A portable Raspberry Pi-based camera setup to record behaviours of frogs and other small animals under artificial or natural shelters in remote locations

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Abstract

Here, we describe a Raspberry Pi-based camera system that is portable, robust, and weatherproof, with a close-up focus (2.5 cm). We show that this camera system can be used in remote locations with high rainfall and humidity. The camera has an Infrared LED light to film in dark places and can continuously record for 21 days. We also describe how to make concrete artificial shelters to mount the camera in. One of the great strengths of this shelter/camera setup is that the animals choose to take up residence and can then be filmed for extended periods with no disturbance. Furthermore, we give examples of how shelters and cameras could be used to film a range of behaviours in many small cryptic amphibian species, but also other small vertebrates and invertebrates globally.

Introduction

Understanding animal behavioural responses to environmental variation and change is a frequent goal in animal ecology and has important implications for conservation (e.g., Hopkins *et al.* , 2023; Kays*et al.* , 2015; O'Brien *et al.* , 2023a). However, collecting behavioural data on animals, especially in remote areas, is very time-consuming and requires a lot of effort and resources. Camera systems are increasingly used to remotely monitor wildlife because they can record behaviour over long and continuous periods and are generally non-invasive (see reviews: Cutler & Swann, 1999; Jolles, 2021; Trolliet*et al.* , 2014). Camera systems can be commercially built systems (e.g., Meek *et al.* , 2014; Trolliet *et al.* , 2014), which are ready to use and generally compact but can be expensive and have less flexibility in program settings, battery life and data storage (Cox*et al.* , 2012; Prinz *et al.* , 2016; Reif & Tornberg, 2006). Alternatively, they can be do-it-yourself assembly, which can be more flexible and cheaper (e.g., Cox *et al.* , 2012), but can be time-consuming to make and harder to use.

Self-assembled camera setups generally use a microcomputer, typically Raspberry Pi (www.raspberrypi.org) or Arduino (www.arduino.cc) (Allan *et al.* , 2018; Greenville & Emery, 2016; Johnston & Cox, 2017). Raspberry Pi-based video recorders have been used in animal behavioural studies; for example, behavioural studies of the waggle dance of honeybees (Ai*et al.* , 2017), the spacing of foraging fruit flies (Churchill*et al.* , 2020), nematode behaviour (Nuñez *et al.* , 2017), monitoring of mammal populations (see review Swann *et al.* , 2004), respiration and pupil dilation in laboratory mice (Kallmyer *et al.* , 2017; Privitera *et al.* , 2020), avian studies assessing nest box use, parental care and other behaviours (e.g. Hereward *et al.* , 2021; Prinz *et al.* , 2016; Zárybnická *et al.* , 2016). The use of Raspberry Pi units to collect video data on behaviour in amphibians has, to the best of our knowledge, only been conducted on Hellbender salamanders (*Cryptobranchus alleganiensis*) in the United States (O'Brien *et al.* , 2023a,b), where cameras were used in artificial aquatic shelters to described courtship and parental care behaviours and nest outcome. Self-assembled cameras can also be combined with other sensors; for example, temperature and humidity sensors (McBride & Courter, 2019).

Artificial shelters have been proven to be a successful tool to monitor amphibian populations. They have an advantage over labour-intensive trapping and observation methods (Sutherland *et al.* , 2016) and reduce disturbance to the animals and their environment (Hesed, 2012). Artificial shelters built with the option of camera observation are a good way to obtain important behavioural data while minimising impacts on animals or their habitat. Once an animal is using a shelter, it can be observed for extended periods using a small camera that is serviced without any disturbance to the animal or the shelter. However, many amphibian species are small, so cameras need to focus on small subjects at close range. Furthermore, many amphibian species live in remote areas (e.g., mountain tops), so shelters and associated camera setups need to be small and transportable and have long recording periods. Previous studies have made portable camera setups, but the minimum focal distance is 15–25 cm (Hereward *et al.* , 2021; O'Brien *et al.* , 2023a, b) and the recording time is limited to a maximum of 96 hours (O'Brien 2023a, b). These cameras are of limited use for the study of small animals under shelters, and need to be serviced regularly or recordings need to be short and/or well-spaced in time.

