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METHODS PAPERS

A guide for ecologists to build a low-cost selective trap using radio frequency identification detection

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Abstract

Behavioral studies often aim to perform specific actions on focal individuals and could benefit from automated procedures. With this paper, our goal is to demonstrate to ecologists that building a selective, automated device triggered by radio frequency identification detection (RFID) running on a battery is easy and affordable (~ 100 Euros). We provide a step-by-step description of how to build such an RFID triggered trap for small animals. We built and tested our selective traps in a colony of 300 captive bats, flying in a 40-m-diameter dome. Our device proved successful in trapping focal individuals using RFID identification while recording every single visit to the trap-feeder. Our guide not only provides information for building RFID-triggered traps, but also offers a general framework for building any device triggered by RFID and can thus help build tailored setups matching specific studies requirement. Home-made selective device using RFID detection have a great potential in opening-up exciting new possibilities for a wide range of studies on animals, ranging from trapping specific individuals, to automatically monitoring activities at the nest-box, or supplementing specific individuals in a population.

Keywords Open source · Raspberry pi · *Carollia perspicillata* · Selective trap · RFID

Introduction

Behavioral and ecological studies often require specific actions to be performed on focal individuals, such as selective supplementation where only one group of individuals should be supplemented (Demeyrier et al. 2017), an audio playback to be played to specific individuals (Hinde 2006), and/or the trapping of specific individuals. Moreover, long-term monitoring of a population often involves regular opportunistic trapping in order to collect data such as presence/absence, or body mass. The automation of data recording would be more efficient in terms of time, impact, and resources invested.

Thanks to technological advances, it is now relatively easy to build inexpensive devices equipped with sensors that can be modulated and customized to fit specific studies requirements. For example, Whytock and Christie (2017) present an inexpensive DIY audio recorder built using a single-board computer. Prinz et al. (2016) also make use of a single-board computer for their custom-made nest-monitoring cameras triggered by movement recognition. Single-board computers enable users to assemble devices that can automatically perform pre-programmed actions when triggered by specific events, for example the detection of an individual carrying a given RFID (radio frequency identification) tag. RFID technology, where a PIT-tag (passive integrated transponder) holding a unique identification number can be read using an RFID reader, is widely used to identify pets, but also to monitor wildlife (Adelman et al. 2015; König et al. 2015). However, although PIT-tags are rather low cost, standard ready-to-use commercially available RFID readers can be prohibitively expensive.

Fabrice Helfenstein and Nicolas Fasel shared last authorship

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Luckily, inexpensive RFID reader circuit boards equipped with an antenna are now available for about 50 Euros (as compared to several hundreds of Euros for a traditional reader). These systems can be readily connected to a small computer to record the tags detected. A nice example of such DIY selective set-up is provided by the audio-recording playback set-up triggered by RFID detection that Lendvai et al. (2015) designed and tested in the field with nest-box breeding tree swallows (*Tachycineta bicolor*) equipped with PIT-tags.

One of the most popular credit-card sized single-board computer is the Raspberry Pi (Rpi), which is low cost, reliable, and easy to program even for neophytes. Although such technology may be intimidating for people with little or no knowledge in electronics and/or programming skills, Rpi are actually easy to handle and customize. Rpi were first released in 2012 and rapidly became very popular, for example for home robotic projects, and increasingly so for research studies (Ambrož 2017; Pasquali et al. 2017). Rpi are equipped with generic metal pins allowing a user to physically connect different devices such as RFID readers, LEDs, or diverse sensors using wires. By connecting a Raspberry Pi, an RFID identification system and a small device that can quickly release a sliding door when triggered (in our case, an electromagnet-solenoid), one can build a low-cost selective trap.

With this paper, our goal was to provide a simple, comprehensive, step-by-step guide to build a low-cost DIY selective set-up. For that purpose, we present a test of our selective traps in a captive population of Seba's short-tailed bats (*Carollia perspicillata*).

