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

Adam Z Lendvai, Çağlar Akçay, Talia Weiss, Mark F. Haussmann, Ignacio T Moore, Frances Bonier

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, such as performing a specific behavior, 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 and to test one of its possible applications, we tagged female and male tree swallows (*Tachycineta bicolor*) from two box-nesting populations with PIT tags and carried out playbacks of nestling begging calls every time focal 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. In addition, the set-up does not require programming knowledge, and it easily customized to many other applications, depending on the research questions. Here, we discuss the possible applications and limitations of the system. The low cost and the small learning curve of the RFID-Raspberry Pi system provides a powerful new tool to field biologists.

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

Ádám Z. Lendvai[1*] Çağlar Akçay[1], Talia Weiss[2], Mark F. Haussmann[3], Ignacio T. Moore[1], Frances Bonier[4]

[1] Department of Biological Sciences, Virginia Tech, 1405 Perry Street, 2119 Derring Hall, Blacksburg, VA 24061 USA

[2] Department of Biomedical Engineering and Mechanics, Virginia Tech, Blacksburg, VA, USA

[3] Department of Biology, Bucknell University, Lewisburg, PA, USA

[4] Department of Biology, Queen's University, Kingston, ON, Canada

running title: event triggered playback and recording

Word count: 4082

*corresponding author: lendvai@vt.edu

Current address: Department of Evolutionary Zoology, University of Debrecen, 4033 Debrecen, Egyetem tér 1.

Keywords: automated playback, RFID, RPi, animal communication

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. Second, 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 distinguished unambiguously 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. And finally, for some animals, presence of the human observer could alter behavior and influence responses to experimental stimuli.

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 single board computer, the Raspberry Pi (RPi) (RPi Foundation, 2015). 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

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

49 The RPi is a credit-card sized computer developed by the Raspberry Pi Foundation. It is a
50 single board computer and thus has all the functionalities of a complete computer, including a
51 microprocessor, memory, and input/output features. In the past decade there has been a growing array
52 of commercially available single-board computers (an up-to-date list can be found online (Wikipedia,
53 2015). RPi currently stands out in this field as the option that is the least expensive and most widely
54 available, and it has a very large user community, making support easily available..

55 RPi currently comes in different models: model A and model B (with upgrades model A+ and
56 model B+) and the most recent upgrade RPi Generation 2 model B. Model A and A+ are less expensive
57 (US $25 and $20, respectively, through official retailers) and use less power than model B model B+
58 and Generation 2 model B (all cost $35), therefore they may be more useful in field conditions where
59 power consumption and research funding are limiting factors. All models are able to run a number of
60 Linux-based operating systems, and have the capabilities of a normal desktop computer. RPi uses
61 micro SD cards to store both the operating system and any data. The memory cards and operating
62 system must be purchased separately (although official retailers offer bundles where the RPi comes
63 with micro SD cards with pre-loaded operating systems).

64 With the goal to create an easily assembled, inexpensive, and versatile system for multi-
65 functional field use, we coupled the RFID reader developed by Bridge and Bonter (2011) with a RPi.
66 Connecting a field-deployable computer to an RFID reader offers a wide range of possible
67 experimental manipulations, where the reader automatically detects specific individuals and the
68 computer analyzes this information and implements specific actions, including playback of audio or
69 visual stimuli (the application described here) as well as providing commands to external devices. In
70 principle, the RFID-RPi system can control any kind of device, including mechanical devices such as

71 food dispensers (for operant conditioning or targeted food supplementation experiments) or traps (for
72 targeted capturing of individuals). Controlling such devices is fairly simple as the RPi has 17 general
73 purpose in/out (GPIO) pins that can be used to receive and transmit arbitrary binary data. All GPIO
74 functionality is available in a variety of programming and scripting languages, such as Python,
75 allowing for very easy control and access to a wide range of peripheral sensors and devices.
76 The RFID-RPi system can also be used for event-triggered recording. For instance, video
77 recording is one of the most useful data collection methods in behavioral sciences, but it often
78 generates a lot of 'waste', i.e. recordings without events of interest. To overcome this problem, a
79 further application of the RPi linked RFID system may be recording of still images or video files only
80 upon detecting target individuals. This function can be achieved either through the Pi Camera modules
81 (either standard or infrared capable modules; they must be purchased separately, cost $25) or through a
82 USB-connected web camera. The same logic can be applied to audio recordings through an external
83 USB-connected sound card with audio recording capabilities.
84 In this paper, we describe the RFID-RPi set-up and functionalities in detail. Furthermore, in
85 order to test one application of the system under field conditions, we used the set-up to trigger
86 playback of specific audio recordings in the presence of specific PIT-tagged birds. Operating this
87 system does not require advanced programming (such as C or reprogramming the microcontroller of
88 the RFID reader) and can be achieved through simple scripting languages. Although we offer one
89 possible solution and provide the code in Python, different languages can be used to achieve the same
90 goal. Also, although we describe the field test of an audio playback system (because audio playbacks
91 are more widespread in field biology than video playbacks) the following methods can be also applied
92 to implement video playback with little modification (using the RPi's HDMI, composite video or USB
93 connections).
94

