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Acoustical Monitoring Research for National Parks and Wilderness Areas

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ABSTRACT

The natural sonic environment, or *soundscape*, of parks and wilderness areas is not yet fully characterized in a scientific sense. Published research in the U.S. National Park System is generally based on short-term sound level measurements or visitor response surveys associated with regulatory evaluation of noise intrusions from motorized recreational vehicles, tour aircraft, or nearby industrial activity. This paper reviews the history of soundscape studies in the National Park System and describes several recent advances that will allow automated recording and analysis of long-term audio recordings covering days, weeks, and months at a time.

1. INTRODUCTION

When the first National Park (Yellowstone) was created by the U.S. Congress in 1872, the telephone and the phonograph had not yet been demonstrated. Powered aircraft, electrical amplifiers, and sensitive microphones were more than 30 years away. Few, if any, could conceive a time in the future that there would be scientific studies of naturally occurring sounds, the impact of human activity, and the issue of sound conservation.

From the start of the 20th century visitors to U.S. National Parks have expected to find unique natural features, sites of historical significance, wildlife living in a natural state, and lands set aside:

> "...to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations." [1]

The inherent tension between the need to "provide for the enjoyment" of current visitors while leaving the Parks "unimpaired for the enjoyment of future generations" has kept park managers on their toes ever since.

Among the features identified by the National Park Service (NPS) for protection and monitoring is the acoustical environment, or *natural soundscape*, of each

This paper includes material from the unpublished white paper: R.C. Maher, "Obtaining Long-Term Soundscape Inventories in the U.S. National Park System," January 2004.

park [2]. The natural soundscape refers to the intrinsic acoustical environment of an area without the presence of human-caused sound. Similar terms include *natural quiet* and *natural sound environment*.

The three basic constituents of the soundscape in a National Park comprise the *biophony* (animal sounds), the *geophony* (geological, hydrological, or meteorological sounds), and the *anthrophony* (sounds caused by humans) [3]. It is important to understand that natural quiet does not imply silence; rather it implies that only the natural sound sources are present. For example, the subtle sound of wind blowing through a forest, the babble of water in a stream, and the vocalizations of birds, amphibians, and other animals are all understood to be features of the natural soundscape. Yet equally valid components of natural quiet may include loud sounds like the rumble of an avalanche, the howling wind and cracking thunder during a summer storm, the crash of ocean waves, and the powerful roar of a waterfall.

As a unique natural feature, the soundscape of a National Park must be evaluated in some scientific manner so that NPS may know the current baseline and establish whether or not there is a trend in the natural sonic environment. If change is occurring, the park managers need to determine if the change is due to some natural process (seasons, migrations, climate, etc.), or due to changes in park use (number of visitors, construction of new facilities, motorized recreation, etc.). Although there is general agreement that objective and scientific acoustical monitoring is desirable, there remain many questions regarding how best to locate the monitoring sites, collect the data, evaluate the results, distinguish between trends and natural sonic variations, and determine what management actions, if any, are required to provide soundscape preservation or restoration.

The remainder of this paper is divided into sections that cover the history of sound surveys in the U.S. National Park System, describe the need for future studies, and give some examples of data collection and off-line processing.

2. HISTORY: SOUND AND NOISE SURVEYS ON U.S. PUBLIC LANDS

Over the years the major studies of soundscapes in the National Parks have been posed in the context of man-made noise intrusion. Published reports and papers regarding sound in public parks and wilderness areas began to appear in the 1970s and 1980s. Prior to that time it is clear that park visitors and managers understood the notion of natural quiet and valued it as a park resource along with fresh air and clean water, but apparently little if any formal research was conducted. Nevertheless, the connection between the natural landscape and the natural soundscape was observed by many influential naturalists.

