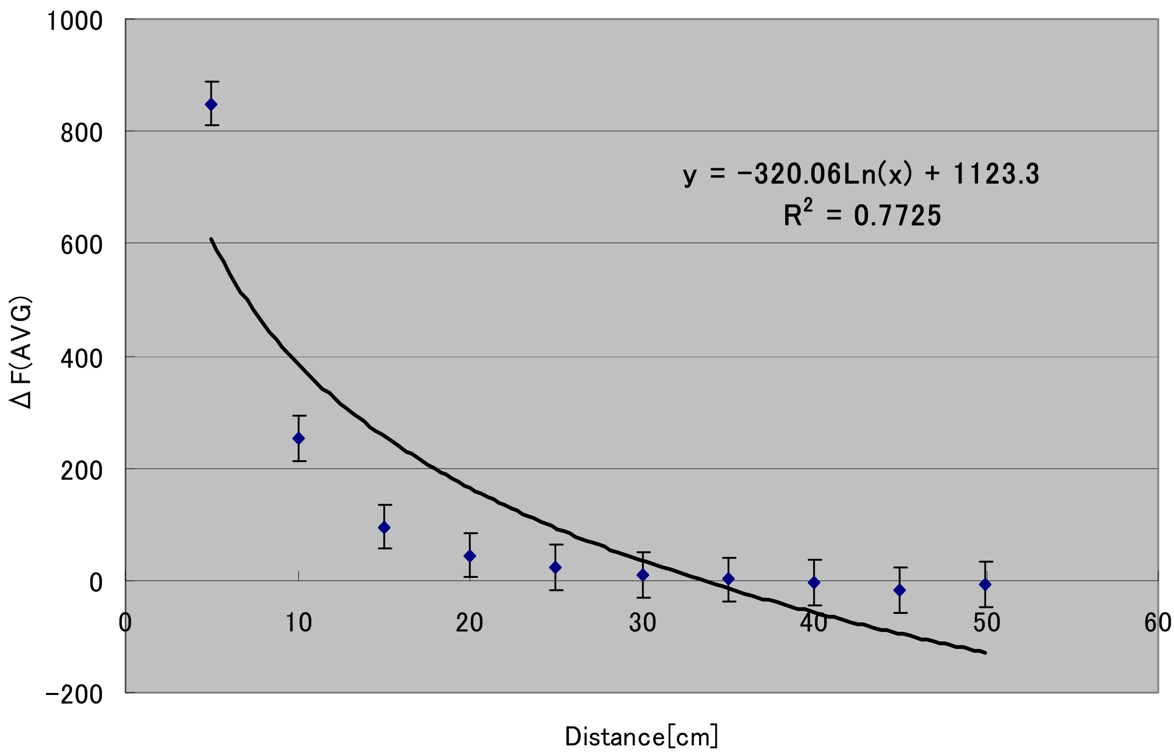


Figure 5.8: Result of distance from a human hand to the antenna on a Theremin vs. observed frequency.

### 5.3.2 Presence detection at mid-range distances with sonographic vocal detection system

This subsystem consists of a networked microphone in a remote location and a processing component at the main server. A microphone (**Figure 2.3, left**) was set up in a remote subtropical forest on Iriomote Island and networked via ADSL to transmit bio-acoustic sound to a user in real-time (**Figure 2.3, right**). The same data communication and archiving system described in Chapter 4.2. was used. The microphone continuously collects and the system transmits bio-acoustic sound from the biosphere ((i) collection and transmission node), and is connected to a network system after analog-to-digital (A/D) conversion ((ii) transmission node). Node (i) is equipped with a microphone, A/D converter and a network card, which allows it to transmit uncompressed bio-acoustic sound in real-time. To achieve faster processing, a real-time kernel was added to the A/D converter and the additional memory/memory was allocated to ensure sound continuity. At node (ii), the input and output systems as well as the synthesizing engine were connected via a high-speed line, and real-time sound transmission technology based on UDP streaming using SoundWire technology was incorporated into the system (**Cáceres and Chafe 2009**). Over extended periods in an unattended environment, this information system continuously records and transmits (via the Internet) bio-acoustic sound from the subtropical forest on the northern coast of the island, where temperature and humidity levels are high.

Through continued technical improvements focusing on the development of a stable information system, it was possible to design a complete system that could operate continuously around the clock. The system has been hosted by SoundBum (**Kobayashi et al. 2000**) since 1997.

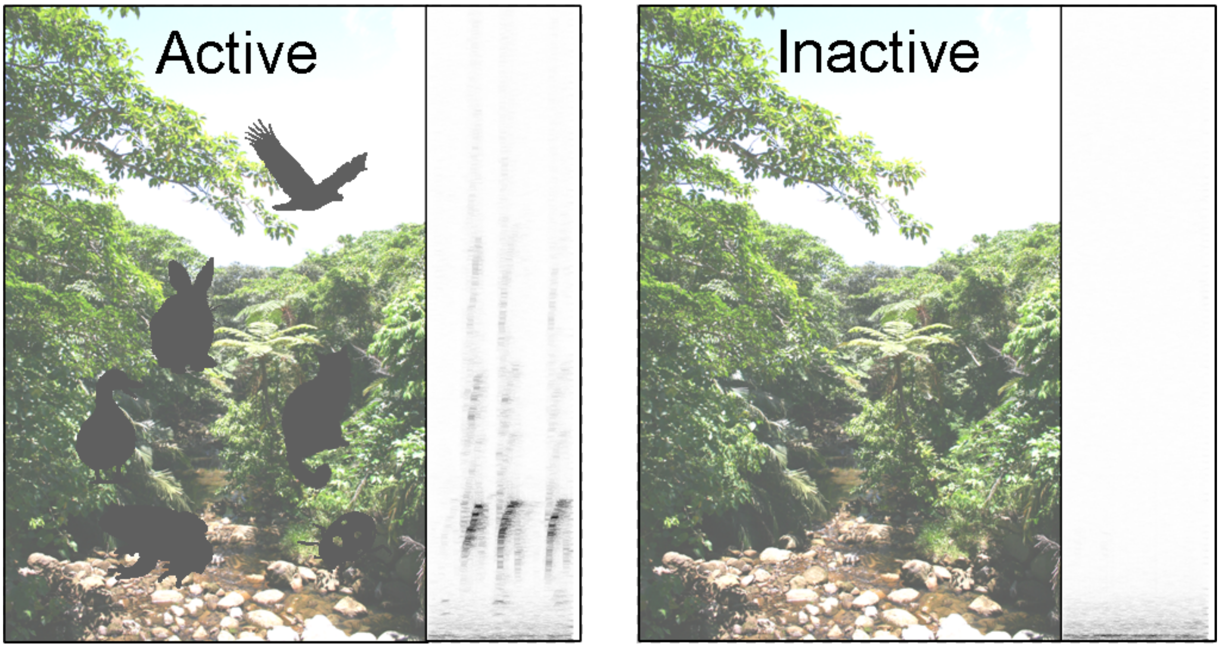


Figure 5.9: Bio-acoustically active (left) and inactive (right) environments with spectrum data (frequency versus time)

Examples of bio-acoustically active and inactive scenes with spectrum data shown are shown in **Figure 5.9**. This figure reflects actual records obtained from the developed system and sonographic data. As can be seen in the figure, in the active condition shot, several sets of vertically long but horizontally short tracks are present. The points shown are radically board spectrum prints recorded over a short period of time. In contrast, in the inactive scene, ash-colored areas show sounds present in the low frequency regions (wind and trees), compared with silence in the high frequency. Through this two condition comparison, it can be concluded that it is possible to monitor the presence of wildlife in subtropical forests, where species exchange information on their presence bio-acoustically, from animal voiceprints. However, the figure does not identify the species of animals calling, and there are always undiscovered species in any remote richly endowed with nature.

