Progress Report
(From July 2021 to November 2021)

Preparations for the project:

A previous project, which was concluded in the year 2017, provided the initial seeds of this project on detecting and tracking wild elephants to minimise human elephant conflict in Sri Lanka through their infrasonic calls. Although that previous project -- called adaptive sensor system for elephant tracking (ASSET) -- aimed at building a complete system for the purpose, it only implemented the prototype hardware components and conducted preliminary experiments in the field. This project funded by the Rufford Foundation borrows ideas and technologies from the ASSET project and works towards practically implementing an elephant monitoring and early warning system on the ground.

This project consists of two major activities, which we are working on in parallel: (1) the development of a reliable and low-cost infrasonic capturing device, and (2) the implementation of an automatic elephant rumble detection and localisation system on software. The first activity involves hardware development and various types of testing inside a laboratory and in the field. Special skills in embedded systems development are necessary to work in this particular area of the project. Meanwhile, the second activity relies on the knowledge of digital signal processing and machine learning to extract useful information and draw conclusions on acoustic data recordings. Although the second activity heavily depends on the findings of the first activity, careful planning can be used to make progress in both activities in parallel.

Upon being selected for Rufford Foundations grant, all the funds were transferred to the International Elephant Project (IEP), which plays an important role in helping to manage funds and assist in coordinating with experts of elephant infrasonic vocalisations. In terms of the human resources required to carry out the project, I myself played the role of the principal investigator, while three other members were assigned to various tasks. For the task of developing a low-cost infrasonic detector device, a research assistant was recruited for a period of 1 year paid by the Rufford funds. For the second task of developing automatic elephant rumble detection using machine learning techniques, a postgraduate student who is studying for her Master of Philosophy (MPhil) degree was inducted. Since the student is working on this project as a part of her MPhil dissertation research, no funds are allocated from the Rufford grants. Furthermore, in order to assist in overall work of the project, a 6-month internship was offered to an undergraduate student. This student is paid a monthly stipend using another source of research funds available to me through the university. So, in overall, 4 members, including myself, are working on the project but only one member is paid through the Rufford funds.

In order to successfully conduct the development of the infrasonic capturing hardware, it is necessary to have access to equipment, such as oscilloscopes, signal generators, power supply units, soldering stations, etc. The hosting organization of the project, University of Colombo School of Computing (UCSC) has a complete electronics laboratory consisting of all the required expensive equipment. Therefore, the Rufford grant funds are only required to be allocated for expendable electronics components during the prototype development of the infrasonic detector hardware.

Designing of the Eloc-NG device hardware:

The elephant infrasonic capturing device is required to meet multiple requirements in order to be useful for the purpose. First of all, it has to be sufficiently sensitive to the range of low-frequency sounds generated by the elephants from a considerable distance, e.g., the frequencies from 14 Hz up to 500 Hz. In order to localise the direction of the infrasonic source, it is necessary to possess a pair of such microphones on-board. As there can be various other sources of infrasonic, such as vehicle engines, the device should have enough computational power to run machine learning algorithms and distinguish between elephant infrasonic calls and other noises. Once the device is deployed in the field, it is less likely that a human technician will have regular access to it for maintenance purposes. Therefore, the device should have a reliable power source and be energy efficient in all of its operations. Last not but not the least, the device should be low in cost in order to be deployed in large numbers in rural areas.

In order to meet these requirements, we designed and implemented a prototype of an infrasonic capturing device during the first part of the project. We name our elephant infrasonic device as Eloc-NG, signifying that it is the next generation of the previous device built by the ASSET project, called Eloc. Figure 1 illustrates the high-level architecture of the Eloc-NG device with its main components. The electronic components chosen and their specifications for the Eloc-NG device are detailed in Table 1. These components were chosen after carefully considering multiple available options to meet the requirements of the finished product.

Table 1: Details of hardware components on an Eloc-NG device.

Component	**Model**	**Description**
Processing Module (MCU)	ESP32 DEVKIT V1	The WROOM-32 DEVKIT V1 is an ESP32 processor development board with WiFi and Bluetooth. It has an integrated antenna and RF balun, a power amplifier, low-noise amplifiers, filters, and a power management module. Processor: 32-bit LX6 Dual-Core Tensilica Xtensa microprocessor, operating at 160 or 240 MHz with 448 KB of ROM and 520 KB of SRAM. Low power consumption ensures that it can be used in ADC conversions during deep sleep. Peripheral interfaces include DMA capacitive touch, ADC, DAC, SPI, I^2S, I^2C, UART, RMII, PWM.

