biology
letters
Animal behaviour

Biol. Lett.
doi:10.1098/rsbl.2008.0075
Published online

A quick guide to video-tracking birds

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Video tracking is a powerful new tool for studying natural undisturbed behaviour in a wide range of birds, mammals and reptiles. Using integrated animal-borne video tags, video footage and positional data are recorded simultaneously from wild free-ranging animals. At the analysis stage, video scenes are linked to radio fixes, yielding an animal's eye view of resource use and social interactions along a known movement trajectory. Here, we provide a brief description of our basic equipment and field techniques to enable other researchers to start their own video-tracking studies.

Keywords:
animal-borne video and environmental data collection system (AVED); biotelemetry; habitat use; home range; New Caledonian crow; very high frequency (VHF) wildlife radio tracking

1. INTRODUCTION

Video cameras are now small enough to deploy onboard many terrestrial species, permitting an animal's eye view of the environment (Rutz *et al.* 2007). Continuing miniaturization opens new frontiers for research, but the use of animal-borne cameras as a research tool is currently under-exploited, mainly because there are no commercial suppliers of tags or receivers (Moll *et al.* 2007; Rutz & Bluff in press). In this paper, we describe basic equipment and field techniques for 'video tracking'—the simultaneous recording of video and positional data from free-ranging subjects by means of integrated animal-borne video tags (Rutz *et al.* 2007; Rutz & Bluff in press). While video tracking is suitable for a wide range of birds, mammals and reptiles, we will focus most closely on flying birds, as their light bodies and aerial lifestyle present particular technological challenges.

2. EQUIPMENT, DATA COLLECTION AND ANALYSIS

(a) *Integrated video tags*

Although the final design will be application specific, a basic integrated video tag comprises video camera, video transmitter, microphone (optional), battery, timer chip and a small, very high frequency (VHF) radio tag for positional tracking (figure 1*a*; for a three-dimensional animation, see video 1 of the electronic supplementary material). Assembled 'spy bugs', featuring battery-powered video cameras with 2.4 GHz transmission, are readily available from internet sources. Stripping these units of excess packaging is the cheapest and easiest means of obtaining a 'bare-bones' tag, or of familiarizing oneself with the technology. Most researchers, however, will require light weight, custom-built tags with superior video resolution, transmission range and battery life. We provide detailed information on component selection and tag construction in the electronic supplementary material.

An integrated VHF radio tag is essential for capturing video footage (see §2*d*), enables recovery of shed tags and provides positional data for linking video-recorded behaviour to certain habitat patches within an animal's home range (Rutz & Bluff in press). We strongly recommend the use of a timer chip, which delays video transmission for a nominated period (manufactured by Ron Joyce; contact via British Technical Films, UK). A delay of approximately 24–48 hours will allow the animal to habituate to the video tag before filming begins, and video shoots can be scheduled to coincide with periods of high activity (e.g. early morning). Longer intervals are possible but come at the cost of reduced transmission time due to battery depletion. Packaging of electronics for deployment on wild subjects requires particular attention (minimizing size, weight and adverse effects; optimizing camera view and durability), and we offer guidance in the electronic supplementary material.

(b) *Mounting integrated video tags on birds*

The welfare of the animal is of paramount importance when selecting video-tag mounting positions. Where possible, researchers should adopt standard techniques and mass guidelines for conventional VHF radio tags (e.g. Kenward 2001). In the interest of subject welfare and for optimal tag construction, prototypes must be tested with captive subjects first, followed by further field trials.

A backpack-mounted video tag with a laterally oriented camera allows the analysis of wing dynamics during flight, whereas a tail-mounted tag with a forward-facing camera permits the recording of foraging behaviour, social interactions and physiological parameters (e.g. breathing and defecation rates). Our tail-mounting technique (Rutz *et al.* 2007; see video 1 and text in the electronic supplementary material) achieves a good camera angle on medium-sized birds and exploits the natural 'release mechanism' offered by bird feathers. For our fieldwork, we specifically targeted the moulting season of our study species to ensure that tags are shed within days or weeks after deployment (Rutz *et al.* 2007). This approach led to successful tag drop-off in all of the 15 cases where we resighted crows 6–12 months after fitting them with video tags ($n=22$ tagged crows; see the electronic supplementary material).

Backpack-mounting techniques permit greater tag mass but are more suited to species where recapture is probable, as designing safe and reliable release mechanisms for small harnesses remains challenging (Kenward 2001). For both backpack- and tail-mounted video tags, coverage of cameras and antennae by feathers should be minimized, observing species-specific constraints imposed by flight performance and ability to habituate to tags.