Blind signal separation (**Aïssa-El-Bey et al. 2007**) requires multiple microphones, which in turn requires significant amounts of electricity, and is therefore an impractical choice for this application. In desktop music applications, some studies were conducted to detect beat and chorus sections (**Goto and Muraoka 1994, Goto 2003**). However, we still do not know the bio-acoustic factors that equate to such beat and chorus aspects in music.

A soundscape can be defined as a set of various sounds that are spontaneously generated in a particular environment and which continually change, diurnally and day-to-day, over the passage of time. It can be likened to a chorus defined by the geography or other physical aspects and acoustic properties of an area.

To extract bio-acoustic prints from streamed sounds, a bio-activity index (BAI) was first used to convert the bio-acoustic activity into numbers. A BAI applies active contour models (**Kass et al. 1988**), to quantify activity from the calculated shape of visualized bio-acoustic patterns in the live soundscape data obtained from the forest.

The active contour model algorithm forms contours highlight features of interest within an image (**Kass et al. 1988**). The model is a controlled continuity spline under the influence of image forces and external constraint forces. The internal spline forces serve to impose a piecewise smoothness constraint. The image forces push the snake toward salient image features like lines, edges, and subjective contours. The external constraint forces are responsible for putting the snake near the desired local minimum.

Representing the position of a snake parametrically,

$\nu(s) = \nu(x(s), y(s))$, we can write its energy functional as

$$
\begin{aligned}
E^*_{snake} &= \int_0^1 E_{snake}(\nu(s))ds \\
&= \int_0^1 E_{\text{int}}(\nu(s)) + E_{image}(\nu(s)) + E_{con}(\nu(s))ds
\end{aligned}
\tag{2}
$$

where $\boldsymbol{E_{int}}$ represents the internal energy of the spline due to bending, $\boldsymbol{E_{image}}$ gives rise to the image forces, and $\boldsymbol{E_{con}}$ gives rise to the external and provides examples of $\boldsymbol{E_{con}}$ for interactive interpretation.

Given an approximation of the boundary of an object in an image, an active contour model can be used to find the actual boundary. Again, this development was designed to detect wild animals at mid-range distances, and thus allows the system to detect animals as they approach.

## 5.4 Results

### 5.4.1 Presence detection at close-range distances using the capacitance-based organism detection system

A male Wistar rat was used as the subject animal of this experiment (**Figure 5.10, top**). The rat was placed into an acrylic box and changes in the estimated position map were observed as the box was moved toward a particular node. The middle panel of **Figure 5.10** shows the initial state of the system and the corresponding estimated position map (inset at up upper right of figure). The estimated position detected by each node surpassed its detection limit. That is, because there was no living body to be detected, each sensor detected the other sensors.

The bottom picture in **Figure 5.10** shows the estimated positions detected by the four sensors when the rat was placed closer to Node C. The map suggests that a living body was detected in the vicinity of Node C and the intersection of the arcs from the four nodes determines where the rat was. A comparison of the initial state (**Figure 5.10**, **middle**) and the state at the time when the rat was detected (**Figure 5.10, bottom**) clearly reveals that the capacitance of each of the four Theremin units had changed.

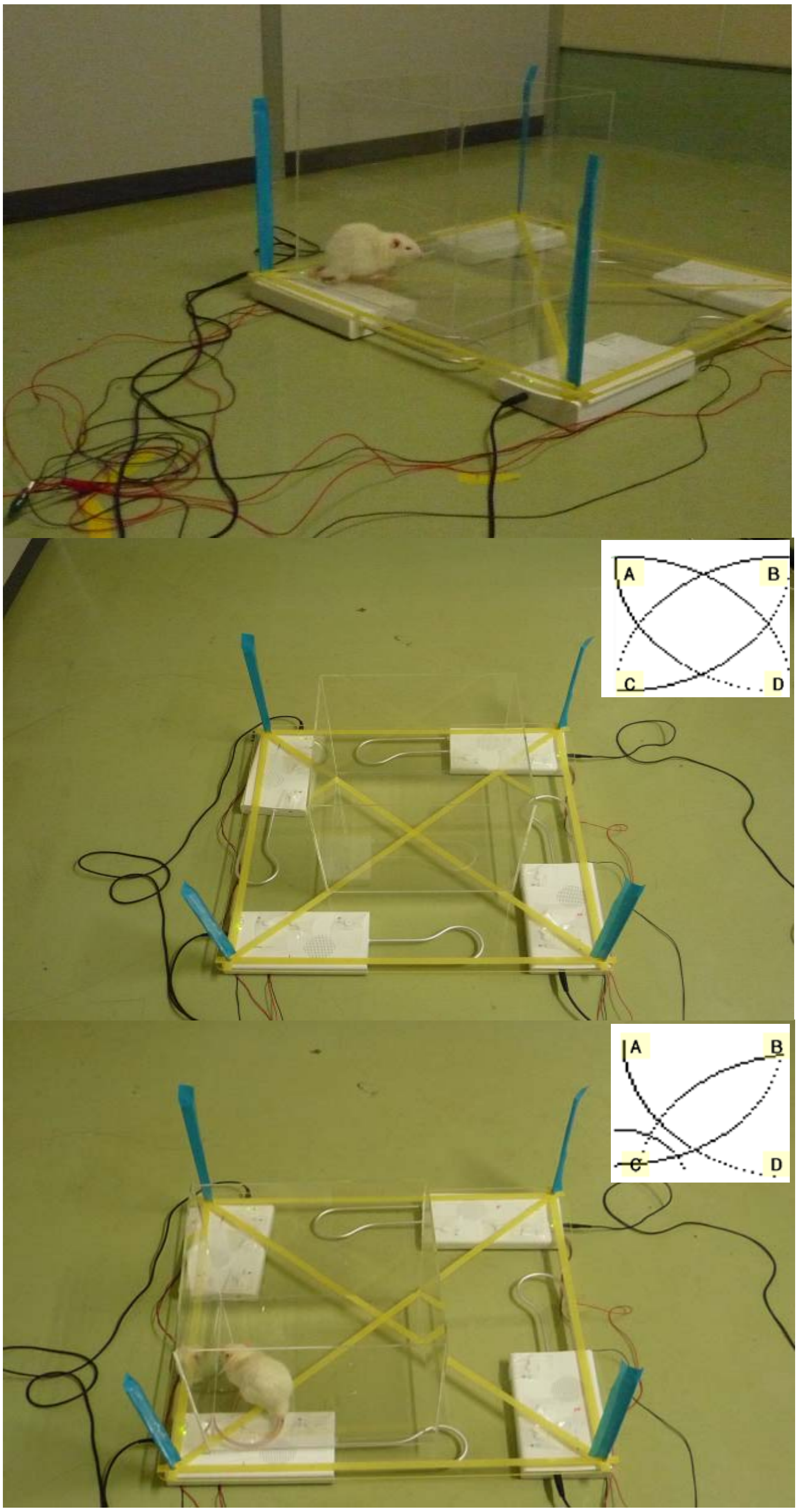


Figure 5.10: Experiment setting with Wistar Rat (top), default condition without rat (middle) and condition with the rat at the left bottom (bottom)

### 5.4.2 Presence detection at Mid-range distances using sonographic vocal detection system

To evaluate the BAI method, we set up a system to receive real-time audio transmissions from the forest, and to calculate and evaluate the BAI using active contour models. The remote system shown in **Figure 2.3** was installed on the island to capture and transmit live sounds from the subtropical forest in CD quality format over the Internet. The local system, OpenCV on Linux Platform installed in the University of Tokyo, was set up to receive and calculate the BAI of the live sounds every second. As shown in **Figure 5.11**, the BAI could be successfully measured.