The Set-up

All the elements and their approximate costs are detailed in Suppl. Info 1.

The RFID reader and antenna

For individual identification, we used a low-cost RFID reader described in Bridge & Bonter (2011). The reader model ("Generation 1 reader") described in Bridge & Bonter, (2011) can be assembled manually based on the detailed instructions and component list that the authors provide on their website (Bridge, 2011). Here, we used "Generation 2" RFID readers, an upgrade of the published model that can be purchased from Cellular Tracking Technology, PA, USA ($35). The Generation 2 readers use SD cards to store the data locally, and provide increased performance and additional options compared with the Generation 1 readers (see details below). The RFID-RPi setup works equally with both models. For this application, a hexagonal or square antenna (diagonally about 6cm) was connected to the RFID reader that attempted to read a signal for 0.3 seconds, then paused for 0.2 seconds to save battery life and then this cycle was repeated continuously. The antenna can be also manufactured easily by hand; instructions are available online (Bridge, 2011). The reader records the unique tag number and the current date and time to the seconds in a log file.

Power source

The RFID reader requires a 12V DC power source. To supply that power, we used small motorcycle batteries (PS1250F1 12 Volt, 5Ah, 8.9×7.1×10.1 cm, 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

119 battery is needed. The 12V battery that is used to power the RFID reader can also be used to run the
120 RPi after the voltage has been stepped down to 5V. To do that a voltage regulator is recommended, but
121 in our experience the inexpensive USB car chargers also work reliably. In either case, a specific cable
122 needs to be constructed to run both units (RFID and RPi) from the same 12V power source (Fig. 1).
123 Making this cable is simple: one needs to connect two electric cables into one end of a wire crimp
124 terminal connector and four electric cables into the other end of the connector. It makes a Y-shaped
125 cable, where the basal part of the Y goes to the battery, one branch of the upper part of the Y goes to
126 the RFID reader, and the other branch needs to be soldered to the USB car charger. Evidently, polarity
127 must be respected for all connections; therefore using colored wires (red and black) is recommended
128 (Fig. 1). The setup then can be insulated with electrical tape.
129
130 *The RFID-triggered playback system*
131 Here, we used a model A RPi, but our setup is not model-specific, so our description would work with
132 any RPi model. We used the RS232 serial communication port of the RFID reader to transfer the data
133 to the RPi. While there are RS232 adaptors that are made for the RPi, we instead used a RS232 to USB
134 converter cable (converters using the low-cost PL2303 chipset are automatically detected by Raspbian
135 operating system, so no driver installation is needed, although we experienced variability between the
136 actual cables – see Results). We used a Python (2.7) script on the RPi to process the incoming data and
137 to trigger the playbacks less than a second after the RFID reader sent a PIT-tag detection signal (the
138 actual delay depends on the RPi script settings – see below). Note that Python offers unlimited
139 flexibility to process the incoming information and control the playback to suit specific needs. The
140 operating system can be set up to launch the Python script automatically on startup, so in field
141 conditions, no user interaction is required. This can be achieved in several ways, probably the easiest is
142 to edit the `/etc/rc.local` file (e.g. by typing `sudo nano /etc/rc.local` to the console) and