Infrasonic Microphone	Panasonic WM-61A	50 Hz ~ 15 kHz Analog Microphone Electret Condenser 2 V ~ 10 V Omnidirectional (-35dB ±4dB @ 94dB SPL) Solder Pads
Storage Module	Micro SD Storage Board TF Card Memory Shield Module SPI	The Micro SD Storage Board supports Micro SD cards and Micro SDHC cards. The communication interface is a standard SPI interface with a 4 M2 screw positioning hole, making it easy to install. 4.5-5.5V power supply is needed to power up the module, and power consumption varies from 0.2–200 mA. The interface level is 3.3 or 5V. Micro SD cards (=2G) and Micro SDHC cards (=32G) are supported. The card module size is 42X24X12mm.
Communication Module	SX1278 LoRa Module Ra-02 Ai-Thinker	Ra-02 is a wireless transmission module based on SEMTECH's SX1278 wireless transceiver. It adopts advanced LoRa spread spectrum technology, with a communication distance of 10,000 meters. The LoRa series module Ra-02 is designed and developed by AI-THINKER Technology. The SX1278 RF module is mainly used for long-range spread spectrum communication. It can resist Minimize current consumption. The SX1278 has a high sensitivity of -141 dBm with a power output of +18 dBm, a long transmission distance and high reliability.
Power Supply	DE 18650 3.7V 3200mAh Li-ion battery USB 5V 1A 18650 TP4056 Lithium Battery Charger Module Charging Board with	The 18650 Li-ion battery includes its own properties: voltage, capacity 3.7V with a capacity of 1200–3600 mah. 2.5-4.2 volts is the operating voltage. 2 to 2.5 volts is

	Protection Dual Functions 1A Li-ion	considered a cut-off voltage. Weight is 30gms to 55gms. The optimum or minimum charging time goes from 2.5 hrs to 3.5 hrs. The battery size is 18x65 mm. Micro-USB lithium battery charging board with overcharge, over discharge, and overcurrent protection. On-board micro-USB and soldering joints, 5V input port, and charging status: red light indicating charging, green light indicating full charge. The input voltage is DC5V, and the charging cut-off voltage is 4.2V. The maximum charging current is 1A. The size of the board is 26x17mm/1.02x0.67inch.

