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INSIGHTS FROM DEPLOYING MULTICHANNEL ACOUSTIC AUTONOMOUS RECORDING UNITS IN BORNEO AND THE UK

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ABSTRACT

Multichannel acoustic monitoring uses recorders with multiple microphones to capture the spatial distribution of sounds, potentially providing an enhanced understanding of ecosystems. However, due to practical barriers such as high power demands, large data needs, and ingress protection challenges, there have been few, long-term deployments of autonomous multichannel recorders (i.e., without manual intervention). Here, we describe new, 2 to 22 week long deployments of the Multichannel Acoustic Autonomous Recording Unit (MAARU) in temperate (UK) and tropical (Borneo) environments. MAARU is a custom six-microphone recorder that uses solar power and 4G data transmission for fully autonomous monitoring. We first outline updates to MAARU's weatherproofing and field installation, including a redesigned enclosure with improved robustness to insect ingress, and share lessons for future deployments. In particular, we found that the membranes that seal microphone holes in the recorder casing fail under heavy rain if not sheltered and that 3D-printed polymer parts with a low glass transition temperature may warp due to heat from the electronics. We also discuss MAARU's capacity to amplify sounds from target directions via beamforming, and consider its application to distinguishing bird communities in neighbouring areas of different land use. In all, we hope these insights advance the successful adoption of this powerful technology.

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1. INTRODUCTION

Capturing natural soundscapes with multichannel recorders can unlock a range of information about the behaviour and distribution of animals. For instance, sounds' direction of arrival can be calculated, facilitating estimates of species abundance or tracking of individual movement [1, 2]. Beamforming can also be used to hone in on sounds from target directions, producing a higher signal-to-noise ratio (SNR) and allowing enhanced bird call classification and other analyses [2–5].

A growing number of commercial and custom multichannel field recorders have been developed (see an overview in [3]), including stereo units [6] and those with four or more microphones [3–5]. However, many remain costly and/or are not designed for fully autonomous deployments, with self-sufficient powering and data transmission alongside robustness to prolonged environmental exposure. Such features are necessary to obtain the large-scale insights of long-term continuous Passive Acoustic Monitoring (PAM) and/or for monitoring ecosystems and illegal activity in near real time (e.g., [7]).

MAARU was designed to fill this gap: it is open source, built from mostly off-the-shelf (OTS) components, and can employ solar powering and cellular data transmission [3]. Building on an existing fully autonomous, open source recorder [8], MAARU's core hardware consists of a Raspberry Pi (2B v1.2, 3B or 4B) with a sound card and circular array of six omnidirectional MEMS microphones (full details in [3]). The existing MAARU design features two weatherproofing options: an affordable, modified OTS container and a custom 3D-printed enclosure for semi-autonomous deployment.

We present a new hybrid weatherproofing design, with modified OTS and 3D-printed parts for improved robustness and ease of use and manufacture. We deployed MAARUs with this updated weatherproofing for up to 5 months at temperate sites in the UK and in the tropical forests of Malaysian Borneo, to validate the revised design and further investigate the applications of beamforming in ecoacoustics. Here, we review how these deployments went, suggest further improvements to MAARU's design and deployment, and discuss forthcoming analyses.

2. MATERIALS AND METHODS

2.1 Weatherproofing Redesign

MAARU's original modified OTS weatherproofing was designed to be highly affordable and require no specialist tools to build. Early deployments revealed robustness challenges, though, in particular from animal interference, such as rodents chewing on power cables, and impacts, such as falling from height. The existing 3D-printed version addressed some of these issues with a sturdier enclosure. However, it was cumbersome to print (>15 hr on a *Prusa* MK3S) and required applying a coat of resin to fully seal against water, limiting accessibility for users without access to a well-equipped workshop. The water resistant ePTFE vents used to cover the microphone holes in both original designs were also found to be susceptible to insect ingress – specifically, termites chewing through the vents – during deployments in the Brazilian Amazon.

For the redesigned weatherproofing, we thus opted for a durable polycarbonate, water-resistant case (*Tactix* Water Proof Case (L), ∼10–15 USD depending on vendor) to house the core electronics (Raspberry Pi, sound card, microphone array, 4G dongle and a 12–5 V step-down converter). The case lid hinges for easy access to the internals. To prevent insect ingress, we used much smaller microphone holes and ePTFE vents, as the MEMS microphone ports are <0.5 mm in diameter. We also attached patches of fine stainless steel woven mesh (100 mesh, 0.15 mm hole size) over each microphone hole on the exterior of the case, using a water- and UV-resistant adhesive (Fig. 1A).