All authors contributed in equal part to this work.

Electronic supplementary material is available at http://dx.doi.org/10.1098/rsbl.2008.0075 or via http://journals.royalsociety.org.

Received 12 February 2008
Accepted 3 April 2008

FirstCite e-publishing

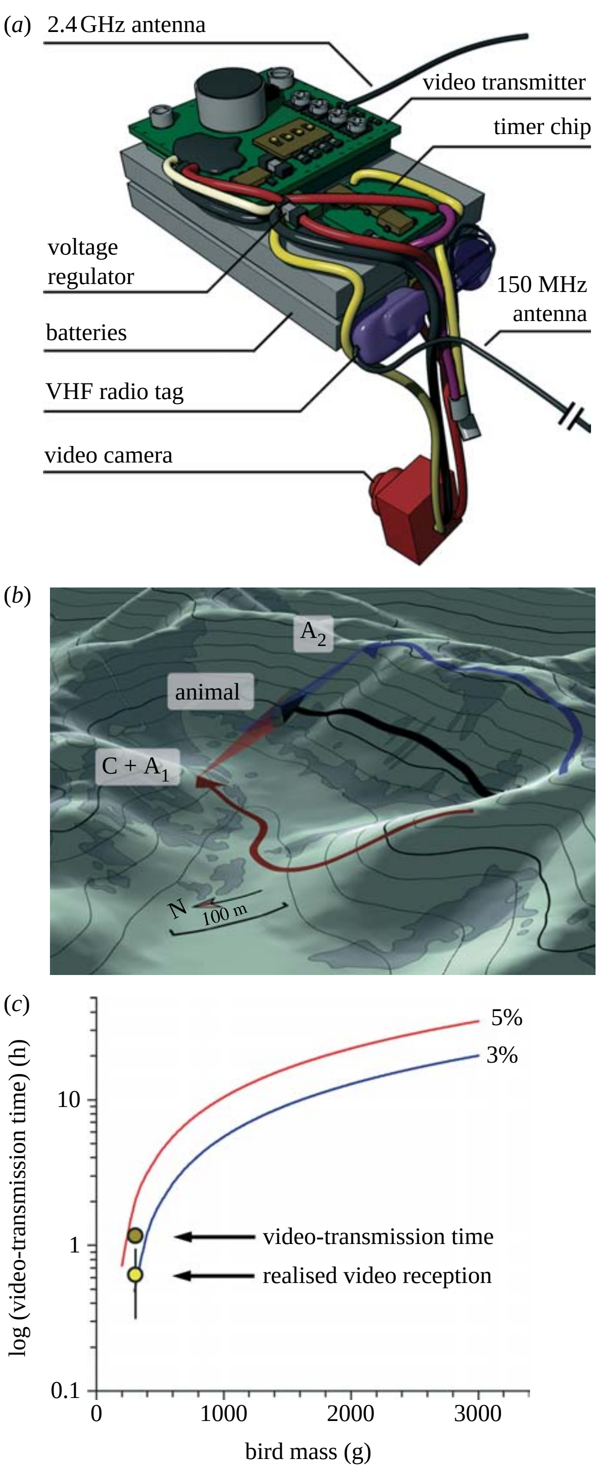

Figure 1. Animal-borne video cameras for studying wild free-ranging birds. (*a*) Computer model of an integrated video tag, as used by Rutz *et al.* (2007) for wild New Caledonian crows. Video tags of this design can be built with a deployment mass of less than 14 g. To expose electronics, the tag is shown without its heat-shrink packaging. For a three-dimensional animation of the model and an illustration of the tag's mounting position on a bird, see video 1 of the electronic supplementary material. (*b*) Video tracking with actively transmitting tags requires two or more fieldworkers (see §2*d*). A 'controller' (C) uses VHF radio telemetry to estimate the animal's location and instructs assistants (A_1 and A_2) on where best to position video receivers. In this case, the controller moves together with A_1 (red arrow) and communicates via walkie-talkie with A_2 (blue arrow). The animal is 'shadowed' as it traverses the environment (black arrow), exploiting the local topography to maximize video reception (note how A_2 moves along the ridge) and avoid disturbance to the subject. The red and blue cones indicate how, towards the end of the video shoot, the two independent video receivers are pointed from different directions at the tagged animal. This is a schematic of the session shown in fig. 1*b* by Rutz *et al.* (2007). (*c*) Larger bird species can carry integrated video tags with heavier batteries, permitting longer video-transmission times. Transmission times are calculated for the basic tag design used by Rutz *et al.* (2007), assuming that tags are fitted with batteries to make total tag mass 3 (blue line) and 5% (red line) of the animal's body mass, respectively. Owing to intermittent signal loss, the amount of video footage recorded in the field is less than the total video-transmission time. Using tags that transmit for approximately 70 min (dark yellow circle), Rutz *et al.* (2007) obtained 38±5 min (mean±s.e.) of analysable footage per successful video shoot (n=12 birds; light yellow circle).