It was found that bio-acoustical information usually occupies several bands of a 20-10000 Hertz frequency spectrum. Other environmental sounds are usually detected below 1000 Hz. Ten spectrum image results are shown in **Figure 5.11**. Darker lines indicate greater amplitude in a particular range.

The red contour on each result is the pattern detected using active contour model. The BAI is the calculated area of the pattern. A large area indicates that biological activity in the forest is active. In the case of a quiet forest, smaller areas indicate that biological activity is absent.

Results A, D and F, which show high BAI, indicate that bio-acoustic activity has definitely been detected by ACM and its area is calculated in pixels However, results, B, C, E and I in **Figure 5.11** show that portions of the pattern were not detected. This indicates that software improvements are necessary. The results G and H, which show low BAI levels, are typical inactive states in bio-acoustic environments. The contours are placed at the bottom part of the spectrum where other environmental sounds are displayed. The result J is a methodological problem for this application when using ACM. Despite the pattern of horizontally long and vertically thin results, a call from a wild animal with a narrow band spectrum could not be properly included in the calculation.

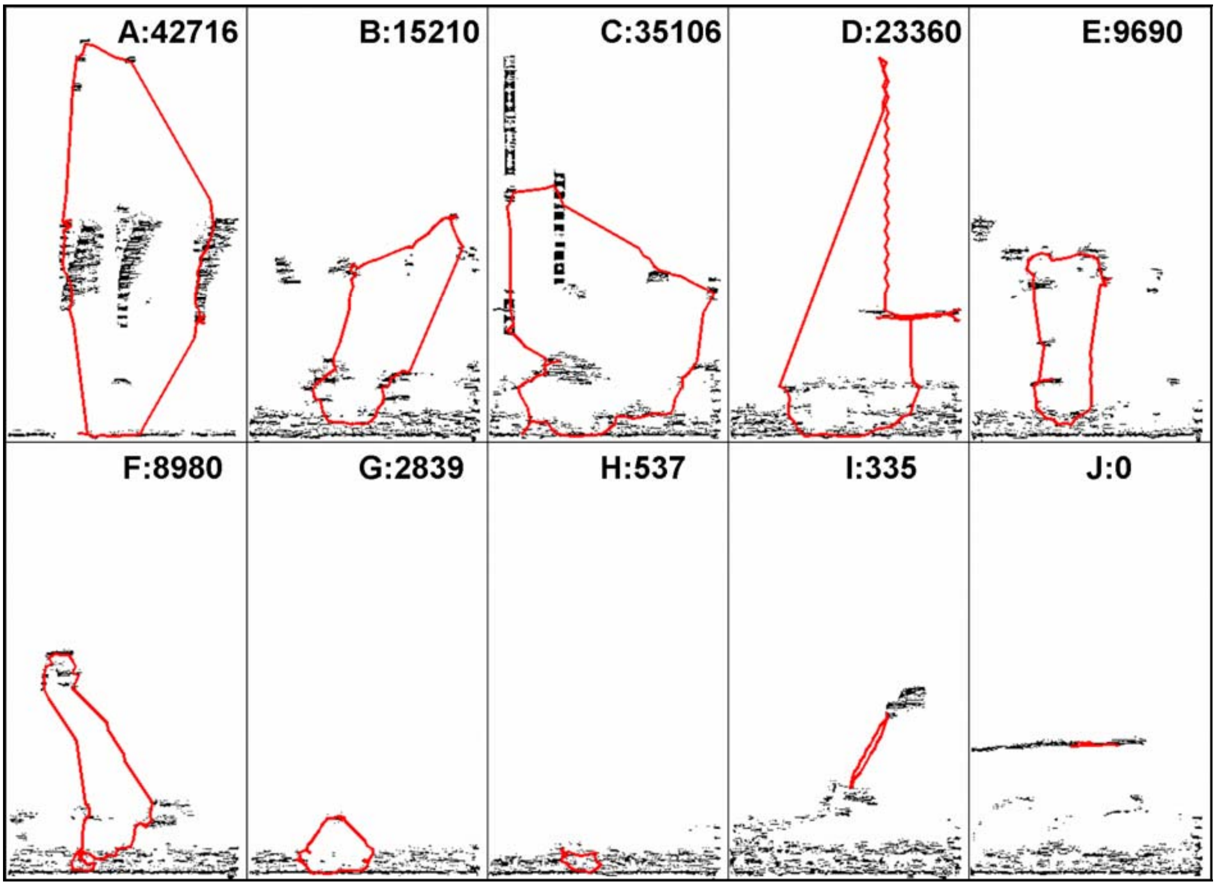


Figure 5.11: BAI Results showing the calculated area on the spectrum data (frequency versus time)

# 5.5 Discussions

This section outlined the development of a system to detect of animals by (1) presence detection at close-range distances using a capacitance-based organism detection system, and (2) presence detection at mid-range distances based on sonographic vocal detection.

With the close-range distance capacitance-based detection system, oscillating frequencies vary depending on the capacitance associated with variations in the distance between the hand and the antenna. It is possible that oscillating frequencies vary in time as well. Therefore, the application of sequential Monte Carlo (**Wang and Zhu 2009**) might be an effective solution to detecting and monitoring wild animals at actual sites during long term observations. In the future, it will be necessary to develop a simplified version of the system described in this section. To accomplish this, it will be necessary to extend the system's detection range past the current 50~70 cm limit.

For mid-range detection, quantizing bio-acoustic activities using a BAI method would be beneficial when operating a monitoring system where electric power is either limited or unavailable, such as subtropical forests. When bio-acoustical activity is active (high BAI value), it simply indicates that wildlife, both predator and prey, is also present and that the system can expect some animals to pass near the camera.

This advance warning permits other sensors to be prepared to take observations. When bio-acoustic activity is inactive (low BAI value), it indicates that there are few or no animals in the vicinity. This information is also beneficial to the system because it allows close-range system components to be placed in standby, which reduces power consumption. Thus, by combining the two different detection methods, it was possible to produce a system capable of more efficient monitoring in areas where electric power is limited.

This development was adopted as one of the core technologies of the "Human-Wildlife Remote Interaction through Bioacoustic" interface, which includes the Tele Yo-Ho system, an augmented speaking tube that bio-acoustically allows a user to interact with a remote forest through a networked remote-controlled speaker and a microphone system (**Kobayashi et al. 2010**), and the Wearable Forest (**Kobayashi et al. 2009**). It is also used as a base for ecological and landscape studies in collaboration with the CyberForest Project (**Fujiwara 2004**) which is based and operates from the Experimental Forest of The University of Tokyo in Chichibu. In addition, as a core technology of the Stethoscope for the Earth's Waters Project (**AquaScape 2007**), the system has been deployed around Sanshiro Pond on the Hongo Campus of The University of Tokyo, the *Suikinkutsu* (literally "water *koto* cave", a Japanese garden ornament and musical device) at Zuishun-in Temple, a subtemple of the Shokoku-ji Temple in Kyoto Prefecture, the city center of Mumbai in India, underwater in San Francisco Bay, U.S.A. and other locations. A system is also expected to be inaugurated in Mexico during fiscal 2010.