Material and methods

Model species and studied population

We study a captive colony of Seba's short-tailed bats (*Carollia perspicillata*) of about 300 individuals, flying freely under a 40 m-diameter dome, in a tropical zoo (Papiliorama, Switzerland). All the bats are equipped with RFID PIT-tags inserted between the scapulae. They are fed with a fruit-based mixture, twice a day, from five feeding stations located inside the dome.

Set-up

a. Feeder

The feeders were shaped as an octagon, with alternating plastic and wire mesh sides, and a top cover made of wire mesh (Fig. 1). The use of wire mesh allowed bats to hang from the feeder, and to easily see and smell the food placed inside. The antenna circling the entrance of the feeder and the sliding door—made out of forex, a light but rigid PVC foam board—was situated on one side of the octagon. The antenna, triggering the release of the sliding door when detecting a focal bat, was located 10 cm away from the sliding door, to avoid hurting the focal bat as the door closes.

b. Electronic set-up

We connected a Raspberry Pi 3 model b to an RFID reader, connected to the antenna and a relay board acting as an on/off switch for an electromagnet-solenoid, powered separately

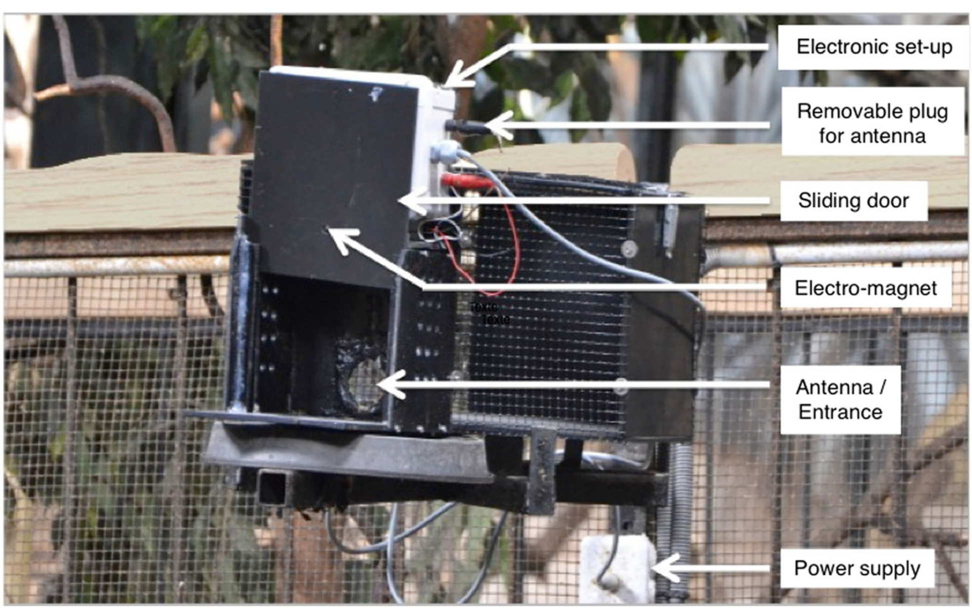

Fig. 1 Picture of the selective trap-feeder

either by a battery or using a charger of the appropriate voltage (see Fig. 2 for picture and Fig. 3 for schematic). We then programmed the Rpi to trigger the electromagnet-solenoid and close the sliding door, when one of the pre-defined focal individuals was detected. The electronic set-up was assembled in a waterproof plastic container, which could easily be removed from the feeder-trap (Fig. 4).

Raspberry Pi—single-board computer A Raspberry Pi can be considered as a small system unit from a standard computer. As such, it requires peripherals, such as a mouse, a keyboard that can be directly plugged in the USB ports and a computer screen that can be connected using the HDMI port without previous configuration. Compatible touch screens that can be powered using the Rpi are also available, making manipulations in the field easier (Fig. 5). The Rpi is powered via a mini-USB port, using a power supply able to provide 5 volts direct current (VDC) and a minimum of 1 A (e.g., phone charger).

Upon first use, it is also necessary to download an operating system for the Rpi onto a micro SD memory card, if it is not already pre-loaded on the SD card. Rpi can run on many open-source operating systems, a popular one being Raspbian, a Debian-based Linux operating system. The operating system can be downloaded from the Raspberry Pi website (https://www.raspberrypi.org/downloads/). The micro SD card can then be inserted in the Rpi, and the power supply plugged in to turn on the Rpi. Once the Rpi is started, it can be used exactly like a standard computer.