In this study, we describe and test a Raspberry Pi camera setup that is portable, robust to weather, can continuously record for 21 days (504 hours), and has a focal distance of 2.5 cm. The camera setup was tested on a small (approximately 3.5 cm long) microhylid frog species that lives among leaf-litter, logs and rocks on remote mountaintops in north Queensland, Australia. We also describe two artificial shelters to mount the cameras in. The combination artificial shelter/camera setup we present could be used to collect natural history and behavioural data on any small, cryptic vertebrate or invertebrate species.

MATERIAL AND METHODS

Camera set up

For the camera setup, we used a Raspberry Pi 4 microcomputer circuit board with a 5-megapixel 1080P camera (25 mm x 24 mm x 17 mm) with a 1300 adjustable night vision fisheye lens (focus 2.5 cm) and a single 5 mm infrared LED light (Fig. 1). We removed the round part of the infrared LED light using a belt sander and added a small semi-transparent piece of sticky tape to diffuse the light throughout the filming chamber (Fig. 1). A Rpi-RTC DS1307 clock module keeps accurate time while not connected to the internet. The microcomputer was placed in an IP65 waterproof electrical junction box (158 x 90 x 60 mm) with four 1 g silica gel desiccant packets. Three holes were drilled in the junction box: two on the long side for waterproof cable glands (fits cables between 3–6.5 mm) and one on the bottom for the PVC male adaptor (SKU 436-010; 3 cm). The power source cable (USB type C) and the USB extension cable were inserted individually through one of the two cable glands and together into a 1.5 m long stainless-steel shower hose to prevent damage by rodents (which chew exposed rubber or plastics). On the side of the stainless-steel hose, the cables were inserted individually through cable glands in an IP67-rated waterproof PVC box (38.8 x 28.9 x 24.3 cm). In this box, the USB power cable is connected to a power converter (12 V to 5 V) connected to a 130 Ah LiFePO4 lithium battery (10 kg). A 1 TB USB drive is connected to the USB extension cable (Fig. 1).

Trials by (Mouy *et al.* , 2020) have found that USB storage used more energy than SD card storage, therefore lowering battery life, and USB storage was less reliable because of its more fragile connection. However, O'Brien *et al.* (2023a, b) and Kallmyer *et al.*(2017) successfully used 64 GB and 32 GB USB storage in their study, respectively. In this study, we chose a 1 TB USB storage because the USB drive and battery are separated from the microcomputer; which has the benefit that the USB drive and battery are replaced in the field after 21 days (often during rain and 90%> humidity), we do not have to open the box with the microcomputer and camera to potential damage by moisture. The total cost for the 21-day camera setup is AUS$790.75 (Table 1).

The camera length can be easily adjusted for different habitats. For example, when filming animals under leaves or artificial shelters (Fig. 4), we used the camera setup with the camera directly placed in the PVC male adaptor (4 cm width) and the lens focusing at 2.5 cm. To ensure that water could not enter the PVC male adaptor, a PVC coupling was placed with a glass lens glued inside and a rubber O-ring was placed between the connections. This way, if necessary, we could still change the focus of the camera by removing the coupling. For filming under natural or artificial wood shelters ('logs'; see paragraph "artificial shelters" below), we use a 20 cm long and 4.2 cm wide PVC pipe in the converter, which goes over the male adaptor. The camera and the infrared LED light were held in place at the end of the PVC pipe with a 3D-printed holder against the glass lens. Both the camera and battery box were covered with square mesh (mesh size 1 x 1 cm) to protect the plastics from chewing by rodents. To record the temperature and humidity a datalogger (Hygrochron iButton) was placed in the chamber when the camera was recording (Fig. 5).

