

**A peer-reviewed version of this preprint was published in PeerJ on 7 April 2015.**

[View the peer-reviewed version](https://doi.org/10.7717/peerj.877) (peerj.com/articles/877), which is the preferred citable publication unless you specifically need to cite this preprint.

Lendvai ÁZ, Akçay Ç, Weiss T, Haussmann MF, Moore IT, Bonier F. 2015. Low cost audiovisual playback and recording triggered by radio frequency identification using Raspberry Pi. PeerJ 3:e877 <https://doi.org/10.7717/peerj.877>

# 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.

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

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10 running title: event triggered playback and recording  
11 Word count: 2819

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15 Keywords: automated playback, RFID, RPi, animal communication

## 16 Introduction

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

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

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

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

### 65 *The RFID-triggered playback system*

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

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

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

(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 Service (#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.

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  $8.89 \pm 0.51$  (SE) playbacks/hr. During this same period, the female visit rate was  $8.96 \pm 0.68$  (SE) per hr, and the



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

## 140 **Other applications**

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

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

## 158 **Limitations**

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

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

## 191 **Conclusion**

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

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210 **Figure legends**

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

