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Low cost audiovisual playback and recording triggered by radio frequency identification using Raspberry Pi

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Carrying out playbacks of visual or audio stimuli to wild animals is a widely used experimental tool in behavioral ecology. In many cases, however, playback experiments are constrained by observer limitations such as the time observers can be present, or the accuracy of observation. These problems are particularly apparent when playbacks are triggered by specific events or are targeted to specific individuals. We developed a low-cost automated playback/recording system, using two field-deployable devices: radio-frequency identification (RFID) readers and Raspberry Pi micro-computers. This system detects a specific passive integrated transponder (PIT) tag attached to an individual, and subsequently plays back the stimuli, or records audio or visual information. To demonstrate the utility of this system, we tagged female and male tree swallows from two box-nesting populations with PIT tags and carried out playbacks of nestling begging calls every time females entered the nestbox over a six-hour period. We show that the RFID-Raspberry Pi system presents a versatile, low-cost, field-deployable system that can be adapted for many audio and visual playback purposes. The low cost and the small learning curve make this set-up a feasible system for use by field biologists.

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Low cost audiovisual playback and recording triggered by radio frequency identification using Raspberry Pi

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Introduction

Using audio or video playback to provide experimental stimuli is a widely used and powerful research tool in behavioral ecology. However, many research questions require that the broadcast or recording of audio or video signals be triggered by a particular event or given to a specific individual within a group or pair. For example, in a study of biparental care, Hinde (2006) used experimental playback of nestling begging calls directed to only one parent (the male or the female). To achieve this, she set up a portable hide from where she observed the provisioning parents and then launched the playback using a remote control system. Such a system has benefits and limitations. First, while human control provides flexibility in the decision of when the playback should be triggered, it requires the presence of the human observer for each trial which may not be feasible in many research situations. In addition, presence of the human experimenter also limits the duration, frequency, and sample size of such playbacks. Second, human control is also prone to observer error, limitations on reaction time, limitations on detectability, and potentially observer bias. For example, when the sexes cannot be unambiguously distinguished in the field (as it is the case in many sexually monomorphic species), remote controlling is either impossible or likely involves errors due to misidentification.

Here, we describe an automated event-triggered playback or recording system, which couples a passive radio frequency identification (RFID) system with an inexpensive and field-adaptable computer, the Raspberry Pi (RPi, *http://www.raspberrypi.org/help/what-is-a-raspberry-pi/*). RFID systems enable the identification of individuals based on the electromagnetic transmission of a unique radio frequency signal from a passive integrated transponder (a.k.a. a PIT-tag) to a reader (RFID-reader) that detects and stores this information. The small size of PIT tags (currently weighing as little as 0.03g) and the theoretically unlimited operational lifetime offers a wide range of possible wildlife applications in both invertebrates and

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vertebrates (Gibbons & Andrews, 2004; Kurth et al., 2007; Lauzon-Guay & Scheibling, 2008; Bonter & Bridge, 2011).

The RPi is a credit-card sized, standalone computer developed by the Raspberry Pi Foundation, and it is currently the least expensive option in a growing array of single-board computers. RPi comes in three forms: model A, model B, and the most recent upgrade, model B+. Model A is less expensive (US $25 through official retailers) and uses less power than model B and model B+, therefore it may be more useful in field conditions where power consumption and research funding are limiting factors. All models are able to run a number of Linux-based operating systems, and have the capabilities of a normal desktop computer. With the goal to create an easily assembled, inexpensive, and versatile system for multi-functional field use, we coupled the RFID reader developed by Bridge and Bonter (Bridge & Bonter, 2011) with a RPi in order to trigger playback of specific audio recordings in the presence of specific PIT-tagged birds.