> You feel the absence of sound—the oppression of absolute silence… But as it is, the spirit of man sympathizes with the deep gloom of the scene, and the brain reels as you gaze into this profound and solemn solitude.
>
> *Excerpt from Nathaniel Pitt Langford's 1905 publication regarding the 1870 Washburn Expedition's arrival at the Grand Canyon of the Yellowstone [4, pp. 30-32].*

> But for the time being, around my place at least, the air is untroubled, and I become aware for the first time today of the immense silence in which I am lost. Not a silence so much as a great stillness—for there are a few sounds: the creak of some bird in a juniper tree, an eddy of wind which passes and fades like a sigh, the ticking of the watch on my wrist—slight noises which break the sensation of absolute silence but at the same time exaggerate my sense of the surrounding, overwhelming peace.
>
> *Edward Abbey on the sounds of Arches National Monument in the late 1950s [5, p. 11].*

> And listen again to its sounds: get far enough away so that the noise of falling tons of water does not stun the ears, and hear how much is going on underneath—a whole symphony of smaller sounds, hiss and splash and gurgle, the small talk of side channels, the whisper of blown and scattered spray gathering itself and beginning to flow again, secret and irresistible, among the wet rocks.
>
> *Wallace Stegner recalling an experience of his youth near a mountain stream [6, pp. 42-43].*

> Silence belongs to the primitive scene. Without it the vision of unchanged landscape means little more than rocks and trees and mountains. But with silence it has significance and meaning. … How swiftly it changes if all natural sounds are replaced by the explosive violence of combustion engines and speed. At times on quiet waters one does not speak aloud, but only in whispers, for at such moments all noise is sacrilege.
>
> *Sigurd F. Olson considering the Quetico-Superior canoe country [7, pp. 51-52].*

2.1. The Early Days

As early as the 1940s the issue of wilderness soundscape preservation was reflected in President Harry Truman's Executive Order 10092, "Establishing an Airspace Reservation Over Certain Areas of the Superior National Forest in Minnesota" [8]. The Executive Order restricted air travel in the Boundary Waters Canoe Area of northern Minnesota by an outright prohibition on float plane landings, and by banning flights of any kind lower than 4000 feet above mean sea level.

The Order represented the first time a ban had been placed on aircraft flight in order to preserve a wilderness area anywhere in the world. Although the Order's implicit intent was to eliminate commercial airborne outfitters within the wilderness boundaries, the explicit objective was to eliminate the aircraft noise. Subsequent federal rule-making restricted motorized watercraft, and ultimately the Boundary Waters area was officially declared a protected wilderness by the Boundary Waters Canoe Area Wilderness Act of 1978 [9].

The U.S. Congress established a new category of federal land protection and conservation with the passage of the Wilderness Act in 1964 [10]. The Act included in its definition of wilderness the characteristics of a landscape

> "where man himself is a visitor who does not remain…land retaining its primeval character and influence, without permanent improvements or human habitation,"

and, furthermore, land that

> "has outstanding opportunities for solitude or a primitive and unconfined type of recreation."

This definition of "wilderness" is clearly distinct from the National Park concept, which embodies the notion of "unimpaired" future enjoyment rather than the more restrictive prohibition on permanent improvements found in the Wilderness Act.

2.2. The Environmental Movement

The rise of the U.S. environmental activist movement in the 1960s included increasing public awareness of man-made noise and its effects on the natural soundscape, particularly in urban and suburban communities. However, there was minimal concern at that time within the National Park Service since noise intrusions in the parks were generally limited to automobile tourist traffic and intermittent overflights by commercial passenger aircraft at cruising altitude. Motorized recreation was not yet popular, nor was there yet much interest in commercial tour aircraft flights.

The U.S. Defense Department sponsored studies of acoustic overpressure effects due to above-ground nuclear blasts during the 1950s. Such tests were only conducted in remote locations of Nevada and the Pacific Islands far from national parks, but the acoustical experiments showed the potential for noise from explosions to propagate over hundreds of kilometers due to atmospheric refraction and focusing [11].