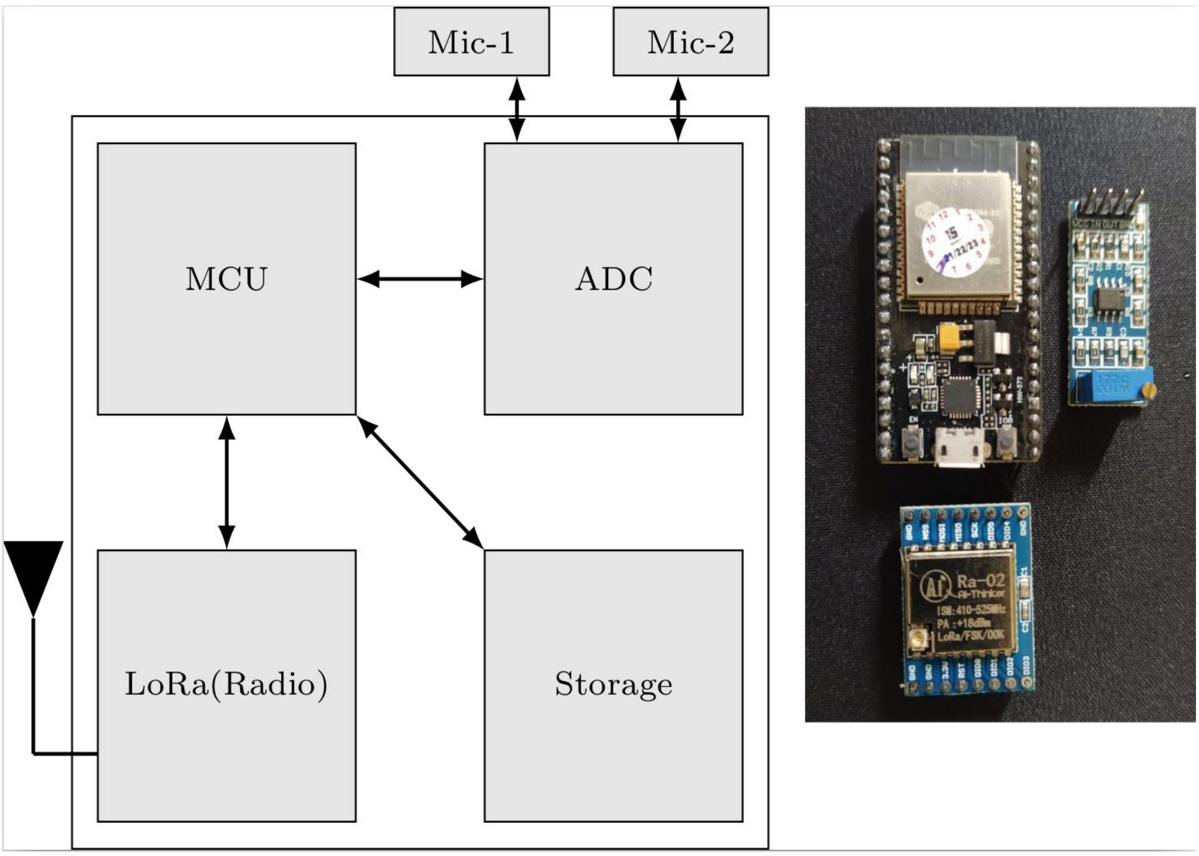

Figure 1: High-level architecture of the Eloc-NG device with its key components

Since the ESP32 module is the heart of the Elog-NG prototype, the firmware code of the device has to be running on the ESP32 module. It can be programmed using either Micropython or C language. The necessity to handle a considerable computational overhead using minimum hardware and energy resources qualifies C language over Micropython for an embedded system application of this nature. Therefore, after considering all the pros and cons of the two potential avenues, it was decided to use C language to write the firmware for the ESP32 module of the Eloc-NG device. The PlatformIO (https://platformio.org) integrated development environment (IDE) on Ubuntu Linux platform was used for writing code, compiling it, and writing the executable binaries to the ESP32 module, which is connected to the development computer via a USB cable.