## 5.6 Conclusions

This chapter described developed methods and systems that could be applied to the detection of wild animals using (1) presence detection at close-range distances using a capacitance-based organism detection system and (2) presence detection at mid range distances based on sonographic vocal detection. It described attempts to establish methodologies for detecting living organisms using a musical instrument called a Theremin, which utilizes indoor capacitance, and clarified problems associated with this method.

It was determined that the Theremin-based system was capable of detecting live animal without requiring traditional wearable and ubiquitous sensors. For mid-range detection, this study also proposed the use of a BAI to convert bio-acoustic activity in a remote soundscape into usable data by applying active contour models to extract vocal prints from sonographic bio-acoustic data.

These developments make it possible for the HCBI system and other ecological monitoring devices to detect the presence of approaching wild animals at mid- and close-ranges, and for devices associated with the system to better survive the high humidity and temperatures of subtropical natural environments.

# Chapter 6

# Ecological Neutrality

## 6.1 Introduction

Our relationship with nature is constantly evolving as human civilization progresses, yet natural environments are suffering ongoing destruction caused by urbanization. Environmental movements, which promote conservation and preservation through news and other media, have ironically increased tourism in undeveloped and pristine areas, which accelerates the speed of environmental destruction.

As describe in Chapter 1, the Iriomote Cat (*Felis iriomotensis*) is a wild cat about the size of a domestic cat that only lives on Iriomote Island. It was discovered by Dr. Imaizumi in 1967 and is considered a “living fossil’ because it has not changed much from its primitive form. The Iriomote Cat is currently the most threatened subspecies of leopard cat, with an estimated population of fewer than 100 individuals. It has dark brown fur, a bushy tail, and unable to sheathe its claws. In 1997, the Iriomote cat was declared a Japanese national treasure in response to development pressures which are a very serious threat. Because of this, one third of the island has be declared a reserve where the trapping the cat is strictly prohibited. The International Union for the Conservation of Nature and Natural Resources (IUCN) has listed the Iriomote cat as

Endangered Species.

One of the most significant threats to the declining cat population is roadkill deaths (**Murayama et al. 2006**). In Taketomi Chou, which is located in the cat habitat, there were less than 500 registered cars in 1979. However, that number increased to more than 3,000 as of 2005. This increase has been accompanied by a drastic increase in the number of cat struck by motor vehicles.

Ironically, the reason behind the rapid increase in registered vehicles and related cat deaths is improvements to the local economy due to tourism. As the fame of the Iriomote Cat spread, it added significant value to the island’s tourism industry and numerous tourists visit the island in hopes of seeing the endangered cat before it becomes extinct.

As the number of tourists increased, so did the number of rental cars. The increased number of rental cars, in turn, pushed up the number of roadkills. A spiral then ensued as news media reported cat deaths by roadkill, which increased the popularity of the cat further, thus resulting even in more tourists to advance local economic conditions – and thus hasten the species decline towards extinction.

In this chapter, we will explore how HCBI can facilitate ecological neutrality by examining current environmental preservation activities, reviewing related works and current prevention methodology, and examining how HCBI can help reduce Iriomote Cat roadkill deaths. We will also review closed ecological systems and materially closed ecological systems while describing how HCBI can be applied to both. The intended point is the need to ensure controllability as there is, at present, no solution to every environmental problem. Environmental problems exist because of problems inherent in our society that result in environmental imbalances.

## 6.2 HCBI and Ecological Neutrality

Having information connectivity with a remote ecosystem under physically disconnected conditions can enable us to control the degree of impact resulting from

HCBI. By turning off the power source of the computer system, the virtual impact on the remote ecosystem can be removed. Traditional experimental facilities do not have this capability. In environmental studies, there are several methodologies used to research ecosystems via simulation, which can be considered a better solution than traditional methods.

In light of the above, this chapter proposes an HCBI-based methodology. Closed ecological systems (CES) are well known artificial ecosystems that are physically separated from outside ecosystems. One such system is Biosphere 2, which is described below:

> "Biosphere 2 is a seven biome closed system first approximation model of Earth's biosphere (Biosphere 1). It is essentially materially closed (air leakage 6.2% per year). It is energetically open with 16,000 square meters of glass surface taking in about 45% of the ambient radiation, with a peak entry of 7,000 kilowatts of solar energy. It covers approximately 12,800 square meters (or about three midtown Manhattan city blocks) in an airtight and contains close to 6,000,000 moles (or 180 tons) of atmosphere, 4,500 cubic meters of water, five-sixths of that in its ocean, and 28,000 tons of soil containing 3% carbon."
>
> John Allen, Chairman, Biospheres, LLC

The primary objective of the Biosphere 2 experiments was to ascertain whether an artificial ecosystem could operate in total isolation. However, it was determined that creating a completely closed artificial ecosystem is currently impossible due to the complexity of such systems. One of the missing elements is an interface by which we can actually interact with a real ecosystem. However, this could result in unexpected side effects. (**Allen 2002**)

While closed ecological systems can be artificially created in laboratories, they are incapable of fully simulating an actual ecosystem and the results obtained from such systems cannot be applied to actual ecosystems. Therefore, while they can be used to increase understanding ecosystems and test environmental problem solutions, implementation of knowledge gained from artificial ecosystems to actual ecosystems courts potential risks.

Another method to interact with ecosystems is through the introduction of new species. Commonly, “invasive (introduced) species” are introduced to certain geographical areas by human activity for purposes of benefiting agriculture, aquaculture or other economic activities. This process affects more than 98% of the U.S. food system at a value of approximately $800 billion per year (**Pimentel et al. 2005**). Such introductions have also been performed for recreational activities, even though it is estimated that the short-term gains they provide result in long-term environmental destruction. It has been that estimated 80% of the world’s endangered species could suffer losses caused by the introduction of non-native species to their ecosystems.

This brings us to the point of ecological neutrality, which would minimize side effects if incorrect solutions are applied. To this end, HCBI achieves the following:

1. **Physically separation:** Information technology allows remote communication to be achieved.

2. **Information connectivity:** The use of nonverbal interfaces with food chain information allows two-way information flow between human beings and remote biospheres.

3. **Ecological neutrality:** HCBI is virtual reality. Simply turning off the power to the remote devices terminates all interaction.

In the HCBI vision, computer systems are able to mimic species in a food chain system and can stimulate behaviors within ecosystems. These capabilities not only give researchers opportunities to interact with members of the ecosystem, they also enable them to control the degree of the interaction when necessary.