To accurately align the microphone ports with the corresponding holes in the case, we designed a 3D-printed mounting frame that sits near-flush against the base and sides of the case. The frame attaches to the case via velcro and the electronics mount to it without adhesives, allowing all parts to be removed with ease. The Raspberry Pi, sound card and microphone array form a sub-assembly, joined by screws and metal standoffs, that rests on springs glued into the mounting frame. A 3D-printed ring also sits around the microphones and flush with the top of the case. It contains a small hole for each microphone port and acts as an additional physical barrier to insect ingress. The springs prevent excessive force being placed on this sub-assembly when the case lid is closed.

A single power cable enters the case via a watertight cable gland. This can either be a USB cable connected to the Raspberry Pi, or, for solar powered deployments, a two-core power cable (AWG 17 was suitable for our powering setup), which connects to the step-down converter via bullet-style crimp connectors. Wherever possible, appropriately-specified crimp connectors were used instead of soldering to make electrical connections, as they can be easily dis/re-connected. The holes for the microphones and cable gland are all manually drilled and accurately located using 3D-printed jigs that can attach to the *Tactix* case. The electronics power cable's other end attaches to a 30 A solar charge controller which is housed with a lithium iron phosphate (LiFePO4) battery in a separate IP56-rated polypropylene box (supplier: *Solent Plastics*, product code: WBAT-S, ∼10 USD). Both the electronics power cable and a heavier duty power cable that runs to the solar panel (in our case, AWG 13 was suitable) enter this box via cable glands in manually-drilled holes. Where possible, we wrapped cables in a semi-rigid plastic cable tidy and nylon cable mesh to protect them from rodents and other animals. If costs permit, we recommend using armoured cable for long-term deployments.

2.2 UK and Borneo Deployments

MAARUs were deployed at four temperate sites at Imperial College's Silwood Park campus (Ascot, UK) for various periods of time (from 14 to 125 days) between February and July 2024. MAARUs and 60 W solar panels were mounted to custom-built metal frames fixed to the ground, with the battery box placed underneath (Fig. 1B). In September 2024, MAARUs were deployed at six tropical sites spanning a land-use gradient in and around the Danum Valley Conservation Area in Sabah, Malaysia. Two devices were deployed in each of: old-growth forest, logged forest, and smallholder oil palm plantations.

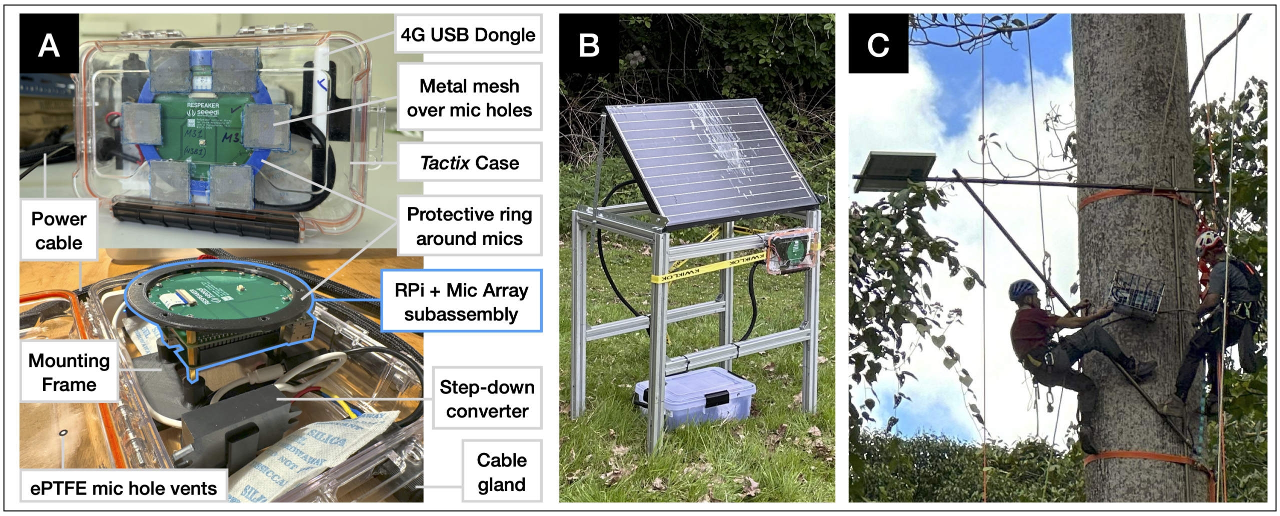

Figure 1. **A:** Redesigned MAARU weatherproofing enclosure. **B:** MAARU deployment in the UK. **C:** Professional tree climbers Jamiluddin Jami and Louis Makhluf mount a MAARU to a tree in Malaysian Borneo.