In the 1960s and early 1970s the planning process in the United States for a civilian supersonic transport (SST) program led to a variety of environmental studies. Since supersonic passenger airliners would inherently create sonic booms, a number of formal studies were launched to gauge the effects of acoustic shock waves on structures, human beings, wildlife, and domestic animals. The U.S. Air Force and Federal Aviation Agency (now the Federal Aviation Administration, or FAA) conducted several sonic boom investigations, including several months of experiments with supersonic military aircraft (F-104) 21,000 to 50,000 feet over Oklahoma City, between February 3 and August 3, 1964 (Operation Bongo) [12]. The sonic booms were produced each day at pre-specified times, and population response surveys were obtained. A total of 1,254 flights were conducted. The results from similar tests during 1961-62 in St. Louis, in 1965 in Milwaukee, Chicago, and Pittsburg, and during 1966-67 at Edwards Air Force Base were similar to the extensive Oklahoma study: the tests resulted in thousands of complaints and damage claims [13]. Ultimately, the test results indicated that a significant segment of the public would not be able to ignore the sound of sonic booms—especially from the anticipated large civilian SST aircraft and their presumably unpredictable boom arrival times.

Citizen groups became active in the late 1960s, most notably the "Citizens' League Against the Sonic Boom," founded by William Shurcliff in 1967. The FAA sponsored a variety of study groups and panels, including the Supersonic Transport (SST) Community Noise Advisory Committee (July 1970), chaired by Leo

Beranek. A general consensus was developing that civilian supersonic overflights would not be tolerable public policy [12].

An 80 ton collapse of rock attributed to the sonic boom of a military aircraft was reported by a ranger at Canyon de Chelly National Monument on August 11, 1966, and a subsequent collapse was also noted on October 4. The collapse damaged a prehistoric cliff dwelling. The rangers at the park also documented 83 sonic booms between August 11 and December 22, 1966 [14]. A rockslide caused by another sonic boom blocked a road in Mesa Verde National Park on February 21, 1968 [11]. These documented incidents of damage to physical and cultural sites within the National Parks caused great concern about the potential for ongoing adverse effects of sonic booms—particularly as the U.S. Congress considered support of a civilian SST development program.

The growing significance of environmental concerns in the United States reached the Congress in the late 1960s. Congress passed the National Environmental Policy Act of 1969, requiring environmental impact statements (EIS) for all projects considered by federal agencies [15]. Legislation authorizing the creation of the Environmental Protection Agency (EPA) was passed in 1970.

Shortly thereafter, the United States Senate voted down funding for the U.S. SST effort on March 24, 1971, based on economic and environmental concerns. The FAA subsequently banned civil aircraft sonic booms. Sonic booms from military aircraft were not then nor are they now restricted by FAA rules, nor are sonic booms caused by spacecraft such as the space shuttle during atmospheric reentry. Nevertheless, the concern of the general public regarding noise and sonic boom issues has led the military to restrict supersonic operations to areas over the oceans, at high altitudes over land (above 30,000 feet), or within specific military reservations [16]. No recent examples of sonic boom damage within the U.S. National Park System have been reported, although sporadic reports of military aircraft causing audible sonic booms continue to occur.

2.3. Federal Environmental Protection

Management authority for the federal government to regulate the use of off-road motorized vehicles and boats on public lands was given in Executive Order 11644, signed by President Richard Nixon February 8, 1972 [17]. The Order specifically prohibited off-road vehicles in protected wilderness areas, and specified that off-road "areas and trails shall be located in areas of the National Park system, Natural Areas, or National Wildlife Refuges and Game Ranges only if the respective agency head determines that off-road vehicle use in such locations will not adversely affect their natural, aesthetic, or scenic values."

Federal legislation concerning community noise appeared with the Noise Control Act of 1972, signed by President Nixon on October 28, 1972 [18]. FAA retained jurisdiction over aircraft noise levels, but EPA was given advisory authority to recommend regulations. The EPA influence in the 1970s was primarily in the area of community noise, with less relevance to National Parks and wilderness areas.

