Chapter 5

DISCUSSION

5.1 CHAPTER OBJECTIVES

This chapter reviews the scientific contributions of the research (5.2). The research questions posed in the introductory chapter are answered (5.3). Finally, the results as expounded in the previous chapter are critically evaluated, and shortcomings in the present study are elucidated in 5.4.

5.2 CONTRIBUTIONS

The use of elephant recording collars that utilise RF signals to transmit sound to a base station has been documented by previous researchers (Leong *et al.*, 2002; Leong *et al.*, 2003; Soltis *et al.*, 2005a; Soltis *et al.*, 2005b; Clemins *et al.*, 2005; Leighty *et al.*, 2008). These RF collars were used for the recording of vocalizations of captive elephants. The work presented in this study provides a potential improvement of this method throught the use of a collar that stores all the sound information onboard (together with temperature information, GPS coordinates as well as time and date information). The new elephant collar was designed and built specifically for obtaining high quality continuous recordings of vocalizations from elephants in the wild for extended periods of time.

The electronics used in the recording collar were developed from first principles, specifically for use in an elephant collar. The latest available technology with respect to flash memory cards and low power consumption was incorporated into the design to extend recording time by improving memory capacity and prolonging battery life. This ensured that the time in between tranquilization of elephants was maximised. In addition, the low power consumption of the device and the use of lithium thionide battery technology ensured that the weight of the battery pack was less than one kilogram for every six months worth of operating time.

The electronics used in animal tracking collars are normally cemented into a collar using dental acrylics. The acrylics provide sufficient mechanical protection when the electronics are completely emerged within it, but are prone to cracking if an outside element like a microphone is introduced. A new way of cementing the electronics by using a hard plastic epoxy was introduced. One end of the collar could not be cemented as this would prevent access to the microphone and memory cards, and was therefore covered with a polycarbonate sheet instead. The combination of the hard plastic epoxy and the polycarbonate sheet provided sufficient protection of the electronics over a limited time period, without the risk of cracking open. A number of experiments were conducted to find the optimal way of mounting the microphone that would ensure protection against physical assault, water, and wind noise whilst retaining adequate sensitivity to pick up the full band of sound frequencies that had to be recorded. The smooth polycarbonate surface ensured that mud will dry and peel off, thereby preventing clogging of the microphone.

The application of speech processing technology to elephant vocalizations is not widely reported. The only known research on this subject (Clemins and Johnson, 2003; Clemins *et al.*, 2005; Clemins and Johnson, 2006) used speech processing techniques to do accurate voice placements of individual elephants. However, a major challenge in the application of the technique was the absence of a large database of elephant vocalizations. It is believed that recordings made by the newly developed elephant collar can be used to provide a more extensive database of elephant vocalizations to aid in such research.

In this study, an algorithm was developed that can successfully detect elephant rumbles from recordings and determine the pitch of these rumbles. This was achieved by modifying the speech detection algorithm proposed by Wu *et al.* (2003). Different window sizes and filter positions were used to compensate for the difference in the frequency ranges between human speech and elephant vocalizations. A new method was devised for the final detection and pitch tracking phase of rumbles (from the raw combined autocorrelation data produced by the main algorithm). Although this method is not optimal, it is computationally inexpensive. The results have demonstrated that the algorithm can detect and track the pitch of a harmonic sound in the infrasonic frequency range with great accuracy. This method is effective even where the SNR is as low as -8 dB, which is comparable to other noise robust pitch detection algorithms used for speech detection (Shimamura and Kobayashi, 2001; Wu *et al.*, 2003). It should, however, be noted that the accuracy of the algorithm decreases sharply if the harmonic structure of a sound is lost. This feature ensures that periodic sounds that have no harmonic structure, like those produces by car engines, are not mistaken for elephant rumbles.

The results of the current research have indicated that the rumble detection algorithm can be changed to enable the tracking of two pitch tracks at the same time. Thus, if two elephants in close approximation to the collar utter vocalizations that overlap, rumble detection and pitch estimation of both the rumbles can be done simultaneously. Using the algorithm in this manner however, means that there is a greater potential for falsely detecting a faint periodic signal like a car engine as an elephant rumble. This results in a trade off situation, where the user must decide what is more important, detecting overlapping calls, or avoiding false alarms.

It has been noted that elephant vocalizations that are analysed by researchers must first be identified manually by experts (Poole *et al.*, 1988; Leong *et al.*, 2002). The automatic elephant rumble detection algorithm could be used as an aid for the identification of rumbles from recordings to speed up the process of assembling large databases containing elephant rumbles. If relatively good quality elephant recordings can be obtained such a database could be created automatically from a large collection of field recordings.

5.3 DISCUSSION OF RESEARCH QUESTIONS

The following conclusions were made with respect to the research questions posed in the first chapter:

1. The problem of developing a recording tool that can withstand operation in harsh conditions and make continuous, high quality recordings for long periods of time was solved by making certain design choices to ensure the following: low power electronic operation; physically robust electronic design; the use of robust, high density onboard memory; small physical size and weight of final electronic product. This was realized respectively by using electronic components featuring the latest micro power technology; using surface mount components where possible and using CompactFlash memory cards that have excellent resistance to physical shocks. A multilayered PCB housing some of the smallest commercially available electronic components ensured that the size and weight of the electronics were kept to a minimum. The mechanical design of the device also played an important role in ensuring the robustness of the device. The electronics were moulded into an elephant collar using a strong plastic epoxy. A removable polycarbonate cover was used to protect the memory cards without restricting access to it.