The Set-up

Power source

The RFID reader requires a 12V DC power source. To supply that power, we used small motorcycle batteries (PS1250F1 12 Volt, 5Ah, Sealed Lead-Acid Battery, PowerSonic Corp. San Diego, CA) that provide long operation times (several days or weeks, depending on the power saving setups of the RFID reader). The RPi requires a 5V power source. When electricity is readily available, e.g. in a laboratory, the most feasible option is to power the RPi directly from a power outlet or through the micro USB connector of the RPi. In field conditions, electric power is often not available and a battery is needed. The 12V battery that is used to power the RFID reader can also be used to run the RPi after the voltage has been stepped down to 5V. To do that a voltage regulator is recommended, but in our experience the inexpensive USB car chargers also

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work reliably. In either case, a specific cable needs to be constructed to run both units (RFID and RPi) from the same 12V power source (Fig. 1).

The RFID-triggered playback system

Here, we describe an audio playback system, which are more widespread in field biology than video playbacks. However, because the RPi contains USB ports in addition to a standard HDMI and composite video output, the following methods can be also applied to a video playback system with little modification.

We used the RS232 serial communication port of the RFID reader to transfer the data to the RPi. While RS232 adaptors are made for the RPi, we instead used a RS232 to USB converter cable (converters using the low-cost PL2303 chipset are automatically detected by Raspbian operating system, so no driver installation is needed, although we experienced variability between the actual cables – see Results). We used a Python (2.7) script on the RPi to process the incoming data and to trigger the playbacks less than a second after the RFID reader sent a PIT-tag detection signal (the actual delay depends on the RPi script settings – see below). Note that Python offers unlimited flexibility to process the incoming information and control the playback to suit specific needs. The OS can be set up to launch the Python script automatically on startup, so in field conditions, no user interaction is required. We provide the Python code (Suppl. Info 1) that contains the following functionality.

The code (1) triggers the playback of a pre-defined sound file upon reading a target tag and also takes a still picture using the Pi Camera module, and (2) triggers a test playback upon detection of a specified test-tag. This allows researchers to test whether the system is operational in the field. The code also (3) specifies an optional refractory period after a playback, so playback can be prevented during that period (if that period is defined to be greater than 0), and (4) assures that the playback is played only once per detection and is suppressed upon continuous readings

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(i.e. while the tag remains in the antenna's reading range). Finally, (5) the script creates a log file in the RPi that records the time since startup and the nature of events (target playbacks or test playbacks). Note, that in the absence of a display/interface device for the RPi, the script needs to be updated and set-up for playback prior to taking to the field.

Deployment of the playback system in the field

In Spring 2014, we tested and deployed the RFID-RPi playback system in two field sites while conducting a study of parental care in nest-box breeding tree swallows (*Tachycineta bicolor*). All procedures followed guidelines for animal care outlined by ASAB/ABS and the CCAC, and were approved by the Virginia Tech's Institutional Animal Care and Use Committee (#12-020) and the Canadian Wildlife Servive (#10771). Briefly, we sought to present female parents but not male parents with playbacks of nestling begging calls every time they entered the box during a specific portion of the period of care for nestlings.

Using nest box traps, we captured male and female tree swallows at two field sites: Davidson College Lake Campus in Cornelius, NC, USA (n=45 females and 43 males) and Queens University Biological Station, Ontario, Canada (n=45 females and 35 males). Each female and male were tagged with a PIT tag integrated with a colored leg band (IB Technology, UK). The combined color band/PIT tag weight was 0.1 g.

The experiment aimed at playing begging call playbacks to half of the females on day 6 of the nestling period (day of hatching = day 0). To achieve that, we programmed the RPi by entering the target female's PIT-tag code into the script and uploading the nestling begging stimuli to the memory of the RPi. The programming was carried out the previous day in the lab. For broadcasting the audio stimulus, we used earbud headphones (Sony MDRE9LP) that were attached to the RPi with a 6-foot audio extension cable such that the RFID/RPi set-up could rest on the ground beneath the nest box.

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We deployed the RFID-RPi set-up on day 6. At each deployment, we tested the set-up by passing a test PIT-tag through the RFID reader and listening for playbacks to verify that the system was working. We then installed the earbuds into the nest-box and left the area. After 6 hrs, we returned to the nest and we tested the playback system again with the test tag and then shut down the system. To shut down the RPi properly, we had to disconnect the serial-USB cable from the RPi that terminated (crashed) the Python process running in the background, because the process expects an active serial connection. Then we attached a keyboard to the USB-port and logged in to the system (by typing a username and password) and then typed `sudo halt` to the command line interface to initiate shutdown. Because we were in the field, we operated the RPi without a display, and so had to type in these commands without being able to monitor the accuracy of our entries. Although it is not recommended, in several cases we simply disconnected the micro USB power source and we never experienced problems associated with the improper shutdown procedure.