The Rpi holds a row of 40 metal pins (Fig. 6), of which 28 are GPIO (general purpose input/output ports), which can be used as input pins to read information from environmental sensors or output pins to control motors, LEDs, or send signals. Other pins are composed of power supply pins (5 VDC or 3.3 VDC) and ground pins (0 VDC).

RFID reader In order to transmit the identity of PIT-tags detected by the RFID reader to the Rpi, one needs to physically connect them using wires (Fig. 7). By using male to female jumper wires, the RFID reader board “TX” (Transmission) connector can be connected to the “RX” (reception) of the Rpi, and the RX to the TX, i.e., to the GPIO 14 and 15 of the Rpi, also known as serial port.

Electromagnet-solenoid—relay board The Rpi could not power our electromagnet using a Rpi’s GPIO since it required more than 3.3 VDC. Therefore, the Rpi could not directly control whether the electromagnet got switched on or off, so we had to use a relay board, which acts as an on/off switch (Fig. 8). Using jumper wires, we connected the relay board to the Rpi: the relay board “In1” connector to a Rpi’s 5 VDC pin and the relay board “Gnd” connector to a Rpi ground pin. We then connected one wire of the electromagnet to the relay board “No” (normally open) connector, and the other one to one wire of an external power supply, from which we had previously cut off the connector at the tip, and stripped the isolation off the cable to have access to the two wires. We then connected the relay board “Com” (common) connector to the other wire of the power supply. In our set-up, when switched off, the bar inside the electromagnet is holding the sliding door up. When

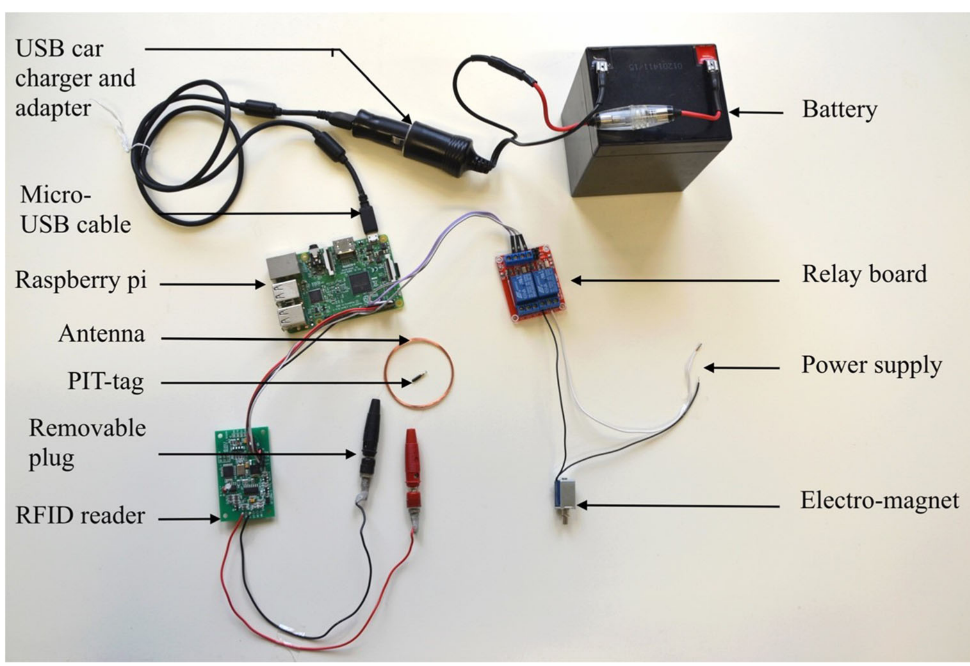

Fig. 2 Picture of the electronic set-up. Details about individual components can be found in the text