## 6.3 Discussions

***-Is inserting electronic technology into natural areas 'eco-friendly'?***

Yes, if done moderately. There is no right or wrong answer, but moderation is the key, just as it is the key to a sustainable society. Any activity, if conducted too often, can be destructive. An example of a behavior that is only eco-friendly in moderation would be ecotourism, which is defined as:

> "Responsible travel to natural areas that conserves the environment and improves the well-being of local people."
> (**The International Ecotourism Society. 1990**)

However, it is estimated that more than 3,000 eco-tourists visit Iriomote Island every day. Such visitors come from urban areas to experience the island's magnificent ecosystem. They walk in the jungles and trample on plants with 6,000 shoes daily. Furthermore, rental cars driven by such tourists accidentally kill endangered species in areas that have been set aside for their protection. Ironically, the increased demand for tourists in these areas to raise awareness of the need for conservation has accelerated the speed of environmental destruction. No matter how calmly and non-intrusively such tourists attempt to behave, their presence inevitably disturbs nature conservation efforts.

In contrast, the author and his associates have been operating a networked bio-acoustic streaming and recording system on the same island (**Kobayashi 2000**) since 1997. In this system, sounds have been continuously streamed in real-time by networked microphones every day, 24 hours a day, 365 days a year, for more than 12 years. To maintain the remote system, the author enters the tropical forest to replace system components just once a year, thus allowing users to listen to live sounds of the ecosystem over the Internet without physically going there.

Even though the author, in essence, becomes a tourist, not to mention a potential killer of endangered species, the environmental destruction caused by two shoes in one day is much smaller than that caused by 6,000 shoes a day, every day for 365 days.

Thus, it can be contended that persons who visit the island for eco-tourism purposes become "*ego-eco-tourists*", even if that is not their intention. Inserting electronic technology into natural areas is moderately eco-friendly. While it is not the best solution, it is a better solution than the alternatives.

Therefore, it is apparent that once new interactions are introduced into an ecosystem, we are never able to fully control the effects. To solve the roadkill accident problem, introduction of other methodologies is necessary to prevent physical contact between wildlife and cars.

To prevent roadkills, wildlife crossings such as "wildlife underpasses" are widely used. Such underpasses are a special type of construction that allows wildlife to cross under artificial constructions such as roads that cut across their habitat. This is an especially serious problem because human constructed roadways often divide local biospheres and native species risk death by vehicle strikes whenever they must cross such roads to look for food.

However, wildlife underpasses can not eliminate such roadkill deaths as wild animals are incapable of understanding the threat of motor vehicles or the purpose of such underpasses. Furthermore, there are numerous inconsistencies in wildlife preservation efforts with strong attention paid to some species while ignoring others. This is counterproductive because any biosphere requires interaction among numerous different species. Therefore, nature preservation movements should not prioritize life values among various species and should treat all species in an ecosystem equally. This indicates that it will be necessary to create a methodology that more efficiently connects biosphere sections that have been separated by road construction.

***-What can we do to help sustain animal/plant life, and the overall ecology system around us?***

The HCBI interface can be adopted as a new intermedium between humans and the biosphere. For example, significant advances in information technology have enabled improved nature education through the multimedia applications. High-resolution pictures of plants, bio-acoustic recordings of animals, and descriptions of the diversity of vast ecosystems are now easily available through interactive learning systems.

However, no matter how advanced the systems and technologies, these remain human-computer interactions that can never substitute for a true human-ecosystem interactive experience. Accordingly, it will be still sometimes be necessary for humans to escape from urban areas to seek out genuine experiences with nature.

However, if current information technology is capable of providing us with a feeling of being closer to nature, and if it can effectively promote the necessity of nature conservation, the number of endangered animals killed by eco-tourists would decrease in world heritage areas. Even though conservation specialists have been actively advocating environmental protection through descriptions of current critical situations and by reaching out to everyone with state-of-the-art information technologies, passive but high-resolution pictures of plants and bio-acoustical recordings of animals can never become more than human-computer interaction and are thus ineffective for preventing environmental destruction.

The missing factor is not knowledge and technologies, it is an interface by which we can experience nature, where such destruction is occurring at this moment, and feel the collapse of food chain relations toward starvation. Again, the nature conservation movement has ironically accelerated the speed of environmental destruction. The goal of HCBI is, through more interactive methods, to create the experience of belonging to nature without causing environmental destruction. Of course, evaluations of the augmented nature experience depend on the personal perspective of the individual, and while HCBI will not be a complete solution to the environmental problems discussed, it can bring users one step closer to a solution.

***-By introducing reproduced bio-acoustical sounds into an environment, is it possible to create an environmental imbalance that we are not aware of?***

It is understood that the impact of HCBI on a natural environment is not negligible. However, what if information technology becomes capable of synthesizing the presence of introduced species? If bio-acoustically created “virtually introduced species” (robots) begin working to benefit agriculture, aquaculture or other economic activities, it might be possible to control the degree of imbalance introduced to the environment. By using “virtually introduced species” and controlling their impact, we may be able to decrease the environment destruction and build a more sustainable society. Again, environmental problems exist because human beings exist on this planet. Therefore, human beings must look for better paths toward a sustainable society.

## 6.4 Conclusions

This chapter described the concept of ecological neutrality in our HCBI vision. Placing computer systems between human and biosphere with the aspect of acoustic ecology promotes physical separation and information connectivity, but also includes the ability to control the degree of the interaction by allowing co computer systems to be turned off if necessary. At which time, the impact of HCBI on the biosphere can be terminated as well.

# Chapter 7

# Conclusions

This thesis presented the author’s vision of promoting Human-Computer-Biosphere Interaction (HCBI) to facilitate a sustainable society. It is the author’s contention that modern society must reform in its relationship with nature, which has been damaged in the process of urbanization. HCBI extends the subject of HCI from countable people, objects, pets and plants into their acoustic environment, which is uncountable, complex, and non-linguistic.

With HCBI, we can listen to and experience the global ecological system through a form of telepresence, thus integrating ourselves with all living beings and their relationships, including their interactions with the biosphere, without causing environmental destruction. Therefore, HCBI has the potential to offer a solution to the problem of incompatible relations between humans and nature by allowing information connectivity in an ecological neutral way while keeping them physically separate.

This study examined the development and construction of a networked, remote sensing, embedded system for evaluating bio-acoustical interaction between wildlife and people observing the wildlife from remote locations. The Linux-based monitoring system generates virtual bio-acoustic interactions between the system and animals in nature by use of tracking collars, microphones, speakers, infrared cameras, infrared heat sensors, microclimate sensors, radio-tracking, GPS locators, radio clocks, high capacity batteries, and high speed wireless communication devices.

The system captures and stores environmental data from the wildlife habitat and transfers it through a high-speed wireless communication network. Bio-acoustic interaction is a two-way process: playing prerecorded calls of prey animals and observing the feedback to the virtual call from target wild animals. To establish interactions and receive feedback from the target animals, the choice of the prerecorded call used requires a careful evaluation of the food chain of the target wildlife in its natural habitat. An incorrect choice of prey will result in no feedback from the target wildlife. The experience of selecting prey and observing feedback in real time can be used to motivate children to become more interested in the natural environment.

This study hypothesized that bio-acoustic information exchange through computers can be an effective interaction intermedium between human and biosphere and therefore sought to develop a system that could be used to evaluate such interactions.

To that end, (1) human to biosphere and (2) biosphere to human experiments were conducted through a computer system. Through these experiments, it was confirmed that the number of computer-based interactions between human beings and the biosphere increase if observations are extended. Thus, the study confirmed that for information interactions in both conditions, food chain information could be an appropriate HCBI intermedium interface.

Additionally, this study examined the development of a system that can detect the presence of animals in real time based on the bio-acoustic activity present in a remote forest soundscapes. It also examined a bio-activity index (BAI) that can convert this activity into numerical data and transmit it over the Internet. Thus, successful bio-acoustic interaction between wildlife (an endangered species of wild cat) and human beings was demonstrated, and the concept of creating a telepresence of wildlife for users living in a city was validated.