(c) *Video-tracking receivers*

Commercially available receivers typically feature pre-programmed channels and low-gain dipole antennae. A helical antenna mounted in a parabolic dish, paired with an analogue-tuning receiver (available from Jonathan Watts; British Technical Films, UK), should markedly improve reception under field conditions. Multi-element antennae provide increased gain but are probably too directional for most applications. Video recording is done by digital camcorders, or hard-drive recorders, with AV-input capacity. Recorders should store full-frame, minimally compressed video at high frame rates and, ideally, should not automatically screen out low-quality footage (as even this may contain valuable information). The choice between NTSC and PAL video standards is determined by the availability of suitable video-tag components. For species with small home ranges, a pre-deployed network of transceivers may allow the efficient relay of signals to the recording unit, but we have not explored this option ourselves.

(d) *Data collection in the field*

Field techniques will be largely determined by the flush distance of the study species and the degree to which the video signal is attenuated by the local habitat. Previous experience in radio tracking the species is invaluable. Transmission may be highly sensitive to the position and orientation of the transmitter antenna—a 2.4 GHz signal diffracts much less than VHF and is more severely impeded by vegetation. Fieldworkers should always strive to get as close as possible to direct-line-of-sight transmission. In forested terrain, this is best achieved by positioning receivers on elevated points, so that the video signal needs to penetrate only a comparatively thin layer of vegetation (figure 1*b*).

The use of redundant receivers will increase the total amount of unique footage recorded if receivers are placed at different vantage points (figure 1*b*). These independent recordings are subsequently merged (see §2*e*). We capture video footage with tracking teams consisting of one 'controller' who uses VHF radio telemetry to locate the animal and anticipate its further movements and 1–2 (or theoretically more) assistants who operate video receivers. The 'controller' instructs assistants via walkie-talkie on where best to position video receivers and how to orient parabolic antennae to maximize reception (figure 1*b*). Training sessions are necessary to achieve good coordination among trackers.

VHF radio tracking plays a key role in data collection. During the habituation period (see §2*a*), we conduct preparatory tracking to map the bird's ranging behaviour and explore features of the local topography that can be exploited during the forthcoming video shoot. On the day of the shoot, we use high-effort radio tracking to follow the subject continuously from dawn to dusk, including the period of video transmission (70 min with our tags). The bout before the camera triggers gives important information for coordinating tracker movements, while all three bouts combined (before–during–after) yield a movement trajectory to which video data can be linked at the analysis stage (Rutz *et al.* 2007). The VHF transmitter of our integrated video tags lasts long enough (approx. three weeks) to enable collection of radio fixes for conventional home-range and habitat-use analyses, and we suggest that researchers use this opportunity to collect additional data from their video-tagged subjects (Rutz & Bluff in press).

(e) *Data analysis*

Multiple-track video-editing software allows the construction of a single 'best' version of footage from independent receivers. For this purpose, recorders should be identical, with standardized settings. Keyframe-based compression is ill-suited to the jumpy nature of animal-borne video and should be avoided for initial recording or construction of files for scoring. While analysis will naturally depend on the research focus, most users will benefit from video-scoring software that synchronizes scoring keystrokes with individual video frames (e.g. www.jwatcher.ucla.edu). Scoring should be done from 'real-time' versions of footage, where breaks in transmission are included. If the start and end of each transmission period is scored, data can subsequently be filtered to include or exclude cases where transmission was interrupted during a behavioural event or sequence.

3. DISCUSSION

As with any other animal-mounted device, the suitability of video tags to both the study system and the research question must be appraised before attempting deployment (Kenward 2001). The fundamental concern is that of animal welfare; video tags must not exceed a reasonable proportion of the body mass of the subject or impede its movements (Moll *et al.* 2007; see text in the electronic supplementary material). Minimizing the impact of the tag on any aspect of the animal's natural behaviour is also in the researcher's interest, given that a key strength of video tracking is intrusion-free data collection.