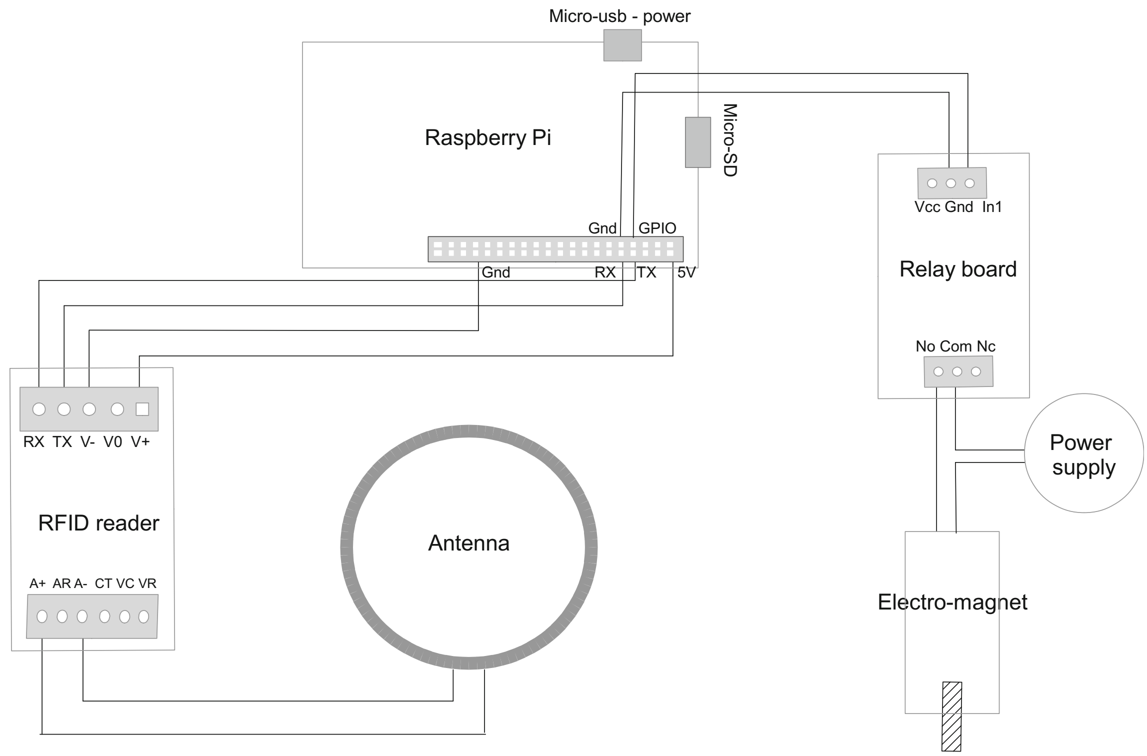

Fig. 3 Schematic of electronic set-up. Black lines represent wires, which are plugged/soldered to the appropriate connectors, represented by the small white circles/squares. Relevant abbreviations for the connectors are reported as they appear on the circuit boards

triggered by a pre-programmed event (here the detection of a focal PIT-tag), the relay switches on, allowing electricity through the electromagnet, which automatically leads the metal bar inside the electromagnet to be pulled back, hence releasing the sliding door, and therefore closing the trap.

Tools Some of the material cited in Table 1 might require some soldering using a soldering iron. Diverse items such as a drill, glue, heat shrink sleeve, jumper wires, and standard wire might also be necessary.

c. Programming

The Rpi can be programmed using multiple languages, including Python. Commands can be issued either directly on the terminal, or using Python IDLE, which may be easier to use as it provides a graphical user interface. With the operating system Raspbian, Python IDLE is available from the desktop menu under *Programming*. It combines an interactive interface ("Shell") to run single commands or script using the combined built-in file editor. The program we used for this project can be found in the supplementary document (S1). In