An investigation into the potential application of remotely controllable capacitance sensor for wildlife tele-monitoring in ecological studies was also conducted. It was determined that, by using the capacitance sensor of a musical instrument, it was possible to detect approaching animals in the vicinity of a microphone without requiring a wearable device on the wildlife. This paper provided a basic explanation and evaluation of each methodology and discussed the positive and negative aspects of traditional observation methods widely used in ecological studies.

Micro-miniaturization of computer hardware technologies shows unprecedented multi-disciplinary applications. Information technology can help us extend our interaction capability beyond the physical and genetic distance inherent among different species. In the future, the author plans to develop human-computer interaction interfaces for use as pragmatized teachware for human-environment interactions from the viewpoints of acoustic ecology and soundscapes.

It is believed that implementation of such a system could make a significant contribution to educating children about nature in classrooms. Development of the system will involve a combination of different technologies and can be expected to open up a range of possible applications for engineers, researchers and educators around the world.

# Appendix 1
# Wearable Forest Clothing System: Beyond Human-Computer Interaction

Figure A1.1. Wearable Forest Local System for Human-Computer-Biosphere Interaction. Non-verbal communication beyond the physical and inter-species barriers. © 2008 Hiroki Kobayashi, Ryoko Ueoka, Michitaka Hirose. Photo Masaharu Hatt

## Abstract

Wearable Forest is a garment that bioacoustically interacts with distant wildlife in a remote forest through a networked remote-controlled speaker and microphone. Iit expresses the unique bioacoustic beauty of nature and allows users to interact with a forest in real time through a network to acoustically experience a distant forest soundscape, thus merging humans and nature without great environmental impact. This novel interactive sound system can create a sense of unity between users and a remote soundscape, enabling users to feel a sense of belonging to nature even in the midst of a city. This paper describes the theory of interaction between the Human and the Biosphere through the design process of the Wearable Forest concept.

## Wearable Forest System: Description

Wearable Forest, shown in (**Figure A1-1**), is a clothing system that bioacoustically interacts with distant wildlife in a remote forest through a networked remote-controlled speaker and microphone as shown in (**Figure A1-2**) (**Ueoka et al, 2008, Kobayashi et al 2009**). It is based on the concept of human-computer biosphere interaction (HCBI) (**Kobayashi et al 2009)**, described in Chapter 2. It aims to express the unique bioacoustic beauty of nature and allow users to interact with a forest in real time through a network and acoustically experience a distant forest soundscape, thus merging human beings and nature without great environmental impact.

Figure A1.2. Wearable Forest Remote System for Human-Computer-Biosphere Interaction. Nnetworked audio I/O system placed in an uninhabited subtropical forest on Iriomote Island, Japan (24°20'Nn, 123°55'Ee). © 2008 Hiroki Kobayashi.

Wearable Forest consists of a local audio-visual interactive clothing system as shown in Figure 1 and an audio I/O system placed in a remote forest as shown in (**Figure A1-2**). The remote and local systems perform remote interaction with non-human creatures. The remote system, consisting of weather-resistant microphones and speakers, is placed in an uninhabited subtropical forest on Iriomote Island in Japan (24°20’N, 123°55’E). The songs of small birds, the trickling of a stream, and the sounds of insects moving about in the forest represent the diversity of organisms on the island. The audio I/O system continuously captures and transfers the live soundscape to a local system over the internet. The local clothing system consists of two paper-thin speakers embroidered on the fronts of both shoulders, a matrix array of 256 white-colored light-emitting diodes (LEDs) sewn with conductive thread, and sleeve-shaped textile sensors woven with thin wires. An embedded CPU system receives the live soundscape data from the remote forest wirelessly, immediately quantizes the bioacoustic activity of wildlife from the data, and visualizes the result as a luminescent pattern through the LED array. To visualize and illuminate the bioacoustic activity contained in the remote forest soundscape as clothing fashion in real time, Wearable Forest ues a bio-activity index (BAI) to convert this activity into numerical data using the internet (**Kobayashi 2008**) as described in Chapter 5. BAI uses active contour models to quantify the bioacoustic activity of the calculated area into the shape of the visualized bioacoustic patterns of the live soundscape data (**Kass et al 1988**). Higher levels of bioacoustic activity are conveyed as larger LED patterns.

To interact with wildlife, users can touch the textile sensors, which transfer the user-selected, pre-recorded sounds of wildlife from the garment to the speakers in the forest on the remote island. This bioacoustic loop, which transfers live sounds bi-directionally from the remote and local sites, gives the user the opportunity to interact with wildlife. For example, in a relatively quiet period after a brief rain shower in the subtropical forest, the users at their urban location can play back the croaking of frogs through the remote speaker; in response, actual frogs might start croaking. If an appropriate sound is played back at an appropriate time, the actual wildlife might respond to the initial call. In this chorus-like experience, intraspecies communication in mixed reality between the user and the frogs could then possibly give the users a sense of belonging to nature in an experience similar to the peak experience in music therapy, which is triggered by choral singing (**Lowis 2002**).