In recent years the issue of personal water craft (e.g., jet skis) has been studied at Everglades (FL) and Glen Canyon (UT) National Parks. NPS has put in place extensive restrictions on where personal water craft may be used. Similarly, the noise caused by snowmobiles in the Grand Teton, Yellowstone, and the connecting roads and trails in the John D. Rockefeller, Jr., Memorial Parkway has been studied and the results have been reflected in recent regulations on allowable snowmobile sound emissions [19].

The noise of industrial facilities and mining operations near to park lands has been the subject of study and some controversy [20]. NPS has also instituted soundscape protection plans for its own maintenance and construction activities and those of the contract concessionaires on park lands to reduce, in effect, the "self noise" of the park facilities.

2.4. The Air Tour Issue

Public Law 93-620, "Grand Canyon National Park Enlargement Act", passed by the U.S. Congress in January, 1975, included language specifying the authority of the Secretary of the Interior [21]:

> "Whenever the Secretary has reason to believe that any aircraft or helicopter activity or operation may be occurring or about to occur within the Grand Canyon National Park…, including the airspace below the rims of the canyon, which is likely to cause an injury to the health, welfare, or safety of visitors to the park or to cause a significant adverse effect on the natural quiet

> and experience of the park, the Secretary shall submit to the Federal Aviation Administration, the Environmental Protection Agency pursuant to the Noise Control Act of 1972 (42 U.S.C. 4901 et seq.), or any other responsible agency or agencies such complaints, information, or recommendations for rules and regulations or other actions as he believes appropriate to protect the public health, welfare, and safety or the national environment within the park. After reviewing the submission of the Secretary, the responsible agency shall consider the matter, and after consultation with the Secretary, shall take appropriate action to protect the park and visitors."

The overlapping jurisdiction of the EPA, NPS, FAA (Department of Transportation) and other federal agencies such as the Bureau of Land Management (Department of the Interior) and the U.S. Forest Service (Department of Agriculture) created a bureaucratic tug-of-war. Congress unequivocally authorized the FAA to promulgate regulations involving all aspects of civilian aircraft operations, but conflicts between aircraft noise and community noise standards or conflicts with the requirements of the Organic Act that NPS manage the National Parks "in such manner and by such means as will leave them unimpaired for the enjoyment of future generations" were not anticipated in legislation before the 1970s.

The passage of the Grand Canyon National Park Enlargement Act in 1975 led to several preliminary studies of the noise caused by air tour overflights at the canyon [22]. The studies included calibrated sound level measurements at several locations and a variety of user surveys. This research work continued off and on for the next decade, resulting in a significant concern by NPS that the visitor experience was being degraded by aircraft noise and that the likelihood of visitor injuries or damage to the park was reaching an unacceptable level. A later study of the effects of helicopter noise on an archeological site at Grand Canyon added to this concern [23].

By 1987 the number of commercial air tour operators at the Grand Canyon grew to 40 and the annual total of individual air tour flights reached 50,000 [24, pp. 41-42].

The increasing air tour concern by NPS was tragically confirmed when a Bell Jet Ranger tour helicopter operated by Helitech, Inc., and a DeHavilland Twin Otter fixed-wing tour aircraft from Grand Canyon Airlines, Inc., collided in mid-air over the park in June, 1986, resulting in the deaths of all 25 people on board the two aircraft [25]. The accident and the existing concerns about the impact of overflight noise on Grand Canyon National Park and other units of the National Park System led the U.S. Congress to take action. The resulting legislation, Public Law 100-91, the "National Parks Overflights Act of 1987," required NPS and the U.S. Forest Service to perform studies addressing specific questions about aircraft overflight issues, and then to prepare a formal report to Congress [26]. Significantly, the legislation included funding to conduct the required surveys and research studies. Other provisions included explicit instructions on the expected restoration of natural quiet at Grand Canyon:

> "Flight-free zones are to be large areas where visitors can experience the park essentially free from aircraft sound intrusions, and where the sound from aircraft traveling adjacent to the flight-flee zone is not detectable from most locations within the zone."