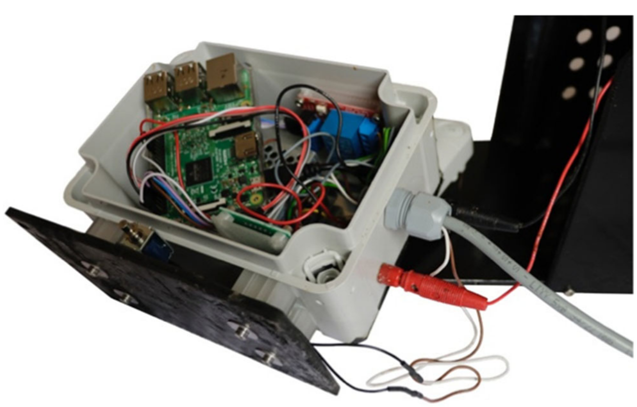

Fig. 4 Picture of the electronic set-up assembled in the waterproof container

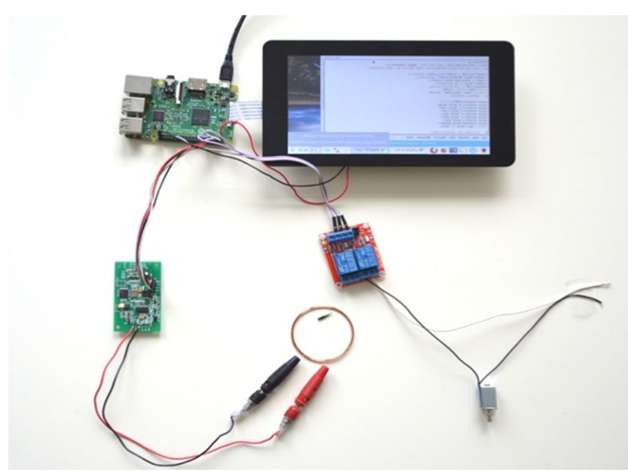

Fig. 5 Picture of the electronic set-up with a compatible screen

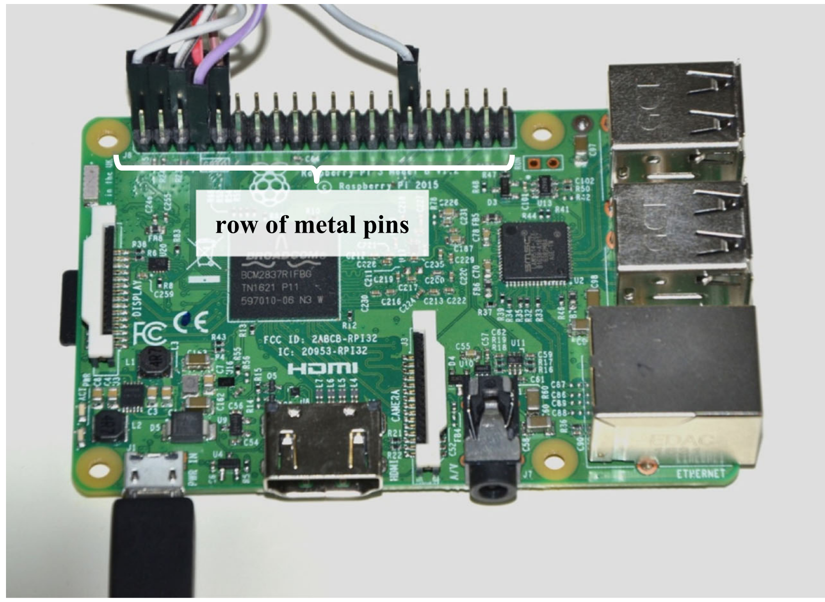

Fig. 6 Picture of a Raspberry Pi 3 model b

our program, we also recorded all the PIT-tags that were detected in a text file, along with the time and date of detection.

d. Trap efficiency

We installed five selective traps in the bat dome for 2.5 months. Visiting bats were recorded, and we aimed to selectively trap 49 1-year-old bats as part of a follow-up study from an experiment looking at consequences of early life conditions. As bats were free to visit the traps without observer interference, capture efficiency test was conducted blindly.

Results

Efficiency of the selective traps

The selective traps functioned very efficiently, and they allowed us to trap all the alive focal individuals targeted. Thanks to the selective traps, 21 of our focal individuals were detected and successfully trapped, while the remaining 28 individuals were never detected in the traps. We could ascertain that we trapped all the focal individuals alive and deduced that the missing ones for which we had no PIT-tag reading were actually dead (MM et al. unpublished data). Indeed, our population lives in closed space, by combining the traps' observations with two other long-term monitoring techniques already in place to study the population, namely opportunistic trapping and video monitoring. The mortality rate found here is identical to the one normally observed in the population (MM et al. unpublished data) and in the wild (Fleming 1988).