Data were collected between approx. two weeks and five months, depending on devices' survival time (see Section 3). For access to sunlight and protection from animals on the ground (e.g., elephants), the old growth and logged forest devices were mounted to trees by professional tree climbers. Solar panels (three 55 W and one 100 W) were attached to triangular structures assembled from aluminium poles (Fig. 1C). MAARUs and battery boxes were placed in a cage built from six steel grills (supplier: *DAISO*, ∼6 USD per cage), to protect them from animals in the trees (e.g., monkeys). The cages and pole structures were fixed to trees with heavy-duty ratchet straps. For the oil palm sites, the device cage and 100 W solar panels were mounted to slotted angle bars inserted in the ground.

Across all sites, MAARUs were deployed near the edges of different habitats or land-use types and/or within audible range of roads or other sources of anthropogenic noise from prevailing directions, so as to explore various applications of beamforming. All recordings were compressed to FLAC on-device and streamed over 4G to *Box* Cloud Storage via FTPS. For continuous 24/7 recording, this creates ∼8 GB/day of data (∼250 GB/month), so all devices had a minimum 300 GB/month cellular data plan.

3. RESULTS AND CONCLUSIONS

MAARU's redesigned weatherproofing improves robustness to previous failure modes while enabling better access to internals and easier manufacturing than the previous 3D-printed enclosure. However, new failure modes have been discovered. For the UK deployments, the 3D-printed parts were made from PLA, which is safe (minimal fumes) and straightforward to print, but has a fairly low glass transition temperature (T_g) of ∼57°C [9]. This was expected to be sufficient, however parts in three units warped due to heat from the electronics, damaging several microphones in these units (sometimes in just two weeks after deployment). The Raspberry Pi and 4G dongle can generate considerable heat, which was likely exacerbated by both being housed in a clear, sealed enclosure exposed to sunlight. For the Borneo deployments, these parts were printed from ABS, which has a T_g of ∼107°C [9], and did not warp. We thus recommend using ABS or other materials with a similar or higher T_g in future.

In Borneo, the old growth and logged forest units failed after ∼2-4 weeks. This appears to be due to water ingress from heavy rainfall piercing the ePTFE microphone vents (not all units have been retrieved yet). All old growth and logged forest units were deployed horizontally (i.e., with the ePTFE vents perpendicular to rainfall) to provide the freedom to beamform in any horizontal direction. MAARUs were deployed vertically in the UK and oil palm and did not face this issue. The oil palm devices were also sheltered by the solar panels. As such, we recommend either sheltering any units deployed horizontally (e.g., with the solar panel or some other cover [4]) or deploying the MAARU units upside down, which should allow for equivalent beamforming and localisation capabilities. Finally, for all deployments, the 55 W and 60 W panels did not provide enough power for continuous 24/7 monitoring (perhaps due to lower insolation in the UK and some obstruction from trees and clouds in Borneo), whereas the 100 W panels in Borneo did, hence we recommend the latter for such monitoring efforts in future.

Despite device failures, sufficient data was gathered to investigate beamforming to distinguish neighbouring habitats/land-use types and to steer recordings away from reasonably directional unwanted noise (e.g., road traffic) towards directions of interest. For the UK deployments, there is also an opportunity to evaluate MAARU's beamforming capacity with fewer microphones undamaged by parts warping. Existing tests with MAARU showed improved confidence scores of avian call classifier BirdNET (which correlate with probability for many species) when beamforming in generic directions [3], likely owing to a higher SNR. Leveraging knowledge of habitat and site structure should allow for scaling these benefits to more ecologically relevant applications. Beamformed audio will also be analysed with acoustic indices and machine learning model embeddings as part of a representative ecoacoustic toolkit. While it is harder to define an improvement in these metrics without ground truth biodiversity data, we hypothesise that they should significantly differ for directions corresponding to different land-use. Should beamforming with MAARU successfully distinguish neighbouring habitats/land-use types, there is a notable opportunity for ecologists to monitor land-use gradients with fewer devices, and thus less cost and disturbance, than if single-channel, omnidirectional recorders are used (many of which cost a similar amount to MAARU). Overall, we hope these forthcoming analyses show that beamforming can segment soundscapes for more efficient and accurate ecosystem monitoring.

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