The number of video tags that can be deployed is limited by money, time and manpower. Currently, the per-unit costs of self-assembled integrated video tags are approximately double that of commercial VHF radio tags. However, the transmission life of a video tag is orders of magnitude shorter than that of a radio tag of the same mass (figure 1*c*). Efficient video capture is more labour intensive than positional radio tracking alone, and the active transmission time is a small proportion of the total time required for each video shoot (e.g. tag construction; preparatory positional tracking). It should also be taken into account that some tags will fail, or some subjects may be inaccessible at the time of transmission. We suggest that a small number of trial deployments are used to estimate a realistic target sample size. In any case, we caution that, with current technology, video tracking is not suitable for one-off deployments, and success of any study will depend on achieving good sample sizes.

Trial deployments will also allow researchers to assess whether acceptable footage can be obtained from a distance without disturbing the subject. The successful transmission range of the video signal will be species and habitat specific and transmission may be intermittent, so it should be considered whether the resulting video data will be appropriate to the research question. For example, at the limits of transmission range, video-signal reception may be possible only when the subject is in an exposed position or remains motionless in a particular orientation—a systematic sampling bias that may be acceptable for some, but not all, projects. Camera resolution will rarely be an issue for behavioural studies, but the camera's field of view may be constrained by body parts depending on tag mounting (see §2*b*).

We developed our video-tracking technology for studying New Caledonian crows (*Corvus moneduloides*)—a species near the minimum body mass at which video tagging is currently feasible (we targeted large individuals for tagging, especially males; mean body mass was 302 g for $n=18$ birds fitted with tags of the final design; see figure 1*c*). The use of video tags on larger birds or terrestrial mammals will benefit considerably from additional tag mass. The most obvious improvements are increased transmission time by using larger batteries (figure 1*c*) and/or improved transmission range and reception quality by using more powerful video transmitters. While larger species will always permit more flexibility in video-tag configuration, technological advances will continue to expand the range of species that can be fitted with video tags.

We anticipate that video tracking will be of particular value to those researchers already employing VHF radio tracking (Rutz & Bluff in press). Integrated video tags resolve the trade-off faced by many field biologists between non-disruptive tracking from a distance (e.g. to assess habitat preference; radio fixes) and approaching animals closely (e.g. to record detailed behaviour; video footage). In fact, detailed video recordings of social interactions and foraging behaviour may greatly facilitate interpretation of longer term radio-tracking data. Another immediate application for video tracking is the calibration of other animal-borne devices, such as posture- or heart-rate sensors (Moll *et al.* 2007; Rutz *et al.* 2007).

4. CONCLUDING REMARKS

Video tracking is a young research technique, and new users should be prepared to invest considerable time and other resources into its successful implementation. We believe, however, that its potential advantages by far outweigh current constraints and therefore encourage field biologists to take on the challenge to adapt and improve the techniques outlined in this primer. Continued technological advancement will not only improve tags of the basic video-transmission design we described here, but will provide alternative means of video-data collection. In our opinion, the next main goal will be the development of cheap, light-weight, solid-state video loggers for mass deployment. Such devices will require recovery for data download, but tag losses will be compensated for by increased sample size and uninterrupted video recordings.

The scope of video tracking for wildlife research is vast. It enables unprecedented, intimate glimpses into the lives of wild animals, and quantitative data collection in places and circumstances where other observation techniques fail. While strongly encouraging its wide adoption, we urge fellow researchers to use video tracking wisely—in systems that are insufficiently accessible with conventional techniques, such as VHF radio telemetry, and for addressing well-defined research questions. We look forward to the many new insights that video tracking will produce in the near future.

Our fieldwork was carried out with permissions from the Centre de Recherches sur la Biologie des Populations d'Oiseaux (France) and the Direction des Resources Naturelles (Province Sud, New Caledonia), and was in accordance with the University of Oxford's procedures for local ethical review.

We thank J. Watts and R. Joyce for their help with technology development, J. Troscianko for artwork and two referees for comments. Our video-tracking research was financially supported by the BBSRC (grant BB/C517392/1 to Alex Kacelnik), two Rhodes Scholarships (L.A.B. and C.R.) and a Linacre College Junior Research Fellowship (C.R.).

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Electronic supplementary material

A quick guide to video-tracking birds

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S1. CONSTRUCTION OF INTEGRATED VIDEO-TAGS

(a) *Selection of components*

The raw components for building integrated video-tags can be obtained from a range of (internet) suppliers. Comparatively cheap components are available from suppliers of light-weight model planes or 'spy gadgets', while more sophisticated and expensive parts are sold by specialised CCTV and video-technology retailers. We largely refrain from endorsing particular products or companies, because research projects will differ widely in their technological requirements (see main text §2 and 3), and because in this fast-moving area, any information we could provide now would soon be outdated.