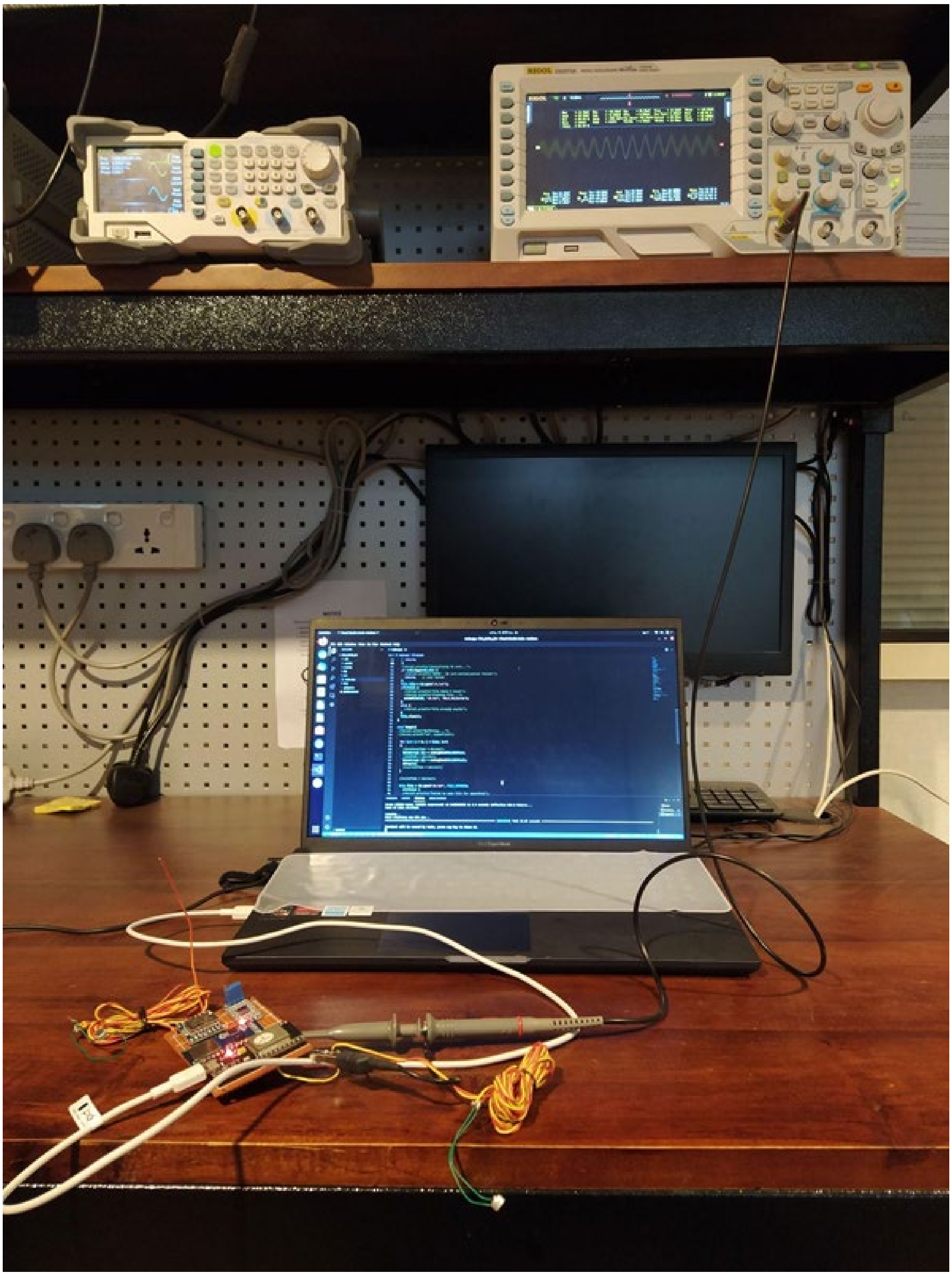

Figure 2: The hardware and software development setup at the university's electronics lab.

The two microphones are connected through two pins but read through the same analog-to-digital converter (ADC). When reading the two mics interchangeably as rapidly as possible, the time it takes to read one mic sample is between 50 to 60 microseconds. Therefore, the maximum achievable sample rate is about 16 to 20 kHz. However, due to the longer time period it takes to write samples to the SD card, it becomes a bottleneck and makes it difficult to achieve the aforementioned sample rate. Furthermore, higher sample rates impose an unnecessary energy consumption to the device. Considering that the elephant infrasonic calls and their harmonics fall in the lower frequency region, it was decided to set the sample rate of the Eloc-NG device to 1000 Hz so that it can capture audio frequencies up to 500 Hz. A time delay of 1 millisecond was set between consecutive ADC samples to achieve this sample rate. Data is captured for a duration of 27 seconds in each round until the device memory is considerably full before the captured data is dumped to the SD card. In order to prevent aliasing of the captured signals due to the low sample rate, a low-pass filter should be employed on the Eloc-NG device before the data is used for elephant rumble detection and localisation.

Figure 2 illustrates the hardware setup inside the electronics laboratory where the Eloc-NG hardware components are wired to a computer running the development IDE, and equipment, such as oscilloscopes. Using such a setup, the ADC input of the ESP32 module was connected to a potentiometer to identify the characteristics of ADC sensitivity. The ADC of the ESP32 module has a resolution of 12 bits, and therefore, produces a value from 0 to 4095 for an input voltage, which can vary between 0 to 3.3V. Figure 3 indicates that the sensitivity of the ADC is sufficiently linear.