Moreover, we additionally record visits to the feeder. We recorded a total of 16,035 visits to the feeders from 240 different individuals, after filtering the data for individuals that remained too close to the antenna and were detected several times during a single visit, i.e., within 5 min. There was a high variability both in the total number of visits in the traps per individual (min 0 visit, max 210 visits, median 63.50) and also in the number of different traps visited per individual (min 0 trap, max all 5 traps, median 3 traps).

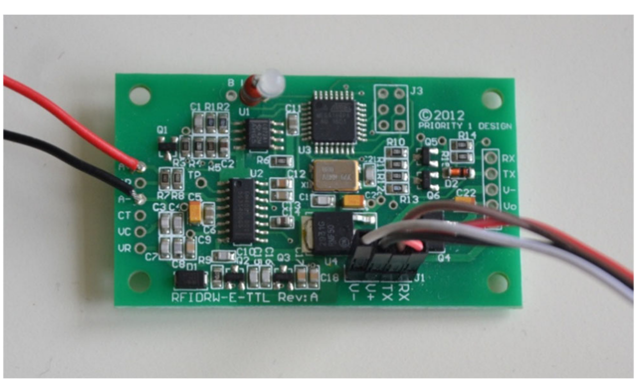

Fig. 7 Picture of an RFID reader board

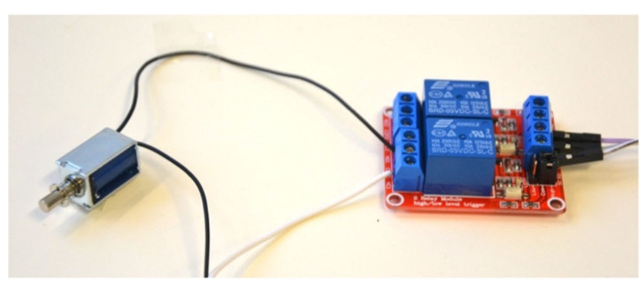

Fig. 8 Picture of a relay board connected to an electromagnet-solenoid

Table 1 Table with costs in Euros and material. Items highlighted in italic are essential to build a selective trap

Component	*Price (in Euros)*	*Model*	*Website*	*Function*
Raspberry Pi	38 €	Raspberry Pi 3 model b	https://www.raspberrypi.org	Single-board computer
Micro USB power supply	15 €	–	Generic	Power Rpi, 5VC, minimum of 1 A
RFID reader + antenna	48 €	FDX-B/HDX RFID Reader Writer with TTL serial port + RFID coil antenna 49 mm	http://www.priority1design.com.au	RFID reader board and antenna to detect RFID tags
RFID PIT-tags	1 €	ISO 11784 certified PIT-tags (134.2 kHz)	http://www.loligosystems.com	RFID tags for the animals
Relay board	10 €	1 channel 5 VDC	Generic	Electrically operated switch, if solenoid not powered by RPi
Micro SD memory card	10 €	Class 10, 16 GB minimum	Generic	To store operating system and acquired data
Solenoid electromagnet push/pull	5 €	Force: 50 g minimum Stroke 6 mm	Generic	Release the sliding door when activated
Waterproof plastic container	4 €	Electric junction box	Generic	Hold and keep set-up dry
PiFace clock	10 €	PiFace real time clock	http://www.piface.org.uk	Keep track of real time
LEDs + resistor	0.50 €	–	Generic	Provide visual signals
Banana connectors, 2 males and 2 females	2 €	–	Generic	Allow to connect disconnect antenna to rest of the set-up
Raspberry Pi touch display	70 €	–	https://www.raspberrypi.org	Screen to allow easy visualization on the field as Rpi does not include peripherals

Finally, we have not detected any failure to record an individual's identity during our visual monitoring of the traps (ca 30 min daily for each trap during the first week of implementation). During the first trials, one trap successfully detected an individual but failed to trap it. The only instances of such failure were due to neither the hardware nor the software, but because of an inappropriate positioning angle of the trap, which did not allow the door to slide. Once that issue was solved by correcting the angle of the trap, all focal individuals detected were trapped.