2. The positioning of the microphone is one of the most important issues in the design of an elephant rumble recording device. The microphone should be mounted in such a way that its sensitivity is not degraded, as this would compromise the quality of the recordings. However, it is also necessary to protect the microphone from excess noise, physical damage and mud clogging, as clogging or physical insult could render the device useless. To prevent the microphone from being clogged with mud, it should be mounted in such a way that the mud would dry and fall off without affecting it. The polycarbonate sheath used as a cover for the collar provides a strong protective barrier and a smooth surface where mud can dry and peel off. A suitable way needed to be found to mount the microphone behind or within the polycarbonate sheath so that sensitivity and bandwidth are kept at desirable levels. A variety of different microphone mounting methods were experimentally evaluated and the most acceptable solution was chosen. This was attained by covering the microphone with a thin waterproofing layer of latex. In addition, the area of the polycarbonate sheath that covered the micro-

phone was only 0.3 mm thick, and perforated over the corresponding openings of the microphone.

3. VAD techniques used on human speech should provide a good basis for automatic elephant rumble detection. Most VAD techniques was developed for use in the telecommunications industry where it is only required to distinguish between silence or speech. This is usually done by determining whether a certain energy threshold has been breached. In real life recordings there are a lot of other high energy components present in a channel besides the voiced speech. A technique described by Wu (reference) was chosen as basis for the elephant detection algorithm in the current study. This technique was selected because it has previously been used specifically for the detection of speech in noisy recordings. The recording is filtered into a number of sub-bands and an autocorrelation function is used to estimate the pitch present in each sound frame of each sub-band. All the channels containing strong evidence of periodicity are summed together to estimate the dominating pitch in each respective time frame of the recording.

4. Elephant rumbles have a harmonic structure (just like voiced human speech) and Wu's algorithm implements a PDA for detecting voice presence in a recording. The main difference between human speech and elephant rumbles concerning the use of the algorithm is the fact that elephant rumbles have a much lower fundamental frequency than human speech. In addition, the voiced components within elephant rumbles continue much longer than in human speech. The cut-off frequencies of the band pass filters used were therefore in the range of 10 up to 250 Hz instead of the 80 - 2.5 kHz used for human speech.

5. The results of the study have demonstrated that the automatic elephant rumble detection algorithm is able detect the presence of sound with harmonic structures with an SNR of -8 dB or better. In low quality recordings with an SNR of less than -9 dB the algorithm will fail. The harmonic nature of elephant rumbles is an important aspect used in the algorithm. If the upper harmonics of a far off rumble is lost there is a good chance that the rumble will not be detected. The presence of bursts of periodic noise which contain upper harmonics increases the chance of false alarms.

5.4 CRITICAL DISCUSSION OF RESULTS

The elephant recording collar was subjected to two field tests. Some good quality recordings of elephant vocalizations were made in both of the field tests. This indicated that the system was able to function in the conditions experienced while fitted on an elephant. The electronics within the collar remained dry and in working condition, showing that the mechanical design of the collar provided sufficient protection. Some undesired results were also obtained. The first test ended prematurely because of battery failure. The cause of the premature battery drainage was the fact that a micro hard drive (with a CompactFlash form factor) was used instead of an authentic CompactFlash card. The micro hard drive consumed 600% more energy than an average CompactFlash card in a write cycle and also took longer to go into shut down mode after a write cycle. Only CompactFlash memory devices should be used in the recording collar, as the superior power efficiency justifies the additional cost of these devices.

The second test was completed without incident, but the results showed that the microphone was periodically obstructed, resulting in some portions of the recording being recorded at a much lower sound level. There was some rainfall during the time of the field test so it was concluded that the microphone was temporarily obstructed by a layer of mud. The mud eventually dried and fell off the smooth surface of the polycarbonate cover, thereby restoring the recordings to normal sound levels. Although the obstruction of the microphone by mud caused only a temporary problem, it indicates the need for improvement in the design to prevent this problem from re-occurring.

It was also observed that the recordings on the micro hard drive contained small periodic disturbances. This was caused by digital noise due to the excessive power consumption of the hard drive disturbing the reference voltage of the analogue to digital converter. The problem did not occur when recording on a CompactFlash card. Nevertheless, this finding indicated the possibility of the reference voltage becoming unstable, especially when the battery is running low, and the issue should be addressed by using a dedicated voltage reference in a future design.

One of the limitations of the electronic design was the fact that the sensitivity of the microphone could not be easily adjusted by the user. In a reviewed electronic design, the user should be able to set the sensitivity of the recordings to one of a range of predefined values. It would also be beneficial to design the system to operate at 3 V rather than 5 V. This will result in a battery pack half the size of the current one.

There are no existing scientific publications with which the automatic elephant rumble detection results of this study can be compared. The accuracy of the algorithm was verified against elephant rumbles that were manually identified using the method described in Chapter 3. A number of vocalizations were isolated from raw recordings that were made with a handheld recorder in the Kruger National Park. Automatic rumble detection performed on a number of vocalizations recorded under good conditions gave an accuracy of 90.47%. Although this is a promising result it should be remembered that the vocalizations used for the test were chosen to represent the quality of average elephant recordings with common background noises which is a subjective concept. A better understanding of the value of this algorithm could be established by receiving feedback from a number of different elephant researchers using the algorithm over a substantial period of time.

Far field recordings like those that have been made by a handheld recorder are prone to periodic noise within the infrasonic range like car engines and aeroplanes. If these sounds have a harmonic structure it could result in the algorithm falsely detecting the sounds as elephant rumbles. The harmonic nature of the elephant rumbles could also be lost if recordings are made from too far away and this could result in the algorithm missing some of the elephant calls. Although the elephant recording collar that was developed in this study should produce recordings that are better suited for use with the automatic rumble detection algorithm than recordings made by handheld recorders, some of the unwanted effects may still occur under undesirable recording conditions.