The Raspberry Pi was coded to start recording when it powered on, and for continuous video recordings of 15 minutes each. These recordings run back-to-back but a 15-minute duration was chosen to keep the file size of each recording manageable (O'Brien *et al.* , 2023a). The 'continuous' recording stretched for 21 days. Videos were saved to a 1 TB USB drive, creating folders of the month followed by folders of the day. The videos themselves were labelled with time (hour.minute.second) (Appendix 1; for detailed instructions on how to program the Raspberry Pi see e.g. Hereward *et al.* , 2021; Youngblood, 2019).

Artificial shelters

We designed the artificial shelters based on the preferred nesting/sheltering microhabitat of microhylid frogs, as described by Felton *et al.* (2006) for *Cophixalus ornatus* (now *C. australis* ; Hoskin, 2012). Sheltering and nesting microhabitats are essentially small crevices or holes in soil or wood, or under leaf litter, logs or rocks. The objective was to make artificial shelters that contain small spaces and can have a camera inserted to film any of these spaces (i.e., a 'chamber') that is in use.

Two artificial shelter types were constructed, one using wood and one using concrete. The wooden shelters were made by splitting logs found at the site (e.g., from a tree fall near a road or path) (Fig. 2A). By splitting the log in half, we produce a flat surface to place against the ground (Fig. 2B). The resulting log size (i.e., surface in contact with the ground) was an average of 60.4 cm in length x 18.5 cm in width. When a frog occupied the shelter and we decided to film, a 42 mm wide hole was drilled through the log to fit the camera. The diameter of the drill hole reflected the size of the end of the camera so that it can be neatly inserted. We also sourced sink plugs of approximately 40 mm diameter and filled these with concrete, so that these could be used to block the hole when the camera was ultimately removed. The concrete was used to add weight to the plug and to add thermal buffering to the chamber.

The concrete artificial shelters are rectangular concrete blocks of (29.5 x 22.5 x 4.5 cm), with six rounded (42 mm diameter) nesting chambers, each with two entrances/exits (Fig. 3B). A plug hole is present above each nesting chamber so that the plug can be lifted to inspect the nesting chamber. The plug sits atop a 40 mm wide and 35 mm long piece of PVC pipe. The plug has concrete packed into it to better buffer the nest chamber. We constructed concrete artificial shelters using a four-two-one concrete mixture (four parts crushed rock; two parts sand; and one part cement). One-third of the concrete was poured in a 4 L Tupperware container, and then six 42 mm-wide plastic-wrapped PVC pipes were equally distributed in the concrete, placed vertically to make chambers and a galvanized 1 x 1 cm mesh hardware cloth was placed around them. The other two-third of the concrete was then poured into the Tupperware container around the PVC pipes. Pieces of garden hoses (each 3 cm) were placed in the concrete where the entrances/exits going to be (Fig. 3A). The whole Tupperware container was then placed on a vibrating plate to remove air bubbles. After drying for at least 48 hours, the PVC pipes and garden hose pieces were taken out of the concrete. The shelters were then soaked in water for 3 days and then dried completely in the sun before being deployed in the field. The cost of making the shelters was AU $20, per mould (4L Tupperware, 42 mm x 100 mm PVC pipe, and 10 pieces of 3 cm garden hose), AU$3 for the concrete shelter (concrete, sand, crushed rock, and galvanized mesh hardware cloth) and about AU$18 for the six lids per shelter (sink plugs, PVC pipe, screws, concrete mixture) (Table 1). So, once you have the moulds, which are reused, the total cost per shelter is around AU$21 (US$14), with potential labour costs not included (Table 1).

Testing the cameras and artificial shelters

The camera setup and artificial shelters were tested in the Paluma Range (north-east Queensland, Australia), where a small (3.5 cm body length) microhylid frog (Robust Whistling Frog *Austrochaperina robusta*) occurs at high abundance. This species is restricted to mid-elevation and upland rainforest, living among the leaf-litter and under logs and rocks (Hoskin & Hero, 2008). It is extremely cryptic, other than the loud whistling calls of males calling after rain. *Austrochaperina robusta* is a terrestrial breeding frog, with direct development (tadpoles develop within the eggs), and the small clutch is laid in leaf-litter and under logs and rocks and is attended by an adult frog (Hoskin, 2004). Details of breeding biology, including the role of the adult in caring for the eggs and metamorphs, as well as their year around microhabitat use are unknown due to the small size and cryptic lifestyle.