In conclusion, the selective traps proved to be extremely efficient at trapping targeted individuals.

Habituation to selective traps

The selective traps were not the only food dispensers for the bats, which greatly lengthened the learning process. To facilitate bats habituation to the modified feeders, we baited the trap entrance with food for about 2 weeks, slowly moving the bait further inside the traps. Within a month, we found that more than 50% of individuals were detected in the traps.

At the end of the study, after 2.5 months, we detected 240 different individuals in the traps, which represent approximately 80% of the population. This proportion would have likely increase if the study was pursued for longer, as new individuals were detected every week in the traps. However, as our goal for recapturing the focal individuals was achieved, we stopped the study before all individuals of the population were detected in the traps.

Limitations with the RFID detection of the bats

With the RFID technology, only one PIT-tag can be identified at a time, preventing simultaneous detection of multiple PIT-tags. However, given the design of our trap, only one bat can go through the antenna at a time, so this was not an issue. After the detection of a non-focal bat, we programmed a 3-s pause to enable the bat to move away from the antenna, and to leave enough time to record ID, time, and date. During that 3-s pause, no other PIT-tags can be read. Another bat could potentially go through the antenna during that time and go undetected. The number of visits to the feeders could thus be underestimated. However, since bats come to feed repeatedly during one foraging bout, they are likely to be detected during one of their visits to the feeders. If this 3-s pause represents a problem for a specific set-up design, it can be shortened to fit the requirement of the set-up.

Trapping of non-focal individuals

Due to the design of the traps, several individuals could be trapped simultaneously, if some bats were already present in the feeder when the trap was triggered by a focal individual. However, it did not represent a problem as these bats are not aggressive toward each other. Non-focal individuals could further be readily identified and released. Occurrences of trapping of multiple individuals decreased with time, as bats became faster to go in and out of the feeders.

Failure of the selective traps

Initially, we had programmed the Rpi to send an e-mail when a focal individual was trapped. However, the WIFI signal was not sufficiently reliable in the zoo and would lead to failure of the program and hence of the traps. We thus decided to stop using the WIFI, and to monitor the traps in person, which successfully prevented traps failures.

The one other occurrence of trap failure was due to a temporary power cut. Indeed, by default, the program does not start automatically upon booting of the Rpi. When a temporary power cut occurs, the Rpi turns off and then back on when power comes back, but without the program running.

In conclusion, our selective traps were highly reliable.

Monitoring of the selective traps and welfare of the bats

The traps were monitored every 10 min during peak activity periods, roughly during 1 h after feeding, and every 30 min during the calm periods of the night. During the day (when bats are roosting in the cave and do not forage), the traps were not monitored. To avoid any accidental trapping during the day, the sliding doors were removed from the traps.

No injury was detected due to any features of the trap. Specifically, we did not observe bats getting hit by the sliding door. Due to the position of the door 10 cm away from the antenna, it is highly unlikely that the bat gets touched by the door. The use of forex (i.e., a light but rigid PVC foam) to build the sliding door was intended to prevent any injuries to the bats in the unlikely event that they get hit.

Discussion

The selective traps we built proved to be efficient, reliable, and affordable. They enabled us to trap all of our focal individuals. Moreover, by recording visits to the feeders, a wide range of questions about foraging habits can be addressed.