The National Parks Overflights Act (NPOA) assessment studies occurred over a period of nearly eight years, culminating in the mandated report to Congress dated July, 1995. NPS hired several acoustical consulting firms to do the assessments (HMMH—Harris, Miller, Miller and Hanson, BBN—Bolt, Beranek and Newman, and Wyle Laboratories). The consultants and the Park Service managers quickly discovered that the aircraft noise standards and measurement procedures suitable for community noise studies were ill-suited to the extremely low ambient noise levels found in many national parks. For example, the sound of distant, high-altitude aircraft that would go unnoticed in an urban or suburban setting were easily audible compared to the natural quiet of the park. Similarly, noise standards based on interference with work or sleep inside a home or office did not apply very well to backpackers out on a hiking trail or sleeping in a tent. A great deal of effort was required to determine not only *what* to measure, but *how*, *where,* and for *how long* it should be measured.

Several of the major studies concluded in support of the NPOA report included experimental measurement of sound levels on the ground due to aircraft at various altitudes [27, 28, 29], dose-response surveys and questionnaires attempting to judge visitor perception and tolerance of overflight noise [30], literature reviews concerning reports on the effects of overflights on animals and cultural resources [31, 32], and surveys of air tour passengers, park service managers, and other park personnel to assess their awareness and expectations regarding overflights [33, 34].

The National Parks Overflights Act also directed the Secretary of the Interior to develop recommendations for changes in aviation regulations that would eliminate adverse effects of overflights on Grand Canyon. The Act further required the FAA to apply the Secretary's recommendations without change except in any case where the recommendation would diminish aviation safety. The Department of the Interior submitted recommendations to the FAA in December, 1987. In response, FAA issued Special Federal Aviation Regulation 50-2 [35], establishing designated flight routes, minimum altitudes for air tours, and special no-fly zones. Studies of the effectiveness of SFAR 50-2 in mitigating aircraft noise were conducted as part of the NPOA report [36]. Additional FAA rules and regulations were put in place in the late 1990s. Recent years have seen litigation by the U.S. Air Tour Association (USATA) challenging several of the flight restrictions, and also court challenges by the Grand Canyon Trust and other environmental groups urging increased flight restrictions.

2.5. The Current Situation

The U.S. Congress acted again in April, 2000, to formalize procedures for air tour operations by instituting the “National Parks Air Tour Management Act of 2000” [37]. The Act continued to split responsibility between NPS and FAA, directing that each unit of the National Park System affected by air tour flights must develop an air tour management plan. The Act also required NPS and FAA jointly to establish an advisory panel, now known as the National Parks Overflights Advisory Group (NPOAG), consisting of representatives from general aviation, commercial air tour companies, environmentalists, and Indian tribes, to provide input on the use and management of airspace over National Parks.

Various NPS units are conducting research and data collection for aircraft, personal watercraft, snowmobiles, off-highway vehicles, and other types of motorized recreation. Active data collection projects are recently concluded or currently underway at Grand Teton (WY), Glen Canyon (UT), Grand Canyon (AZ), Yellowstone (WY, ID, MT), Haleakala (HI), Denali (AK), and other park units.

3. FUTURE STUDY REQUIREMENTS

The attribute largely missing from prior studies is **a truly long-term evaluation of the natural soundscape covering all hours of the day and all seasons of the year**. Very little is known in a scientific sense about the diurnal and seasonal variations in natural sound, nor about the long-term trends in the natural soundscape. In addition to assessing human-caused sound and noise, the availability of long-term sonic data can provide a different viewpoint for studying biology and ecology within the parks.