143 specifying the script, e.g. by `sudo python /home/pi/RFID/rfid.py &` (where the path and the name
144 of the script is followed by `&`, which specifies that the script should be run in the background).
145 We provide the Python code (Suppl. Info 2) that contains the following functionality. The code
146 (1) triggers the playback of a pre-defined sound file upon reading a target tag and also takes a still
147 picture using the Pi Camera module, and (2) triggers a test playback upon detection of a specified test-
148 tag. This allows researchers to test whether the system is operational in the field. The code also (3)
149 specifies an optional refractory period after a playback, so playback can be prevented during that
150 period (if that period is defined to be greater than 0), and (4) assures that the playback is played only
151 once per detection and is suppressed upon continuous readings (i.e. while the tag remains in the
152 antenna's reading range). Finally, (5) the script creates a log file in the RPi that records the time since
153 startup and the nature of events (target playbacks or test playbacks). Note, that in the absence of a
154 display/interface device for the RPi, the script needs to be updated and set-up for playback prior to
155 taking to the field.
156 The script works with both Generation 1 and 2 RFID readers. The two models use different
157 communication settings (baud rate), and therefore it needs to be adjusted to handle the serial
158 communication correctly. This is done automatically by the script if we supply the reader ID (the
159 Generation 2 readers can be assigned a four character alphanumeric code, which is recorded in log file)
160 to the script using some naming conventions, see details in Suppl. Info 2.
161
162
163 *Deployment of the playback system in the field*
164 In Spring 2014, we tested and deployed the RFID-RPi playback system in two field sites while
165 conducting a study of parental care in nest-box breeding tree swallows (*Tachycineta bicolor*). All

166 procedures followed guidelines for animal care outlined by ASAB/ABS and the CCAC, and were
167 approved by the Virginia Tech's Institutional Animal Care and Use Committee (#12-020) and the
168 Canadian Wildlife Service (#10771). Briefly, we sought to present female parents but not male parents
169 with playbacks of nestling begging calls every time they entered the box during a specific portion of
170 the period of care for nestlings.

171 Using nest box traps, we captured male and female tree swallows at two field sites: Davidson
172 College Lake Campus in Cornelius, NC, USA (n=45 females and 43 males) and Queens University
173 Biological Station, Ontario, Canada (n=45 females and 35 males). Each female and male was tagged
174 with a PIT tag integrated with a colored leg band (EM4102 tags from IB Technology, UK). The
175 combined color band/PIT tag weight was 0.1 g (the average ± SD body mass of tree swallows in our
176 populations is 20.7 ± 1.2 for males and 22.9 ± 1.8 for females).

177 The experiment aimed at playing begging call playbacks to half of the females on day 6 of the
178 nestling period (day of hatching = day 0) (the other half of the females were controls). To achieve that,
179 we programmed the RPi by entering the target female's PIT-tag code into the script and uploading the
180 nestling begging stimuli to the memory of the RPi. The programming was carried out the previous day
181 in the lab. For broadcasting the audio stimulus, we used earbud headphones (Sony MDRE9LP) that
182 were attached to the RPi with a 6-foot audio extension cable such that the RFID/RPi set-up could rest
183 on the ground beneath the nest box (Fig. 2). The earbuds played the stimulus files at approximately 55
184 dB (measured by a portable digital sound level meter) which is comparable to natural begging calls
185 (Leonard & Horn, 2006). Nestling begging calls were recorded on nests at the same stage (day 6) by
186 quietly approaching the nestbox and putting a directional microphone into the entrance. The change in
187 the light conditions and the microphone appearing in the entrance elicited begging calls from the
188 chicks. The raw recordings were then edited in Syrinx (John Burt, Seattle ,WA; www.syrinxpc.com) to
189 standardize call rate. We used 10 different stimulus calls that were randomly allocated to the

experimental females. Earbuds and audio cables were installed in control nests, but RPi was not connected, and playback was not used.

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 RPi did not receive any signals from the reader. In the other case, the problem could not be identified.

213 Across all of the nests, the playback system generated an average of 8.89 ± 0.51 (SE)
214 playbacks/hr. During this same period, the female visit rate (number of visits per hour, calculated from
215 the RFID records) was 8.96 ± 0.68 (SE) per hr, and the two measures were highly correlated across N
216 = 37 nests ($r = 0.83$, $p < 0.6^{-10}$). The visit rate was higher than the playback rate because of the
217 refractory period we specified, so if birds appeared at the box in quick succession (within 2 minutes
218 from the first entry) then playback was suppressed during this period. Thus, the playback system
219 seemed to work with great efficiency.
220
221
222 **Limitations**
223 The RPi is a versatile and inexpensive system that promises to be valuable in field studies that call for
224 automated data collection or playback. However, there are some drawbacks to the RFID-RPi system.
225 The first drawback is the need for a display and interface device (e.g., keyboard) for troubleshooting
226 the RPi in the field. In conditions where the field site is not far away from a home base, or where the
227 RPi is used in the lab, this drawback may not be significant. However, troubleshooting problems with
228 the RPi in remote field locations can be a significant hurdle. This drawback can be overcome with the
229 use of one of several custom made display/interface devices available on the market that can connect to
230 a RPi. Smaller displays (TFT board monitors) can be connected to the GPIO pins of the RPi, and do
231 not require an independent power source, but their small size may be a limitation in certain cases.
232 Alternatively, external monitors can be attached through the HDMI port, but these may require their
233 own power source that (depending on the device) may have a different voltage requirement than the
234 RPi or the RFID reader. Finally, an external Bluetooth transceiver can be connected to a USB port and
235 it could be used for wireless data transfer.