At the time of writing, the smallest available cameras weigh approximately 1.5 g, including voltage regulator; these are NTSC format and have an effective resolution of *ca*. 75% of full NTSC, which is sufficient for most behavioural research. However, some users may require the higher resolution provided by slightly heavier units. Even the smallest cameras have manually adjustable focus, which should be optimised for the application and then fixed in place before tag construction. Some cameras are available with optical-fibre attachments, which may facilitate positioning of the lens for certain applications.

The video-transmitter is likely to be the component most limiting to the success of a video-tracking project. The smallest 2.4 GHz units are not the most powerful, and we found that slightly larger units (~3 g, including microphone) provide substantially improved transmission. It is worth mentioning the recent availability of equally small transmitters that broadcast at 1.2 GHz or 900 MHz, which propagate better through forested habitats than 2.4 GHz. Additionally, lower frequencies equate to longer wavelengths and thus longer antennae, which can project further from the animal. Small, light-weight VHF radio-tags are available from a range of suppliers (see Appendix 1 in Kenward 2001).

For the video circuit, lithium ion polymer batteries (Li-Po) are desirable, as they come in flat cells (ideal for producing compact, well-balanced units), are relatively inert, and have higher energy density than alternative chemistries (e.g. Li-ion). Care should be taken to protect the batteries from physical damage (e.g. pecking), which may lead to combustion. If tags are intended to be re-used without re-casing, batteries should be fitted with a cut-off that prevents complete discharge and permanent reduction of battery capacity. Alternatively, if tags are overhauled between deployments, new batteries need to be fitted to guarantee maximum tag life. We use two Li-Po batteries wired in series that supply >8 V at full charge, a voltage that may exceed the manufacturer's specifications for the camera and/or video-transmitter. If after trialling, this is found to cause malfunction, a voltage regulator must be used (see figure 1*a*, video 1). The integrated VHF radio-tag is fitted with its independent power source, in our case a 1.55 V silver oxide button cell.

We use a timer chip to delay video transmission after tagging (see main text §2*a*) and had two versions of this bespoke component built for our project (Ron Joyce): chips set to 24 and 48 hours, respectively. The chip is installed between the main battery and the video circuit, as shown in the animation in video 1. We recommend that, when initially activated, the timer chip should: (i) turn on video transmission for a short period (~30 s) to allow the assessment of circuit function before the delay period is initiated; and (ii) illuminate a miniature LED to communicate its own functional state (our chips signalled whether they were 24 or 48 hours).

While VHF radio-tracking receivers and Yagi antennae are widely available (see Appendix 1 in Kenward 2001), customised, field-worthy video-receivers with helix antennae are, to our knowledge, currently only offered by British Technical Films, UK (Jonathan Watts; www.britishtechnicalfilms.com).

(b) *Construction*

The tag's physical structure is determined by the tagging technique and the desired camera view (see main text §2*b*). In general, surface area should be minimised to reduce packaging mass and the likelihood of external damage. Within the tag, the heaviest components should be located nearest to the animal's centre of gravity.

The positioning of the video-transmitter antenna is critical to maximising transmission range. Because this antenna is comparatively short (typically a quarter of a wavelength, i.e. ~3.1 cm at 2.4 GHz), its projection from both the tag body and the animal itself should be maximised (see §S1*a*). During early trials, we experimented with replacing stock antennae with longer antennae tuned to higher fractions of the transmission wavelength, but observed no measurable increase in transmission range. Additional care should be taken to position the antenna of the integrated VHF radio-tag well away from the GHz antenna (figure S1*g*, video 1). We found that, if the two antennae are mounted close together or crossed, VHF transmission may be inhibited during video transmission, which can make positional tracking of the animal impossible. Loss of stable VHF contact with the subject usually results in a failed video shoot, as strategic positioning of video-receivers is jeopardised (see main text §2*d*, figure 1*b*); at the very least, it makes it impossible to link video scenes to movement trajectories at the data-analysis stage (Rutz & Bluff 2008; for conceptually similar work with marine animals, see Davis *et al*. 1999; Heithaus *et al*. 2002).

Tag reliability and performance are dependent on high-quality soldering. In addition to the obvious need for good electrical connectivity (particularly on the camera-to-transmitter video wire), all joints must be physically robust to withstand handling during packaging and possible manipulation by the animal. All naked contacts should be electrically insulated to avoid short-circuiting. Given the importance of minimising tag mass, wiring between components should be as short as possible and the amount of solder should be minimised. However, this increases the difficulty of soldering connections and the likelihood of overheating sensitive components. Previous soldering experience is desirable.