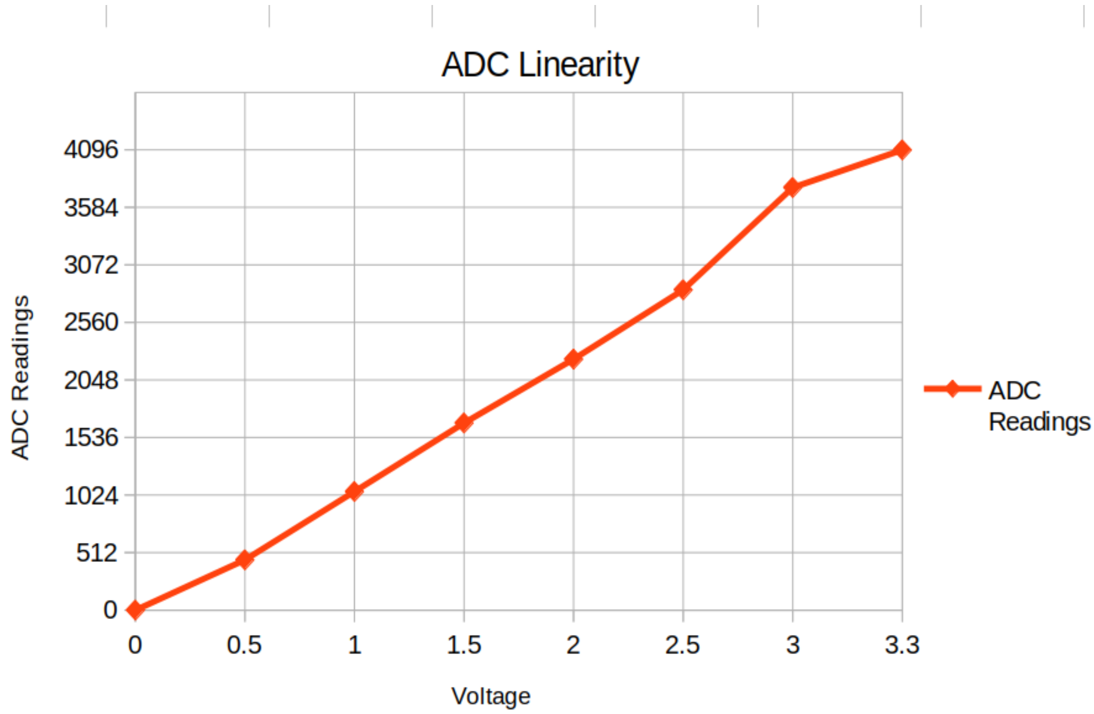

Figure 3: The readings produced by the ADC of ESP32 module with varying input voltage.

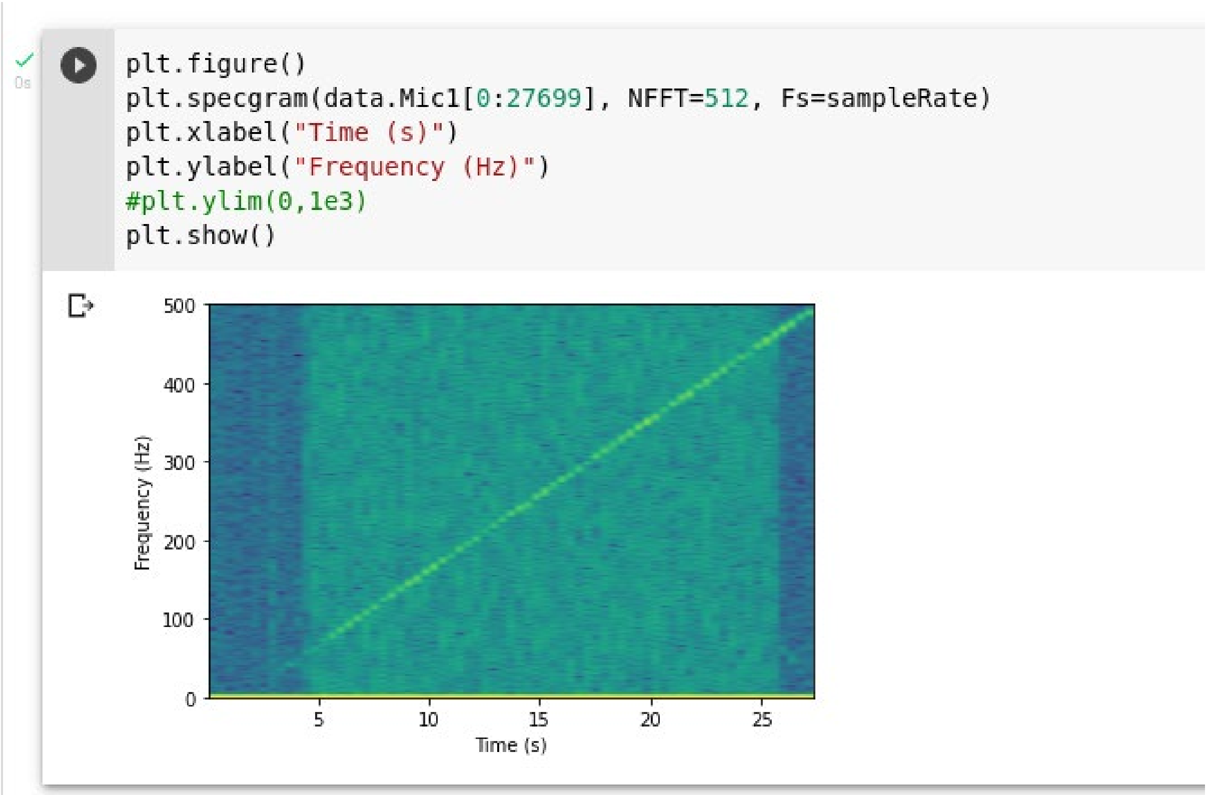

Figure 4: A spectrogram illustrating a chirp signal captured by the Elog-NG setup