Results

The playback system had a high efficacy. In 21 deployments of the playback system in NC site, the playback system worked in 19 cases. In two cases the playback did not work with the test tag. In both cases, we traced the problem to the Serial-USB Cable (i.e. the RFID readings were not communicated to the RPi), as the same set-up worked with a different cable suggesting that cables should be checked prior to field deployment. In Canada, the playback system worked in 18 out of 20 attempted deployments. In one case, the problem was with the RFID antenna, so the Raspberry Pi did not receive any signals from the reader. In the other case, the problem could not be identified.

Across all of the nests, the playback system generated an average of 8.89 ± 0.51 (SE) playbacks/hr. During this same period, the female visit rate was 8.96 ± 0.68 (SE) per hr, and the

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two measures were highly correlated across N = 37 nests ($r = 0.83$, $p < 0.6^{-10}$). The feeding rate was higher than the playback rate because of the refractory period we specified, so if birds appeared at the box in quick succession (within 2 minutes from the first entry) then playback was suppressed during this period. Thus, the playback system seemed to work with great efficiency.

Other applications

The RPi has all of the functionalities of a desktop computer, and therefore this system can be used to for a variety of other purposes. For instance, video recording is one of the most useful data collection methods in behavioral sciences, but it often generates a lot of 'waste', i.e. recordings without events of interest. To overcome this problem, a further application of the Raspberry Pi linked RFID system may be recording of still images or video files only upon detecting target individuals. This function can be achieved either through the Pi Camera modules (either standard or infrared capable modules) or through a USB-connected web camera. The same logic can be applied to audio recordings through an external USB-connected sound card with audio recording capabilities.

Another application of the RFID-RPi system would be to enable operant conditioning experiments in the field. For instance, the RPi can be programmed to dispense food or play a stimulus in response to a pre-defined action by a certain individual. Controlling such devices is fairly simple as the RPi has 17 general purpose in/out (GPIO) pins that can be used to receive and transmit arbitrary binary data. All GPIO functionality is available in a variety of programming and scripting languages, such as Python, allowing for very easy control and access to unlimited peripheral sensors and devices. Such applications have an array of potential benefits for studies focused on learning in the wild.

Limitations

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The RPi is a versatile and inexpensive system that promises to be valuable in field studies that call for automated data collection or playback. However, there are some drawbacks to the RFID-RPi system. The first drawback is the need for a display and interface device (e.g., keyboard) for troubleshooting the Raspberry Pi in the field. In conditions where the field site is not far away from a home base, or where the Raspberry Pi is used in the lab, this drawback may not be significant. However, troubleshooting problems with the Raspberry Pi in remote field locations can be a significant hurdle. This drawback can be overcome with the use of one of several custom made display/interface devices available on the market that can connect to a Raspberry Pi. Smaller displays (TFT board monitors) can be connected to the GPIO pins of the Raspberry Pi, and do not require an independent power source, but their small size may be a limitation in certain cases. Alternatively, external monitors can be attached through the HDMI port, but these may require their own power source that (depending on the device) may have a different voltage requirement than the Raspberry Pi or the RFID reader.

A second drawback is the lack of a real-time clock (RTC) in the RPi. This can be circumvented by synchronizing the Raspberry Pi with an external device that does have a real-time clock (such as the RFID reader). For example, in our playback system, we used the test tags in the first deployment to create an entry in both the RFID log with a timestamp and in the Python script log. Since our Python script recorded the time elapsed between recorded events, the real time entry of the first detection of the test tag could be used to assign real times to all subsequent entries in the RPi log. Additionally, there are ways to install an external RTC with dedicated battery to the RPi. Alternatively, the internal clock of the Raspberry Pi can be updated upon startup – but again, this requires a display unless these operations can be performed blind.