An important consideration is how the two circuits within the tag (video and VHF) will be activated before deployment. We initially fitted units with micro 3-pole connectors, but subsequently found that soldering wire-to-wire joints (see video 1) before tag deployment was lighter and more reliable. Sufficient length should be left on connecting wires to allow them to protrude from the packaged unit for external soldering (figure S1*f*). Reed-switch arrangements are not suitable for the video circuit, as the Li-Po batteries should be charged immediately prior to deployment to ensure maximum capacity.

Additional weight savings can be achieved by removing non-essential packaging from the raw components, or even by filing-off excess material (figure S1*c*). Light-weight VHF radio-tags for integration into the video-tag should have minimal potting or none at all. We used PIP-tags from Biotrack Ltd. (Dorset, UK) with a thin coating of Plasti Dip (Plasti Dip International) to avoid electrical contact with the (much higher voltage) video circuit during construction (figure S1*b*). Components may be held together with small pieces of two-sided adhesive tape to provide structure before the final packaging.

(c) *Packaging*

While some applications, for example deployment on marine birds (Takahashi *et al*. 2004; Naito 2006; Watanuki *et al*. 2007), may require the physical strength of a rigid casing, we found 'heat-shrink' tubing to be an excellent material for packaging units. It provides a snug fit for the electronics, is light-weight, withstands birds' beaks and weather, and it can be re-shaped to a certain degree to achieve the desired camera angle. Heat shrink should be of the smallest diameter into which the assembled tag will slide without forcing, have a low shrink temperature and high shrink ratio, and be ductile at <100 °C. We initially used black heat shrink (figure S1*g*) to camouflage the unit better against crow plumage, but found that transparent heat shrink (figure S1*h*) greatly facilitates the packaging process. The following is a step-by-step description of our packaging protocol.

(i) Packaging mass can be substantially reduced by briefly submerging a length of heat shrink in simmering water, with the tag inserted. Generous margins (~10 cm) are left on either side of the electronics, such that the ends can be kept above water while the body of the tag is fully immersed. The tube is folded back on itself at both ends, and gripped firmly at each end with long-nosed pliers to avoid penetration by water or steam. The electronics should only be held in the water momentarily, until the heat shrink reaches its glass-transition temperature. This will happen at a higher temperature than the initial contraction.

(ii) When the heat shrink becomes ductile, the package is removed from the water and both ends are pulled in opposing directions, as strongly as can be managed without tearing the tube. The pliers are held under tension until the heat shrink cools, maintaining the elongated shape. The aim is to reduce the thickness of the heat-shrink walls and, thereby, minimise final tag mass. Care should be taken as contact with boiling water is deleterious to the health of both the tag and its constructor. We recommend practising with dummy units before packaging precious electronics.

(iii) Further shrinking and shaping are achieved by selectively heating the packaging with a fine-tipped hot air gun (standard accessories on gas-powered portable soldering irons). The angled bend in our packaging is made by heating the inner base of the projecting camera tube, then laterally grasping the base in circlip pliers, and holding at the appropriate angle until cool. This has the additional benefit of producing grooves that permit the bird's central rectrices to continue past the camera tube with minimal deflection (figures S1*d*–*h*). Standardisation of tag shape can be improved by using a temporary internal template, which provides support to the components during the initial stretching process (see points (i) and (ii) above), and is removed before final shrinking and sealing; we used a heavily modified metal dining fork for this purpose.

(iv) Small exit holes for the two antennae are drilled through the heat shrink, after the structure has been finalised. These should be positioned at the base of the respective antennae to maximise free-standing antenna length, but should remain as sheltered as possible from potential manipulation by the bird. The antennae are then 'fished' from the inside of the packaging, using a hooked wire or a loop of string. All holes in the heat shrink must be carefully sealed with at least two generous coats of Plasti Dip (figure S1*a*).

(v) The connector wires are retrieved by drilling an appropriate hole, then 'fishing' with a hook or loop, as with the antennae (see point (iv) above). Wires should be left protruding until the video and VHF circuits have been closed and the tag is about to be attached to the animal (figure S1*f*).

(vi) The lens of the video camera must also protrude through the heat shrink. A hole of a slightly smaller diameter than the lens is cut in the distal end of the camera tube. The lens is then pushed through this hole, stretching the heat shrink to a tight fit. Camera positioning and focus are tested at this stage, before the lens is sealed in place with Plasti Dip (figure S1*d*).