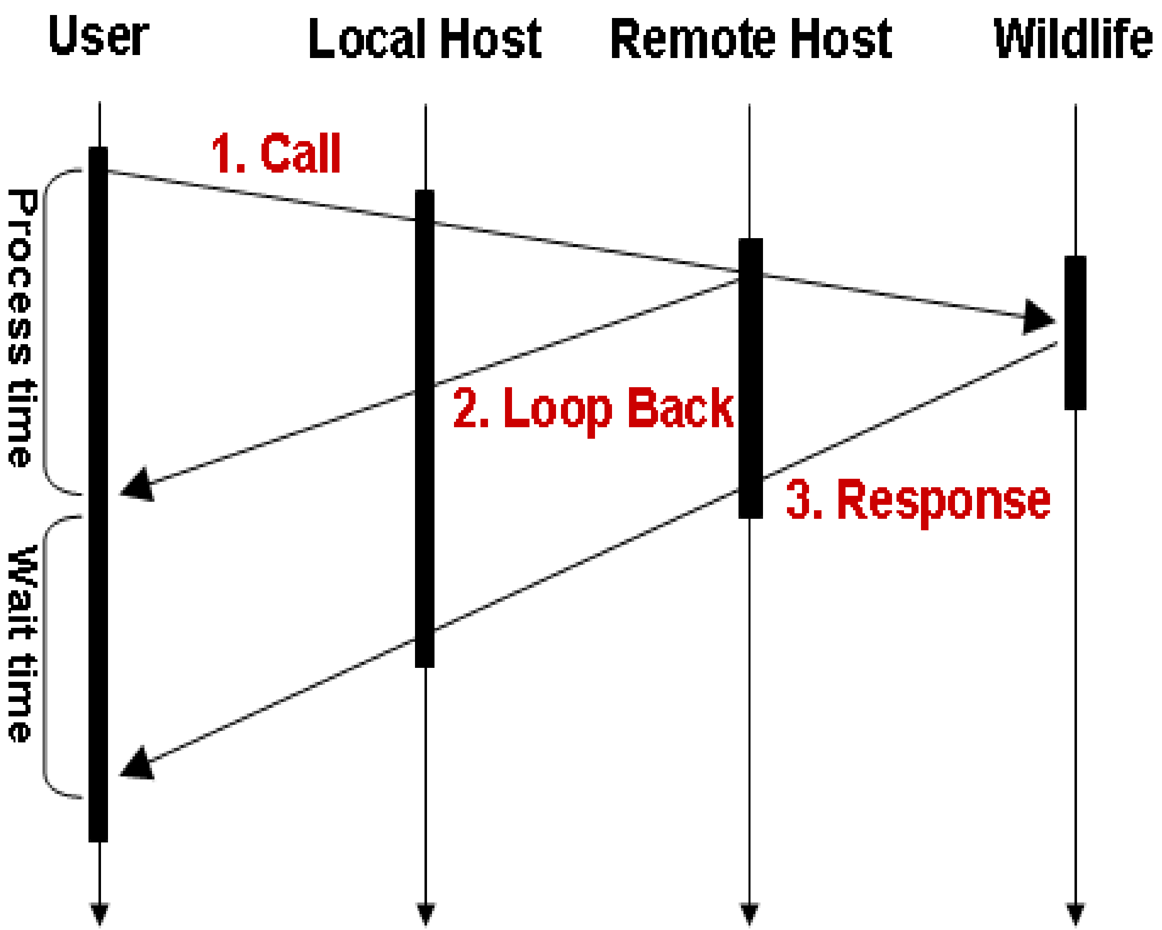


Figure A1.3: Diagram of non-verbal interaction between user and wildlife. © 2008 Hiroki Kobayashi, Ryoko Ueoka.

First, the user can send an initial pre-recorded animal call to the remote host through the local host as shown in (**Figure A1-3**). The pre-recorded calls of the Elegant Scopes Owl (Otus Elegans) and the Ruddy Kingfisher (Halcyon coromanda) are used to initiate the interaction with wildlife in the forest. Both species actually live in the forest. The Elegant Scopes Owl is nocturnal. The remote host receives the call, plays back the call from the speaker in the forest, and performs a loopback operation. If the wildlife is present in the forest, it listens to the call. The loopback call at the remote host occurs because the playback sound from the speaker is captured and transferred to the user by the remote host. When the users receive the loopback call from the forest, they recognize that the initial call did actually travel through the forest environment. The users wait for sounds that indicate that the wildlife is actually responding.

The system was exhibited and evaluated over five days during SIGGRAPH 2008 in Los Angeles, USA, and over six days during ACM Multimedia 2008 and Science World British Colombia in Vancouver, Canada. During the first exhibition, the “out of synchronization” problem was confirmed (**Gurevich 2004**). Visitors were unable to identify a specific sound from other sounds on the audio live feed from the remote forest. This resulted in users’ inability to recognize the potential auditory response from the wildlife, even if the response had occurred to the user in the distant forest. Therefore, even if no response is transferred from the wildlife after the loopback call of the initial call, other acoustical activities in the forest can be perceived as believable responses, such as the sounds of birdsong, buzzing insects, gently swaying leaves, and a tree falling. Those sounds indicate the non-linguistic telepresence of entities in the forest. From a psychological aspect, participants who experienced Wearable Forest in the ACM Multimedia 2008 art exhibitiondescribed “a sense of oneness” with the remote forest. They rated the episode on a number of scales indicating characteristics of transcendence (**Williams and Harvey 2001**), such as sense of union and timelessness. The result indicates that the Wearable Forest HCBI interface is able to create a sense of oneness between human beings and wildlife beyond physical and genetic distance.

## Conclusions

The HCBI paradigm defines a new conceptual approach to establishing communication between humans and natural environments through the use of computer-based media in order to create a sense of unity. We believe that the fundamental work outlined through the Wearable Forest project will create new possibilities for relationships among humans, computers, and the biosphere.

# Appendix 2 Tele Echo Tube- Augmented Speaking Tube for Echo Sounding Experience in Nature

Figure A2.1. Tele Echo Tube for Human-Computer Bioshere Interaction. Non-verval communciation beyond the physical and mythologycal barriers. *ARTECH Exhibition in National Museium of Emerting Science and Innovation* @2009 Hiroki Kobayashi

## ABSTRACT

Tele Echo Tube is a speaking tube installation that vocally interacts with a remote forest through a networked remote-controlled speaker and microphone through the slightly vibrating lamp-shade like interface. It allows users to interact with Mr.Yambiko, “a mountain Echo” in a forest in real time through an augmented echo sounding experience with the physical vibration over network, experiencing a distant forest soundscape in immersive and ambient ways. This novel interactive multi sensory system can create a sense of unity between users and a remote soundscape, enabling users to feel a sense of belonging to nature even in the midst of a city.

## Tele Echo Tube System: Description

Tele Echo Tube, shown in (**Figure A2.1**), is a speaking tube that vocally interacts with a remote forest through a networked remote-controlled speaker and microphone through the slightly vibrating lamp-shade like interface. It is based on the concept of human-computer biosphere interaction (HCBI) (**Kobayashi et al 2009**), described in Chapter 2. It allows users to interact with a forest in real time through an augmented echo sounding experience with the vibration over network, experiencing a distant forest soundscape in immersive and ambient ways as shown in (**Figure A2.2**). This novel interactive multi sensory system can create a sense of unity between users and a remote soundscape, enabling users to feel a sense of belonging to nature even in the midst of a city.

Figure A2.2. Tele Echo Tube for Human-Computer Bioshere Interaction. The remote system placed in an uninhabited subtropical forest on Iiriomote Island, Japan (24°20'N, 123°55'E). © 2009 Hiroki Kobayashi.

Tele Echo Tube consists of local and remote speaking tube systems with one-way echo canceller through a full duplex audio I/O system over the globe. The remote and local systems perform a remote interaction to create a pseudo echo sounding experience with ECHO ("Mountain Nymph" in Greek mythology also called "YAMABIKO" in Japanese mythology) through its live sound pipe. The remote system, shown in (**Figure A2.2**), consisting of weather-resistant microphones and speakers, is placed in an uninhabited and subtropical forest on Iriomote Island in Japan (24°20'N, 123°55'E, 2000 km from Tokyo.). The songs of small birds, the trickling of a stream, and the sounds of insects moving about in the forest represent the diversity of organisms on the island. The system continuously captures and transfers the live soundscape to a local system over the internet within several seconds. The local speaking tube system consists of networked microphones, speakers with vibrator, and echo canceller as described in (**Figure A2-3**). An embedded CPU system receives the live soundscape data from the remote forest wirelessly, immediately performs echo cancelling on the sound signal, and send it back to the remote side immediately. Tele Echo Tube runs on a full-duplex audio pipe over the internet and uses an echo cancelling process for preventing the audio feedback in the loop.

## Interaction Design: From a Mythology

Natural communities contain a spectrum of life forms that interact with each other (**Begon 1996**). Many scientists agree with the judgment that the essence of ecology is the study of interactions among species in their native habit (**Ricklefs and Schluter 1993**). Moreover, in Japanese mythology, it was believed that there are many *Yokai (妖怪 literally demon, spirit, or monster.* ECHO, Mountain Nymph in Greek mythology*)* living with other animals in the nature environment. Japanese folklorists and historians use yōkai as "supernatural or unaccountable phenomena to their informants" because yōkai generally have a sort of spiritual or supernatural powers. In 1737, Sawaki Suushi, a Japanese artist in Edo Period Japanese published a picture of a monster called *"Yamabiko"* in a collection of pictures "Hyakkai-Zukan" **(Sawaki 1737**) as shown in (**Figure A2.4**). This is a well known *yokai* who creates mountain echo. Tele Echo Tube creates pseudo collaboration with Mr. Yamabiko and provides echo sounding experience to user.