RFID-based set-ups are being increasingly implemented in a wide variety of research projects. To fit specific needs, it is possible to customize RFID-based set-ups associated with single-board computers with devices such as temperature sensor, audio recorder, camera recorder, a scale, etc. Notably, it is possible to fit servo-motors to perform rotating or linear actions. The selective RFID-based set-up we presented in this paper could easily be modified to address multiple research questions. It could be fitted to nest-boxes in order to trap individuals or to monitor activities at the nest, such as parental provisioning rate, or even record visits from prospecting or extra-pair conspecifics (see Lendvai et al. 2015; Prinz et al. 2016 for examples of nest-boxes monitoring set-ups). Social learning could be studied, with a precise monitoring of which and when individuals triggered the set-up. It could also be used to perform cognitive trials, without requiring isolation of the individuals or constant monitoring. For example, to study social learning in a monitored population of wild great tits (*Parus major*) in the Wytham Woods, UK, Aplin et al. (2013, 2015) made use of an RFID-based cognitive trial system, deployed at a large-scale in the field. RFID-based system could be used to compute social networks, if individuals are regularly detected at similar locations at the same time as shown notably with the Wytham Woods population of great tits (Psorakis et al. 2012) and with a captive population of zebra finches (*Taeniopygia guttata*) (Farine et al. 2015). In captivity, it could also be used to restrict food access or to supplement focal individuals while remaining in the same enclosure as the control group. In some cases, if individuals are habituated and come readily inside the set-up, it could even allow for experiments to take place in the natural environment of the animals, without restraining them in cages.

The main limitation of our selective traps was linked to the detection range of the antenna, about 5 cm using 7 mm long PIT-tags. To optimize detection bats had to crawl inside the antenna, which circled the entrance. As this species is not used to crawling and individuals previously had to hover to access the open-air feeder, it required time to acclimate bats to the modified feeders. Such a limitation should be less problematic in other species, such as passerine birds, where the PIT-tag can be attached to an identification ring and be detected when bird steps on the antenna.

In the process of building our set-up, we found out several technical details that greatly improved its conception. First, it is preferable to avoid models of RFID reader equipped with a USB port if detection range is an issue, because USB connection can be "noisy," and thus decrease detection range. For researchers looking for a cheaper alternative than commercially available RFID readers, Bridge and Bonter (2011) provide detailed explanations to build a low-cost RFID reader, along with the making of antennas using copper wire, which allows flexibility in the size and shape of the antenna to fit specific needs. Second, a classic cable, rather than a coaxial cable, will ensure a better connection between the antenna and the reader. Third, power consumption was not a concern for us so we used the Raspberry Pi 3 model b, but other models of single-board computer have lower power consumption, such as Raspberry Pi A+. If standard electricity is not available, it is possible to power the Rpi using a car battery, fitted for example with a USB car charger. Using a standard car battery of 50 Ah, (i.e., able to deliver 1 A for 50 h), the set-up could run for about 10 days continuously using a Raspberry Pi A+, consuming approximately 80 mA (0.4 W).

Our set-up is very flexible and thus offers numerous possibilities for improvements For example, it is possible to send a text or e-mail when the traps get triggered, or for any pre-determined event. Prinz et al. (2016) provide a good example of a Rpi-based set-up connected to WIFI, which allows remote monitoring. Moreover, LEDs can be used to signal-specific events, for example when a PIT-tag is being detected. We also used LEDs to address the problem of power-shortage, which can lead to failure of the set-up, as the Rpi can be on without the program running. LEDs can easily be used to signal whether the program is running, and hence whether the set-up is in function. Alternatively, one can modify the program so it automatically starts upon booting of the Rpi, which might be a better option if the set-up is not monitored regularly. Finally, it is important to know that the Rpi does not automatically record "real" time, but a time based on a pre-set date. However, several methods can be used to set-up real time on the Rpi, as described in Lendvai et al. (2015).

With reasonable costs and efforts, we were able to build open-source, programmable selective traps, which can be customized for very specific needs, which may not be the case for commercially available set-ups. Therefore, when planning for future experiments, it should be taken into account that building a selective set-up tailored for a study can be achieved in a fair time, for a low cost, and without previous background knowledge.

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Authors' contribution MM, AF, NF, and FH conceived the ideas.
MM and AF designed the methodology.
MM and AF build the set-up.
MM wrote the manuscript, with contributions from all authors.
All the authors accepted the final version of the manuscript.

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Compliance with ethical standards

Ethical approval This study was performed under the authorization 2015_43_FR, delivered by the veterinary office of the Canton Fribourg, Switzerland after examination by its ethical committee. All applicable international, national, and/or institutional guidelines for the use of animals were followed.

Conflict of interest The authors declare that they have no conflict of interest.

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