Although it may not be a limitation in most cases, one should be aware that the RPi, being an exposed chipboard, needs good protection from the elements in field conditions. There are commercially available cases for the RPi that are waterproof, however when the required number

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of systems is large, these cases may be prohibitively expensive. In our deployment, we used a plastic container (roughly the size of a shoe-box) that held the RFID board, RPi, the batteries, and all the cables. The plastic containers were waterproof when sealed. In such a system boards should not touch each other or the battery, which can be avoided by using wooden or cardboard. Another important factor to be considered is the overheating of the system, especially in open field condition with direct sun exposure. In such cases, the set-up needs to be shielded by a cover to prevent over-heating.

Conclusion

We present here a flexible, versatile, and relatively inexpensive system for automated data-logging and audio or video playback and recording in field conditions. We believe the RFID technology, already widely used in ecology and evolution, when coupled with the RPi or other single board inexpensive computers, presents many interesting opportunities for experimental and observational field research.

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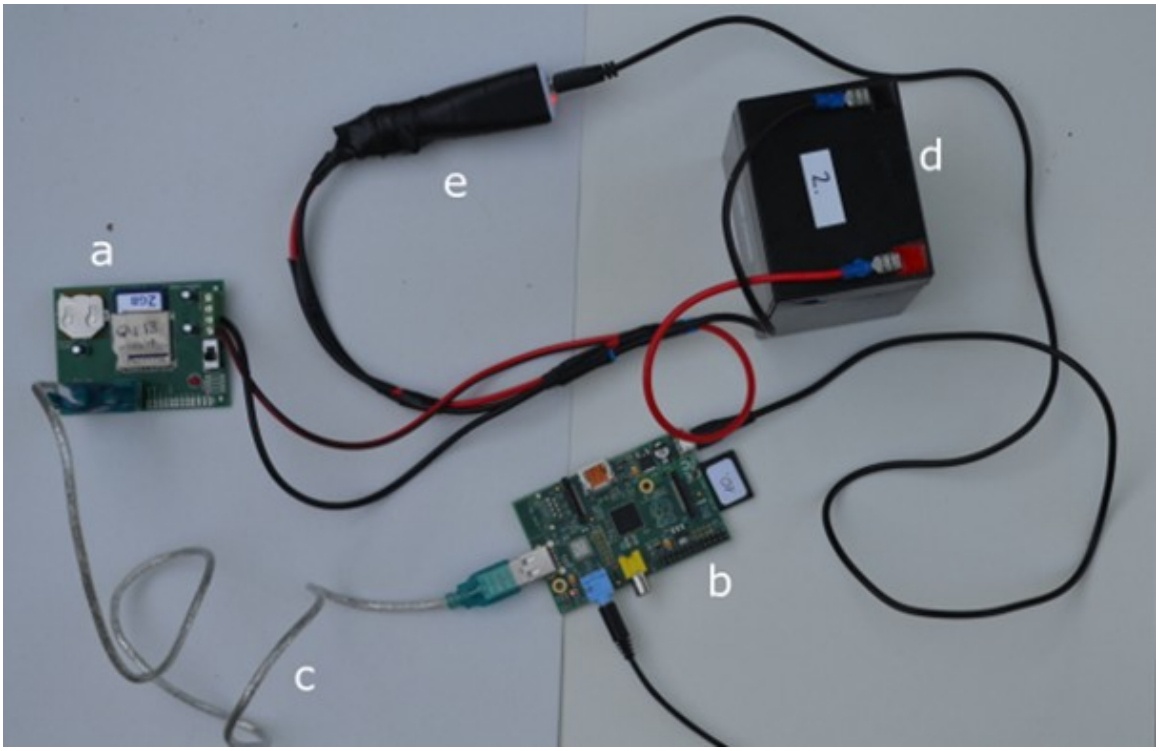
Figure legends

Figure 1. The RFID-RPi set-up. The RFID board (a) is connected to the RPi (b) by a serial-USB cable (c). The battery (d) is connected to both RFID board and the RPi, the latter through a USB car charger (e). Not shown is the RFID antenna.



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