A second drawback is the lack of a real-time clock (RTC) in the RPi. This can be circumvented by synchronizing the RPi 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 RPi 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 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 a wooden or cardboard divider. 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.

An additional limitation comes from the RFID reader itself: the reader cannot detect more than one tag at a time, and when multiple tags are present in the antenna's reading range, the device is not capable of storing any tag's record (Bridge & Bonter, 2011). By reducing the size of the antenna however, one can minimize this effect. For instance, in our study, it is possible that in some cases both the males and the females were present at the nestbox entrance at the same time, and we missed those

readings. However, because only one bird can pass through the entrance at a given time, this effect is only momentary and unlikely to bias the results. However, if the tags are not present at the antenna's reading range simultaneously but in quick succession, the setup can deal with those cases. The RPi may be programmed to withhold playback in these cases when two tags are registered in close temporal proximity

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.

Acknowledgments

We thank Eli Bridge for help and troubleshooting with the RFID readers. We thank Miyako Warrington and David Wilson for useful and constructive comments on an earlier version of this manuscript. Funding was provided by a U.S. National Science Foundation (NSF) grant (FB, ITM, and MFH; IOS-1145625), and by the Natural Sciences and Engineering Research Council of Canada Banting Postdoctoral Fellowship (FB).

278

279 **References**

280 Bonter DN, Bridge ES. 2011. Applications of radio frequency identification (RFID) in ornithological
281 research: a review. *Journal of Field Ornithology* 82:1–10.

282 Bridge ES. 2011. *Radio Frequency Identification (RFID) for Birds*. Available at:
283 http://www.animalmigration.org/RFID/index.htm (Accessed 5 February, 2015)

284 Bridge ES, Bonter DN. 2011. A low-cost radio frequency identification device for ornithological
285 research. *Journal of Field Ornithology* 82:52–59.

286 Gibbons WJ, Andrews KM. 2004. PIT tagging: simple technology at its best. *BioScience* 54:447–454.

287 Hinde CA. 2006. Negotiation over offspring care?—a positive response to partner-provisioning rate in
288 great tits. *Behavioral Ecology* 17:6–12.

289 Kurth J, Loftin C, Zydlewski J, Rhymer J. 2007. PIT tags increase effectiveness of freshwater mussel
290 recaptures. *Journal of the North American Benthological Society* 26:253–260.

291 Lauzon-Guay J-S, Scheibling RE. 2008. Evaluation of passive integrated transponder (PIT) tags in
292 studies of sea urchins: caution advised. *Aquatic Biology* 2:105–112.

293 Leonard ML, Horn AG. 2006. Age-related changes in signalling of need by nestling tree swallows
294 (Tachycineta bicolor). *Ethology* 112:1020–1026.

295 RPi Foundation. 2015. What is a Raspberry Pi? | Raspberry Pi. Available at:
296 http://www.raspberrypi.org/help/what-is-a-raspberry-pi/ (Accessed 5 February, 2015)

297 Wikipedia. 2015. Comparison of single-board computers. *Wikipedia, the free encyclopedia*. Available
298 at: http://en.wikipedia.org/w/index.php?title=Comparison_of_single-board_computers
299 (Accessed 5 February, 2015)