3.1. Are Long-Term Recordings Really Needed?

For the obvious practical and cost savings, it is reasonable to consider whether occasional acoustical monitoring at a few selected locations for short periods is sufficient for most soundscape studies. For example, one might arrange to observe the soundscape at a particular location for 12 hours beginning at midnight on the first Monday of a month, and find a few dozen identifiable events such as a particular bird song, a tree snapping and falling over in the wind, a bumble bee flying by, a helicopter overflight, and the howl of a coyote. Although this information may be useful, the measurement has not necessarily provided a statistically meaningful sample of the soundscape since it is not know if the particular day is truly representative. Changes are expected due to temperature, wind, and other meteorological details, as are changes due to migration of wildlife, presence of wandering predators, growth of seasonal vegetation, etc. For some purposes, such as evaluating the characteristic sound level of a specific aircraft flight corridor at Grand Canyon, the data can be temporally sparse and still provide useful insights. On the other hand, for research involving animal population studies, correlations between sound and meteorological conditions, and discovering diurnal and seasonal trends, data must be obtained and evaluated for weeks and months at a time.

Obtaining a long-term recording of the soundscape in a particular location makes it possible to make strong and statistically significant statements about trends, wildlife observations, the impact of management decisions, and so forth.

3.2. Soundscape Instrumentation

Long-term scientific soundscape data has been difficult to obtain due to the lack of affordable, effective, and easily deployed sound monitoring gear. The equipment used for most of the existing formal sound studies is expensive precision acoustical instrumentation costing $10,000 or more per setup [38]. The gear requires special training to use. It is not intended for widespread deployment, nor is it typically designed for obtaining continuous audio signal recordings.

The NPS and Federal Aviation Administration overflight and general soundscape studies currently use a monitoring system based on a laptop computer attached to a calibrated sound level meter [39]. The 1-second L_{eq} (the mean-square sound pressure, expressed as a level in dB) and 1/3 octave sound levels calculated by the meter are collected by the laptop from a serial connection. Meanwhile, the analog signal from the sound level meter's microphone is sent to the laptop's audio input where it is sampled at 44.1 kHz with 16-bit resolution. The software continuously samples the audio data into a 20-second circular buffer. The software provides a user-selectable threshold that causes a 20-second segment of the sampled data to be saved; otherwise the buffer contents are written over. The laptop software also automatically records a 10-second sample every 4 minutes whether or not the threshold has been exceeded.

The laptop systems have been deployed for several weeks at a time and have been found to be quite reliable. However, the platform is bulky, delicate, and power-hungry. The sound level meter provides a calibrated and standardized acoustical reference, but it is expensive and perhaps redundant given the computing resources of the laptop. Power for the laptop must come from a conventional power line, or in the case of a system deployed in a remote area a photovoltaic panel and rechargeable battery must be provided [40, 41].

Furthermore, because it is difficult to anticipate all the information that may be desirable to glean from long-term sound inventories, attempting to specify acoustical preprocessing and data reduction properties in advance may be counterproductive. For example, many published acoustical studies in the National Parks have used *A-weighted* sound level measurements and one-third octave-band analyses that are considered suitable for assessing the audibility or annoyance caused by intrusive noise. The A-weighting is typically considered appropriate for noise assessment because acousticians often use weighted sound levels for comparisons and regulatory purposes. Unfortunately, the common sound level data provide insufficient information about specific natural sound sources and their temporal distribution. This shortcoming is due to the assumption of human audibility and community noise standards with the explicit goal of assessing noise intrusion rather than the general soundscape evaluation, inventory, and sound source classification.

A-weighted measurements use a frequency response filter that is intended to model the non-uniform sensitivity of the human hearing system for low-level sounds. The filter results in a degraded signal-to-noise ratio because the signal level is deliberately reduced at low and high frequencies.

Future long-term soundscape studies in the U.S. National Park System will require specialized—yet economical—test equipment. A truly useful acoustical inventory will require simultaneous monitors deployed in numerous locations for weeks and months at a time, ideally with essentially no day-to-day hands-on maintenance. Furthermore, it seems likely that the acoustical monitoring gear will be handled and deployed by non-technical personnel such as volunteers, so compact packaging, modular assembly, rugged design, and attention to human factors is vitally important.