To interact with the "ECHO", users can sing out "YO-HOOOOO!" very lively from the local speaking tube to the speakers in the forest on the remote island, as described in (**Figure A2.5**). The loopback call at the remote host occurs because the playback sound from the speaker is captured and transferred to the user by the remote host with spontaneous network delay. When the users hear the loopback call, "their voices within the soundscape" from the forest with the slight vibration by their hands through the interface, they recognize that the initial voices did actually travel through the forest environment. This echo sounding loop, which transfers live sounds bidirectionally from the remote and local sites, creates echo sounding effect, and in doing so, gives the user the opportunity to feel the presence of "a fickle ECHO" in the forest in a multi sensory way.

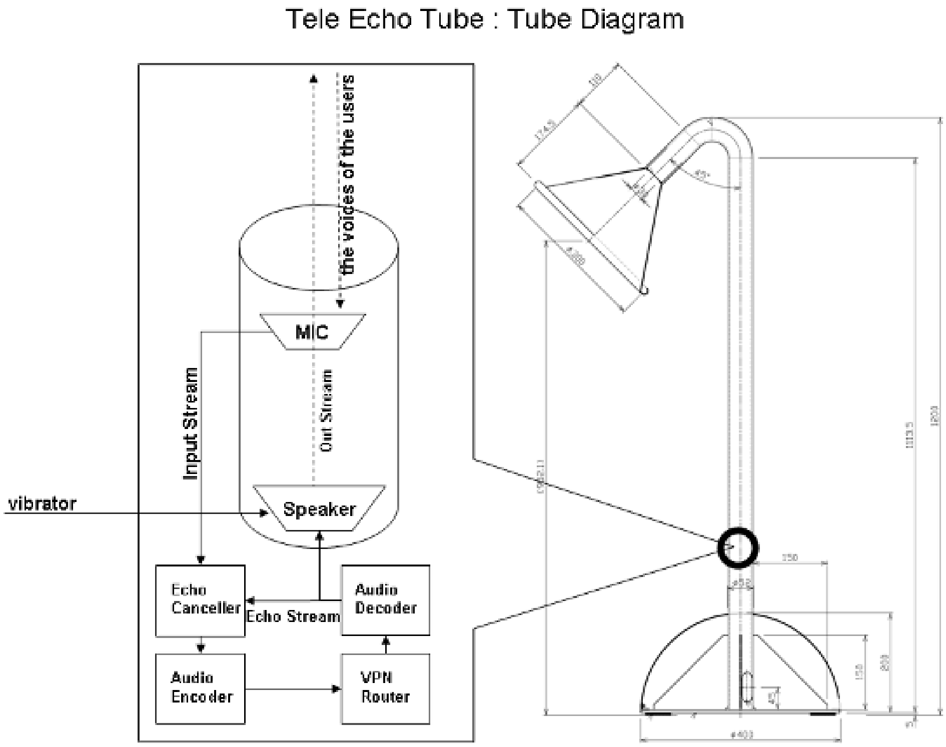


Figure A2.3. Tele Echo Tube Local system. Using Speex13) C Library (1.2 beta2) and ALSA driver (1.0.4) with CCRMA Linux RT kernel for FC7


Figure A2.4. Mr. Yamabiko, ECHO in Japanese mythology. Left: “Yamabiko” in a collection of pictures “Hyakkai-Zukan” (**Sawaki 1737**). Right: The Illustrated Night Parade of A Hundred Demons (**Toriyama 2005**)

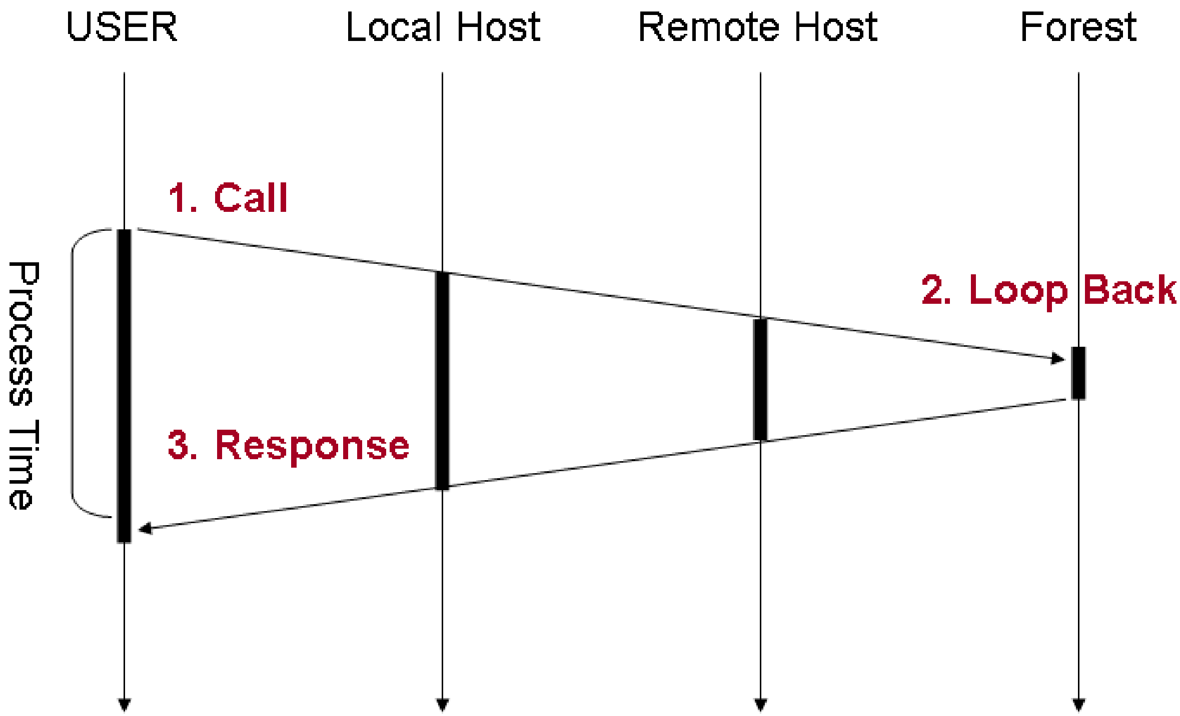


Figure A2.5. Diagram of non-verbal Interaction between user and forest. @ 2009 Hiroki Kobayashi

Those sounds interaction indicate the non-linguistic telepresence of externalized users in a form of mythological metaphor of the forest. This chorus-like experience of believable interaction in augmented reality between a human and Mr. Yamabiko gives the users a high degree of sense of excitment as shown in (**Figure A2.6**). Thus, the Tele Echo Tube of the HCBI interface successfully achieves a feeling of belonging to nature beyond the physical distance.

## Conclusions

The HCBI paradigm defines a new conceptual approach to establish communication between humans and natural environments through the use of computer-based media in order to create a sense of unity. We believe that the fundamental work outlined through the Tele Echo Tube will create new possibilities for relationships among humans, computers, and the biosphere.

Figure A2.6. Tele Echo Tube in ARTECH Exhibition in National Museum of Emerting Science and Innovation @2009 Hiroki Kobayashi

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