300

Figure legends

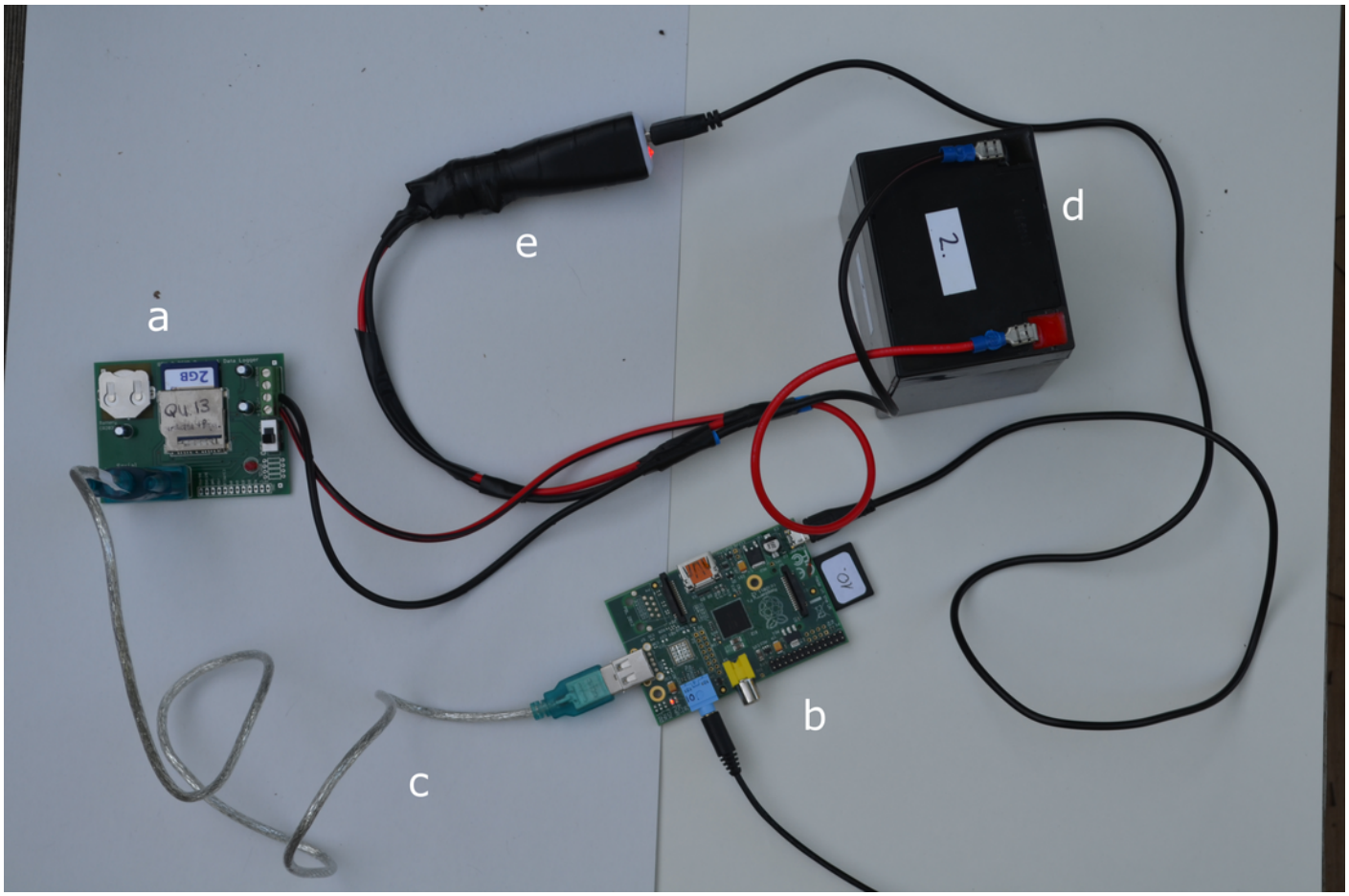
Figure 1. The RFID-RPi set-up. The RFID board (a) is connected to the RPi (b) by a serial-USB cable (c). The battery (d) is connected to both RFID board and the RPi, the latter through a USB car charger (e). Not shown is the RFID antenna.

Figure 2. The field set-up. The picture shows the RFID antenna fixed to the nestbox entry and the Raspberry Pi-RFID setup in the plastic container (including the battery and the RFID reader). Note that we took this picture when the field setup was being removed; therefore the Raspberry Pi is already removed from its container (and placed on the lid). The white cord around the pole is the cable of the earbud (used to broadcast the playback), and the black cable connected to it (on the predator guard) is the audio extension cable, which is also disconnected from the Raspberry Pi.

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.



2

The field set-up.

The picture shows the RFID antenna fixed to the nestbox entry and the Raspberry Pi-RFID setup in the plastic container (including the battery and the RFID reader). Note that we took this picture when the field setup was being removed; therefore the Raspberry Pi is already removed from its container (and placed on the lid). The white cord around the pole is the cable of the earbud (used to broadcast the playback), and the black cable connected to it (on the predator guard) is the audio extension cable, which is also disconnected from the Raspberry Pi. Photo by AZL.

RFID antenna
Audio cable
Raspberry Pi- RFID set-up