Thirty artificial concrete and 30 wooden shelters were placed in a known high-density *A. robusta* area between November 2022–January 2023. To test the most risk-prone parts, switching out batteries and USB drive in the field, we used 30 mAh 12V batteries that can run up to 5 days. Cameras were deployed 14 times during the subsequent breeding season (21 November–23 February), with a minimum deployment of a camera being 3 days and a maximum deployment being 30 days at a shelter. During this period, the batteries and USB drives of the cameras were changed every 3–5 days. This involved a total of 62 battery and USB changes.

RESULTS

Twenty-four out of the 30 concrete shelters and 19 out of the 30 wooden shelters were occupied at least once by *A. robusta* during the field test period. Cameras were placed in 11 shelters, each of which had a different *A. robusta* individuals. The film quality was generally excellent, including good lighting (Fig. 5), and a total of 850 hours of video footage with an *A. robusta* in view was generated. Eight individuals stayed longer than 5 days in a chamber that was being filmed, while three stayed over 30 days. This suggests that the camera was accepted by the frogs, and not a source of disturbance. In addition to frogs, various other species sought refuge under the artificial shelters and were captured in the video footage. These included other small vertebrates (skink species) and invertebrates such as ants, earthworms, velvet worms, cockroaches, and millipedes.

Although the cameras were thoroughly tested before being deployed in the field, a few issues arose during field testing. In two camera setups, the dates and times displayed on the video files were inaccurate after batteries were replaced. To resolve this issue, we reran the codes for the clock, which successfully fixed the problem for one camera. However, we had to replace the clock module in the other camera. In one camera setup, the brightness of the Infrared LED light decreased in some videos before eventually turning off. This occurred towards the end of the expected video duration and was likely due to the lower voltage available. The issue was resolved by changing the battery and always using fully charged batteries. The final issue was that despite adjusting and testing each camera's focus before deployment, some cameras produced out-of-focus video. This was primarily attributed to the camera sliding down too deep (and hence out-of-focus) in the shelter setup. This was sometimes due to the camera hole in the artificial shelters being slightly wider than the camera PVC pipe, causing the camera to slide down too far. In other cases, it appeared that the camera had been moved during filming, probably due to disturbance from wildlife such as brush turkeys or feral pigs. To address these issues, we applied multiple layers of Duct tape around the camera PVC pipe to secure it in place and prevent any sliding or moving. Another common cause of unfocused videos was the gradual elevation of the soil beneath the camera due to the burrowing behaviour of earthworms, but this could not be prevented.

We initially envisaged that the camera setup could be damaged by moisture. They were sitting in a wet rainforest environment with regular heavy rain, and the 62 battery and USB drive changes were all performed in >90% humidity and sometimes during rain. However, no water damage was observed on the cameras, batteries, or USB storage drives. This was even the case for one of the cameras which spent time with its lens end underwater when one of the chambers was flooded during heavy rain. The camera kept recording and was not damaged.

DISCUSSION

In this paper, we have described and demonstrated the successful building and testing of a Raspberry Pi-based camera that produces high quality close-up (2.5 cm) videos and is portable and weatherproof. The camera setup can record continuously for up to 21 days in remote locations, and we have demonstrated how they can be used in natural settings or paired with artificial shelters. The cameras could be used for many different research topics, in many different species and settings. Collecting long-term continuous behavioural data, especially in the field and from small species, is very intensive and often logistically not possible (for example, at night or when the animal is in their shelter). This camera setup will enable behavioural data to be collected on the natural history of small and cryptic species.