The specialized nature of the proposed test equipment makes it difficult to count on commercial development. Rather, initially it is likely that it will be necessary to rely on custom development of prototype systems [42]. Nevertheless, the increasing availability of low-cost and low-power microelectronic components used in commercial portable products will provide an opportunity to develop custom acoustical monitors using commercially available parts.

4. PROSPECTS FOR DATA COLLECTION AND PROCESSING

Most research to date in the National Park System has focused on human audibility and annoyance of intrusive noise sources. The use of average overall and 1/3-octave levels has been found adequate for this purpose. Future research will ultimately yield automated means to identify sound sources [47, 48]. This will only be possible if continuous audio recordings are available.

The most significant research challenge will be in the interpretation and documentation of the acoustical data. Although human listeners are quite adept at detecting and classifying sounds in audio recordings, it is not sensible to assume that the hours of recordings from each monitoring system would be analyzed solely by human ears: new means for automated acoustical processing must be developed, tested, and refined. Reliable parsing of complicated audio recordings is a difficult, and remains an active research area in the field of signal processing.

These practical issues point toward two parallel research initiatives: (a) methods for acoustical data processing, and (b) prototype equipment design and evaluation.

4.1. Acoustical Data Processing

Once a multi-day audio recording has been made, the data can be returned to the research lab for analysis. To begin with, a standard set of basic measurement algorithms will be performed to characterize the sonic environment. These simple measurements will include short-time and long-time average sound pressure level, percentage of time specific levels are exceeded, and estimates of the time-variant spectral envelope of the soundscape. Moreover, since the actual audio data has been recorded, it is entirely possible to perform many different analyses on the data at any time in the future.

Next, it will be desirable to identify and classify sounds within the recording. The extreme length of the measured recordings makes analysis by human listeners essentially impossible. An automated and reliable means to detect sonic events in the hours and hours of recorded data must be invented, implemented and validated.

Identifying sound events may seem trivial since everyday experience involves many situations in which one must recognize the phone ringing, a dog barking, or rain falling on the roof, but no reliable automatic algorithms for parsing multiple concurrent sounds in an audio recording have been demonstrated. Automated detection of sound level, changes in the background noise level, and similar general features can be quite effective, but this sort of segmentation may still require considerable manual intervention. Nevertheless, the fact that the entire audio recording has been obtained allows the ongoing advances in automated audio source analysis to be used as they become available.

Significant signal processing research will be conducted to identify and classify the natural sound sources, such as animal vocalizations, flowing water, and wind interacting with vegetation and terrain. Additional research will focus on reliable methods for extracting specific sound sources of interest such as aircraft, vehicles, and other mechanical sounds. The identification and classification framework will be carried out in software using a time-frequency decomposition of the input signal followed by a stimulus matching procedure [e.g., 43, 44, 45].

4.2. Prototype Monitoring Equipment

For the prototype design/evaluation phase a rugged and self-contained monitoring platform will need to be designed and constructed. There does not appear to be a standard catalog item that satisfies the continuous long-term recording requirements, but at least one specialized product is under development by Sanchez Industrial Design, Inc. The model PADR-100 Portable Audio Data Recorder [46] is a development platform designed for long-term continuous recording (up to 7 days) with a variety of communication ports and optional accessories.

If time and cost constraints allow, it may also be feasible to develop a custom recording platform. The proposed platform would contain a digital signal processor (DSP), a calibrated microphone and data acquisition subsystem, a memory subsystem, and a power supply. The platform is intended to be deployed unattended in a remote location for at least 14 days at a time while continuously making a digital recording of the acoustical environment. Every 14 days the monitoring platform would be serviced: the recorded audio data on the hard disk drive would be brought back to the lab for subsequent off-line analysis, and the system battery would be swapped with a fresh power source. In some situations it might be possible to consider a wired or wireless data connection from the recording platform to a host computer, and perhaps rely upon remote line power so that the battery is used only for power backup purposes, but in general the platform must be designed to operate with full-time battery power and data storage for the entire 14 day period.