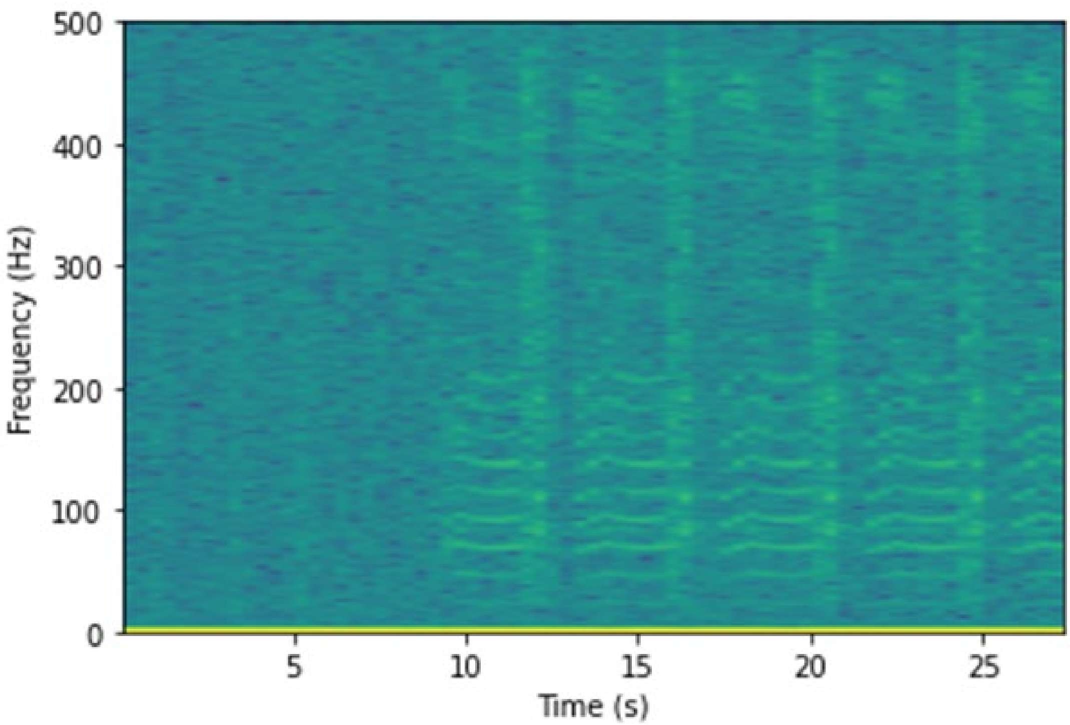

Figure 5: An elephant rumble repeatedly played by a speaker and captured by Eloc-NG.

In order to evaluate the sensitivity of the microphone pair of the Eloc-NG device, the following experiment was performed in a laboratory setting. Using a speaker attached to a computer, a chirp signal was played that increased the frequency from 0 to 500 Hz within a time period of

27 seconds. The Eloc-NG device captured the played chirp from a close proximity and saved into the onboard SD card. Later the captured data was sent through a low-pass filter with a cut-off frequency of 500 Hz. Figure 4 illustrates the spectrogram of the resulting data. As expected, the chirp signal has been captured sufficiently by the Eloc-NG device. The wideband noise that is visible in the spectrogram is potentially a by-product of the imperfections of the speaker that was used to play the chirp signal. Furthermore, the speaker is not designed to play frequencies in the infrasonic range (< 20Hz), and therefore, the spectrogram of the captured signal by Eloc-NG shows a weaker pattern in that region.

Moving another step forward, an actual elephant rumble was repeatedly played on the speaker and captured by the Eloc-NG device. The rumble is a recorded clip from the elephant vocalisation dataset produced by Dr. Shermin de Silva. Figure 5 illustrates the captured data as a spectrogram by the Eloc-NG device. The device has been able to successfully capture important frequency components of the elephant rumble, indicating its suitability for the purpose of capturing elephant infrasonic calls.