A benefit of the camera is that you have control over programming when to record. In this trial, we programmed the camera to continuously record for 21 days. We recommend starting with this method to get an idea of the species daily time budget. However, the camera can be coded to record whatever data is required for the specific research questions; for example, for 30 minutes every four hours, or only day- or night-time. Specific recording periods will increase battery life and increase the camera data collection time. The self-assembled camera setup could be combined with sensors such as temperature and humidity loggers (McBride & Courter, 2019). We deployed the cameras on a mountain in the tropical rainforest which has high rainfall (average annual rainfall of 2534.7 mm) and humidity during the summer months of >90% 24 hours a day. We therefore did no attach temperature and humidity sensors because adding these would have required extra holes to be drilled, increasing the chance of moisture entering the setup. Adding sensors would also decrease the battery life. The goal of this study was to build a camera setup that is robust, extremely weatherproof, with as long as possible recording time, and relatively cheap to make. We did use separate temperature and humidity sensors (Hygrochron iButtons), which are robust and don't connect to the camera setup or battery (Fig. 5).

The artificial shelters proved to be very successful because they were voluntarily occupied by the frogs in high numbers and enabled filming at optimal distance. Importantly, they also enabled extended behavioural observations without influencing the frog's behaviour. Obtaining sheltering and breeding information in a species like this would otherwise require regular turning of logs and other cover, disturbing (and potentially injuring) the frogs and damaging the micro-habitat. Due to this success, we now have increased the number of shelters and expanded the research to other upland areas, with the objective of recording the breeding behaviours and breeding success of Critically Endangered microhylid frog species. While both artificial shelter types (concrete and log) were successful, filming and maintenance of the concrete shelters was easier, due to the sturdier and stable material, and the predrilled holes. In addition, the log artificial shelters will disintegrate and fall apart with time and will need to be replaced. In contrast, the concrete shelters will last and will increasingly 'integrate' with the environment (e.g., moss growing on them, leaf-litter falling on them).

During our trial many other species of small animals occupied the chambers and were filmed. Of particular interest were cockroaches (*Periplaneta australasiae*) that occupied the shelters for short periods of time. We discovered that the infrared LED light used in the camera setup illuminate through the exoskeleton of the cockroaches, showing the internal organs (Fig. 4C). In one set of filming, the infrared LED light showed that one of the cockroaches had a gut parasite that could clearly be seen moving internally. This shelter/camera setup could be used to study, for example, the prevalence of gut parasites in cockroaches in different habitats, the development of the gut parasite, and the effect on the cockroach.

A strength of this shelter/camera setup is that the animals choose to take up residence and were then filmed with almost no disturbance. Servicing of the batteries and storage cards does not impact the camera end or shelter. We suggest these shelters and cameras could be used to film a range of behaviours, for example, parental care behaviour, shelter use, species interactions, and courtship behaviour, in many cryptic amphibian species and also other small vertebrates and invertebrates, globally.

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Data availability statement

All data and code are available in the main text or the supplementary material: Table 1. and Appendix 1.

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Table and Figures

Table 1. Items, and their costs, required to build a camera setup that can record continuously for 21 days.

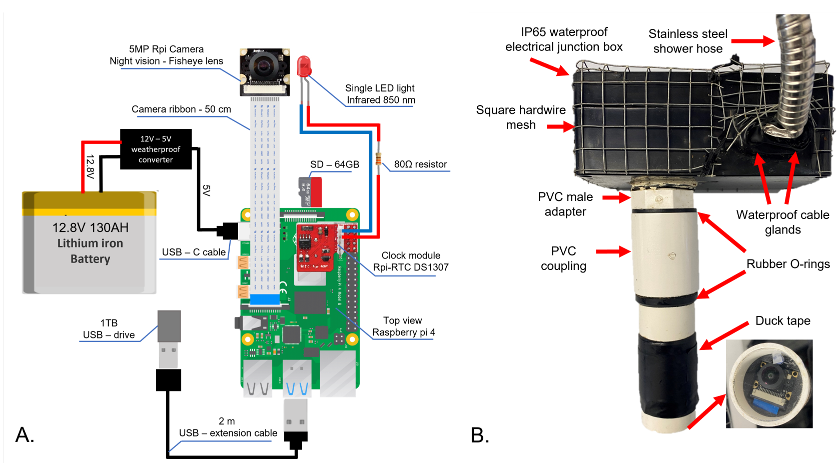
Figure 1. Circuit diagram of the camera setup (A.), and a photo of the camera housing (the Raspberry Pi unit is inside the black electrical junction box; B.).