(vii) The ends of the tube are sealed by locally over-heating the heat shrink with a fine hot air gun, then clamping it tightly with needle-nosed pliers until cool. Excess heat shrink is then cut away. With practice, it is possible to achieve a strong seal with minimal excess material (figures S1*d*,*g*,*h*).

(d) *Activation and mounting*

Using a timer chip, video transmission can be scheduled to coincide with periods of animal activity or suitable filming conditions (see main text §2*a*). The timing of video shoots need not be constrained by trapping success: for example, if a tag with a 48-hour timer is activated at 6 a.m., a bird trapped at any time on the same day may be fitted with that tag. If trapping is unsuccessful, the circuit is disconnected and the Li-Po batteries are re-charged. Note, however, that the VHF radio-tag should only be started immediately prior to attachment. Once both circuits have been activated, all wiring is pushed back through the hole in the heat shrink and the packaging is sealed well with at least two coats of Plasti Dip (figure S1*a*). Before the tag is attached to the animal, the functionality of both video and radio circuits should be confirmed.

Mounting methods will be highly species- and application-specific (backpack harness on eagle: Carruthers *et al*. 2007, Taylor *et al*. 2008; taped to back feathers on shags: Watanuki *et al*. 2007; taped to tail feathers on crows: Rutz *et al*. 2007). We position the video-tag on the inner rectrices of birds, using double-sided tape attached to the flat under-surface of the batteries. The tag is placed as close to the base of the feathers as possible, without touching skin or interfering with the preening gland. Two thin (<5 mm) bands of adhesive tape (e.g. electric insulation tape) are then wrapped around the tag and the rectrices, with one band positioned at the front of the tag and the other near the angled bend (figure S1*e*). To enable birds to actively remove tags with their beaks, we reduce the adhesiveness of the tape by repeatedly touching it with fingers prior to use; additionally, breaking points can be created by making small incisions in the tape *in situ*. We tie the VHF antenna to one of the inner rectrices with 4–5 knots of dental floss, sealing knots with drops of superglue (see Kenward 2001).

S2. 3D-ANIMATION OF INTEGRATED VIDEO-TAG

Video 1 in the electronic supplementary material (created by J. Troscianko) is a computer animation that illustrates how our integrated video-tags are mounted on the tail of a bird, and how individual electronic components are arranged within a tag of our basic design. The illustration of our tagging technique is schematic, with the blue cone indicating the camera view (forwards-facing between the subject's legs); for movies and still images, see Rutz *et al*. (2007). The computer model of the tag was created from photos of real tags used in our research, but for illustration purposes, the heat-shrink packing is shown in red colour, rather than black or transparent (see figures S1*g*,*h*).

S3. ETHICAL NOTES

Detailed discussions of ethical considerations are available for video-tracking studies (see main text §2*b* and 3; Rutz *et al*. 2007) and for wildlife tagging in general (e.g., Kenward 2001; Cooke *et al*. 2004; Ropert-Coudert & Wilson 2005; Wilson & McMahon 2006; Moll *et al*. 2007). Here, we just wish to provide a brief update on re-sightings of camera-tagged crows from our recent field project (*cf*. Rutz *et al*. 2007).

We fitted four crows with prototype video-tags between November 2005 and January 2006, of which three were re-sighted between October 2006 and February 2007. Eighteen crows were fitted with units of our final design between October 2006 and February 2007, of which 12 were re-sighted between October 2007 and January 2008. All observations between October 2007 and January 2008 were made opportunistically: during this time, none of the birds in our study area had a working VHF radio-tag (which would have facilitated re-sightings), and no specific searches for marked birds were conducted. The re-sighting frequency of camera-tagged crows compares favourably with that of birds that were only ringed and wing-tagged, or fitted with conventional VHF radio-tags.

S4. CONCLUDING REMARKS

While we have tried very hard to provide useful and accurate information in this primer, we cannot accept any liability for personal injury (hot water!), damaged property, financial loss, project failure, frustration, or any other problems arising from following our recommendations.

Furthermore, as pointed out in the main text (see §4), new users of this technology should be prepared to make substantial investments into adapting techniques, building prototypes, lab- and field-testing of equipment, and assembling tags for quantitative deployment. Until video-tracking gear becomes commercially available, researchers will have to accept the challenges involved in building their own equipment. While we are happy to correspond with colleagues, we wish to note that our limited resources do not allow us to supply components or assembled tags, or to provide major technical support.