Experiments with Machine Learning-based Rumble Detection:

For the Eloc-NG devices to identify the direction of the targeted infrasonic sources, i.e., the elephants, it is necessary to accurately detect that a particular infrasonic signal has originated from an elephant in the first place. This requires performing machine learning-based classification on-board the Eloc-NG device. Due to the limitations of computational and energy resources, such machine learning classifications need to be designed in an energy efficient manner. That means, a classifier should be able to work with lower sample rates and shorter data recording durations. The current prototype design of the Eloc-NG device set the bar at 1000 Hz for the sample rate and 27 seconds for the recording duration. Therefore, it is necessary to develop and finetune machine learning models to operate on data of that nature.

As a starting point for the development of machine learning models to detect elephant rumble on Eloc-NG devices, preliminary experiments were conducted without considering the constraints in a low resourced environment. The elephant vocalisation dataset produced by Dr. Shermin de Silva was used for this purpose. Figure 6 illustrates the waveform plot of an elephant rumble from this dataset. A total of 1429 audio clips from the dataset were chosen, which represent either a rumble or some other vocalisation to train and test binary classifiers. Figure 7 depicts the distribution of the audio samples to the two classes. Although the dataset is imbalanced, the difference between the number of rumble and non-rumble samples is not too large. Three machine learning classifiers, i.e., random forest, decision tree and k-nearest neighbours, were used to train and test models. Table 2 indicates the classification accuracy achieved by each model for detecting elephant rumbles.

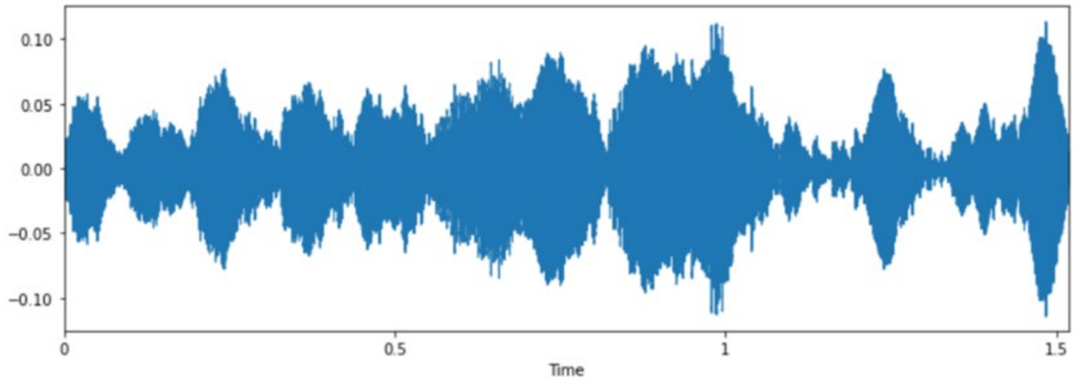

Figure 6: Waveform of a rumble from the dataset.