4.2.1. System Features

The proposed features of the prototype system include:

- Continuous wideband (at least 20Hz – 20kHz) 24-bit audio recording capability.
- Omnidirectional calibrated microphone system, ±0.5dB 20Hz – 20kHz, suitable for extremely low ambient sound levels [38].
- Overall system design capable of IEC Type 1 performance (IEC 61672-1:2002)
- Hard disk storage with at least 14 days@24 hours/day capacity.
- Low-power electronics designed for 14 day operation on one 36 amp-hour rechargeable battery.
- Design suitable for production at a cost well below $1,000 per unit.
- Weather-tight, animal resistant, and easily portable physical design.
- Operating environment -25C - +85C.

4.2.2. Power and Storage Requirements

The requirement of 14 day continuous operation on a 36 amp-hour battery leads to the following calculation for the average battery current:

$$\frac{36\,\text{amp hour}}{1}\cdot\frac{1\,\text{day}}{24\,\text{hours}}\cdot\frac{1}{14\,\text{days}}=107\,\text{milliamps}$$

.

The roughly 100mA average current at 6V nominal battery voltage indicates an average power consumption of just 600mW. This power limitation is particularly challenging because most existing hard drives require several hundred mA just to maintain the disk spinning. Therefore, it will be necessary to implement an audio cache system using solid-state memory (e.g., Flash memory) so that the disk need only be spun up when absolutely necessary. It is estimated that a 15 second spin up and write cycle every 10 minutes will meet the design goal.

It should also be noted that the battery size could be reduced (or battery life extended) if a supplemental power source such as photovoltaic panels (solar cells) or fuel cells were considered feasible.

The 14 day continuous recording capability will require considerable data storage capacity:

$$\frac{48\text{k samples}}{\text{sec}}\cdot\frac{3\,\text{byte}}{\text{samp}}\cdot\frac{60\,\text{sec}}{\text{min}}\cdot\frac{60\,\text{min}}{\text{hr}}\cdot\frac{24\,\text{hr}}{\text{dy}}\cdot\frac{14\,\text{dy}}{1}=162\,\text{gigabytes}$$

(where 1 gigabyte is 1,073,741,824 bytes). It is expected that the data storage requirement could be reduced by performing lossless data compression prior to placing the sound data onto the hard disk, so the actual storage necessary may be reduced to 80 GB or less. Drives of this size are becoming available in the sub-$100 range. Provision for more data channels, higher sampling rates, and other enhancements, would necessarily increase the required storage.

4.2.3. Other Features

Several additional features are anticipated for future development, as listed here.

- Integration of a GPS module for precise time-of-day and position determination. This feature could potentially allow acoustical beamforming and direction finding using time-aligned data from multiple independent sensors.
- Alternative power sources, including supplementary solar, fuel cell, and thermoelectric. Additional power for heating/cooling the system may also be needed for some applications.
- Streamlined packaging to allow NPS to send a system to a park superintendent with minimal training and configuration.
- High speed network access to allow data transfer from the recorder to a laptop or removable storage drive.
- Provision for additional data storage, such as meteorological observations.

It is expected that testing and evaluation of the prototype sound recording system will reveal the need for additional features and capabilities.

5. CONCLUSION

Since the 1970s the U.S. National Park System has been the host of many acoustical measurements. Although most studies have been in response to noise intrusions from tour aircraft, industrial operations, and motorized recreational vehicles, the development of new long-term recording devices and signal analysis procedures will extend the existing knowledge base regarding the sonic environment of the parks. Long-term data will be suitable for archiving, data analysis, park planning, and biological surveys. The availability of this data will allow correlation with other ecosystem measurements and trends.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

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