Figure 2. Wooden "natural" shelter in place (A.), and photo showing the underside of the natural shelter installed in the field, the ground is cleared from leaves before the shelter is being placed (B.).

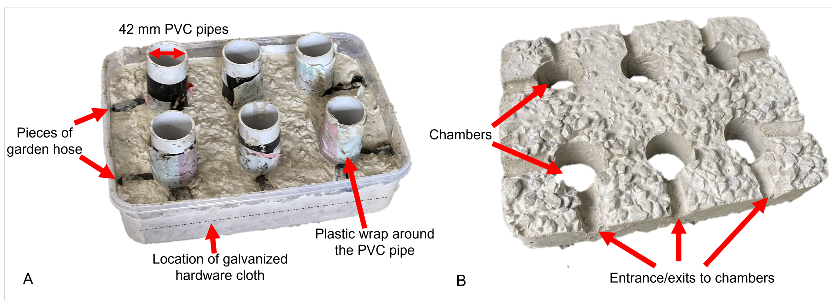
Figure 3. Construction of an artificial concrete shelter (A.), and photo showing the underside of the resulting concrete shelter, with the six chambers and associated entrances/exits (B.).

Figure 4. Example of how the camera is placed in an artificial concrete shelter (A.), a natural log (B.), and in leaf litter (C.).

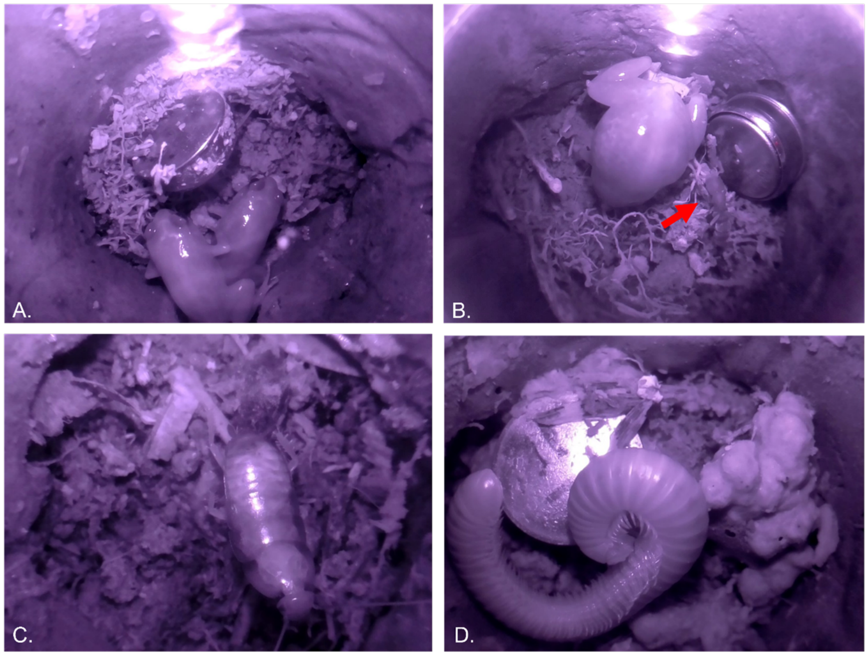
Figure 5. Video screenshots of animals in chambers of the concrete shelters. (A.) Two *Austrochaperina robusta* next to the temperature and humidity data logger (Hygrochron Ibutton). (B.) An *A. robusta* showing defensive behaviour against an intruding ant (red arrow). (C) A cockroach, and (D.) a millipede grooming itself.




A
B


42 mm PVC pipes
Pieces of garden hose
Plastic wrap around the PVC pipe
Location of galvanized hardware cloth
A
Chambers
Entrance/exits to chambers
B


A
B
C



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`Table 1.docx` available at https://authorea.com/users/661133/articles/664342-a-portable-raspberry-pi-based-camera-setup-to-record-behaviours-of-frogs-and-other-small-animals-under-artificial-or-natural-shelters-in-remote-locations