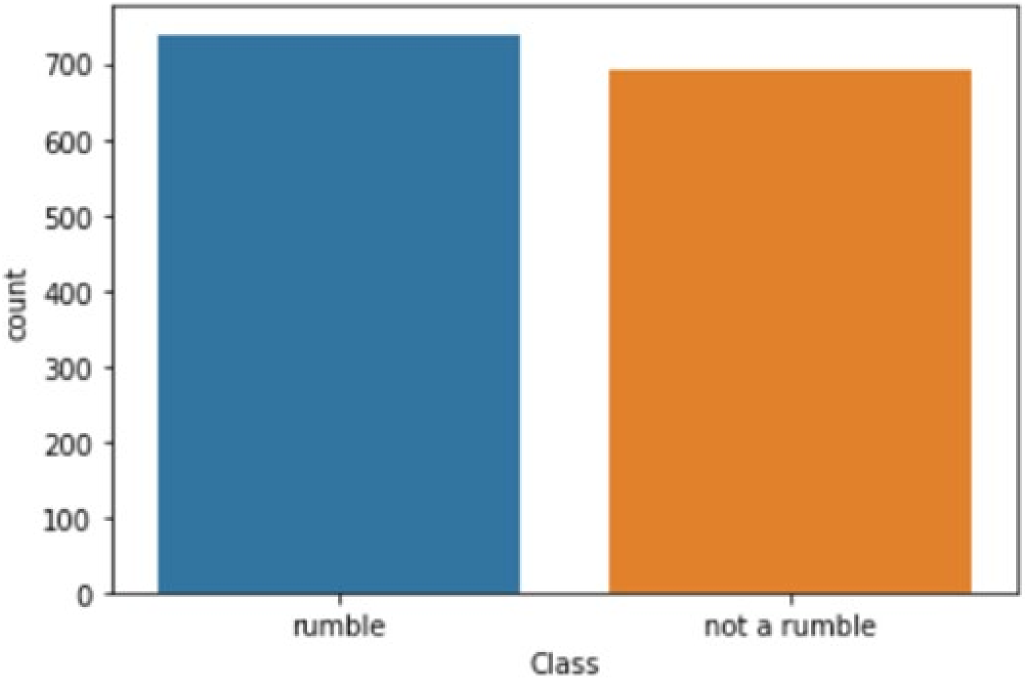

Figure 7: Number of samples used for the two classes.

Table 2: Accuracy of multiple binary classifiers predicting elephant rumbles.

#	Name of the Classifier	Accuracy
1	Random Forest	82.42%
2	Decision Tree	73.74%
3	K-nearest neighbours	73.46%

The considerably high classification accuracy achieved in this initial stage indicates that elephant rumble detection using machine learning techniques is possible. However, it is important to note that these classifiers were implemented using audio data sampled with a high sample rate, i.e., 48 kHz. In order to achieve elephant rumble detection on an Eloc-NG device, the sample rate of the dataset needs to be reduced significantly. This can be done by resampling the audio clips in the dataset to different lower sample rates and then training and testing machine learning models. Similarly, the potential to accurately detect an elephant rumble using a much shorter audio clip length will also be useful to minimise the required signal capturing duration, hence saving energy on the Eloc-NG device.

The ESP32 microcontroller chip consists of an ultra-low-power (ULP) co-processor with an 8-bit CPU, in addition to its 32-bit powerful two CPU cores. In order to save energy on ESP32, it is possible to keep the energy-hungry CPU cores in deep sleep and perform some work on the ULP core. We are planning to exploit this hardware facility on our rumble detector on the Eloc-NG device. Our detector is planned to consist of two stages: first stage and second stage. At the first stage, the Eloc-NG device is in deep sleep mode, while the ULP co-processor keeps checking the reception of any audio signal at the ADC from microphones. When the ULP co-processor picks up a signal with a considerable amplitude, it awakes the main CPU cores, which effectively run the second stage of the detector. This second stage captures a 27-second-long signal with a 1000 Hz sample rate, filters it, and passes it into the machine learning classifier to detect if it is a rumble. If it is a rumble, the direction calculation will be performed to locate the elephant.

Challenges and status of the project:

As it was for all the other sectors in academic and scientific research, the COVID-19 pandemic caused a serious disruption to this project. The COVID-19 lockdown in Sri Lanka prevented us from accessing the university to conduct the development work using laboratory facilities. Being unable to access equipment and facilities of laboratories in the university, we were confined to homes and had to use minimum hardware equipment for the initial tests. The COVID-19 lockdown was only lifted in this month, and therefore, we worked on the project from home until then. We are rapidly executing some of the missing experiments these days to catch up with the lost time. Additionally, the economic impact of COVID-19 in Sri Lanka has created a shortage of imported electronic components, which is heavily challenging this work. Despite shortage of supply, we didn't give up and found what we needed from various sources and continued the development of the Eloc-NG prototypes. We hope that the situation will improve further in the coming weeks and enable us to conduct the planned activities to succeed in this project.

Next steps of the project:

- Eloc-NG hardware development:
    - Replaying elephant vocalisation recordings using a powerful subwoofer outdoors and measuring Eloc-NGs sensitivity over long distances.
    - Evaluating the ability and the precision of calculating direction to an infrasonic call using the time-difference-of-arrival (TDoA) technique. The same powerful subwoofer playing recorded elephant vocalisations will be used for this purpose.
    - Designing and implementing a renewable energy source for the Eloc-NG device, such as solar panels and rechargeable batteries.

    - Recording real elephant vocalisations in the field using Eloc-NG devices -- in both Sri Lanka and Indonesia.

- Automatic elephant rumble detection:

    - Resampling Dr. Shermin de Silava's elephant vocalisation dataset to different lower sample rates and evaluating the possibility of training machine learning models to accurately detect elephant rumbles -- the target is to achieve a good classification accuracy with data of 1000 Hz sample rate.

    - Implementing the entire software pipeline on the Eloc-NG device to capture data, detect elephant rumbles, and calculate the direction to the elephant. This includes the porting of trained and tested machine learning models to the ESP32 platform to run on the Eloc-NG device.