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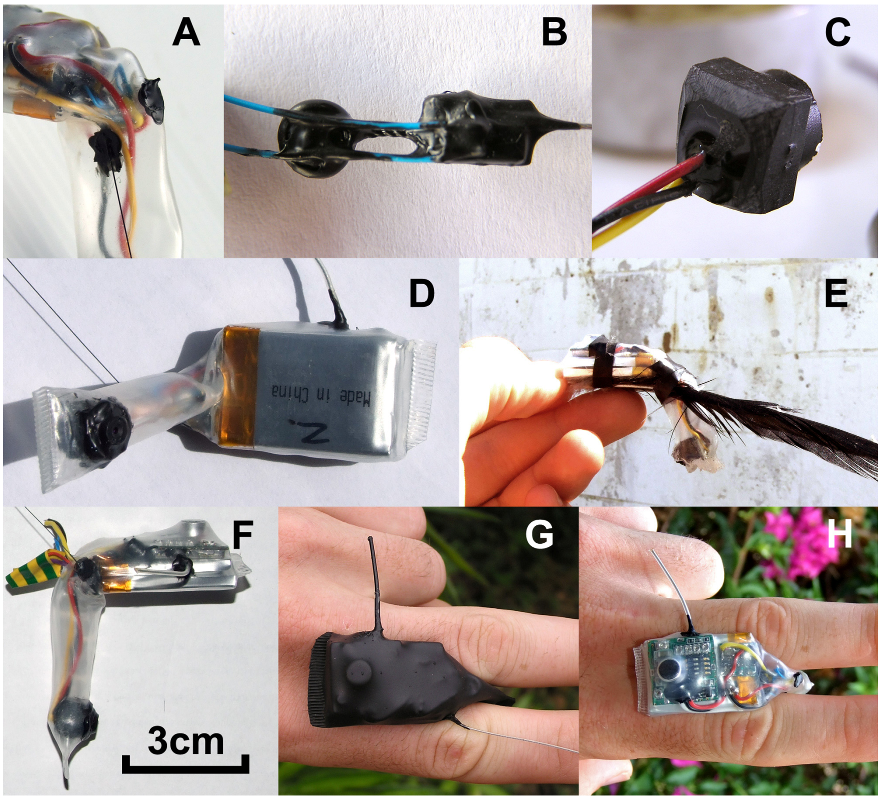

Figure S1. Integrated video-tags for studying wild New Caledonian crows (*Corvus moneduloides*).

(*a*) Rear of unit, showing bend at base of camera tube. Note the use of black Plasti Dip to seal the exit holes of VHF antenna (centre) and connection wires (right) (wires were pushed into the tube after both circuits had been closed).

(*b*) Close-up of VHF radio-tag. The tag is covered in Plasti Dip to avoid physical damage and electrical contact with the video circuit. The blue connecting wires allow the VHF circuit to be closed after the tag has been packaged.

(*c*) Close-up rear view of video camera. Non-essential plastic casing material has been filed-off to reduce excess mass.

(*d*) View of video-tag from below. Both ends of the heat-shrink tube have been firmly sealed by heating and crimping with pliers. The video camera protrudes from the heat shrink and is held in place by Plasti Dip. The lateral grooves at the base of the camera tube minimise deflection of the central rectrices and provide additional support for the mounted tag (*cf*. panel (*e*)).

(*e*) Side view of an integrated video-tag recovered after moult of the central tail feathers. The unit is secured to the feathers with two thin, pre-weakened strips of adhesive tape. Note how the main tag body sits flat on the base of the rectrices, while the camera tube projects between them for a clear view.

(*f*) Side view of an integrated video-tag. The connecting wires (top left) protrude from the heat-shrink casing to allow the main battery to be charged, and video and VHF circuits to be closed immediately prior to deployment. The lateral groove at the base of the camera tube is clearly visible.

(*g*) View of an integrated video-tag from above. The VHF (top) and 2.4 GHz antennae (right) project cleanly from the unit and do not touch. Note the crimp-sealing of the heat-shrink tube (left). Black heat shrink makes the tag less conspicuous against crow plumage, but final packaging is more difficult.

(*h*) View of an integrated video-tag from above. The 2.4 GHz antenna projects cleanly from the main tag body. On this tag, the VHF antenna exits the heat shrink from the base of the camera tube, enhancing tamper protection (*cf*. panel (*a*)). Excess heat-shrink has been trimmed after crimp-sealing (left). The 2.4 GHz video-transmitter with integrated microphone is clearly visible.