Tracking Toads using Photo Identification and Image-recognition Software

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Vital demographic information about animal populations in support of ecological research and endangered species management can best be gathered by tracking known individuals over time. In a great many animal species, patterns of spots, blotches, dots or stripes on the skin are sufficiently variable between individuals that they can be used for identification (Auger-Methe and Whitehead 2006; Faber et al. 2013; Gilkinson, et al. 2007; Chim and Tan. 2012). For dealing with just a few individuals, all that may be required is a set of images or drawings that can be matched to the animals' markings by eye. Employing these patterns effectively for recognizing more than a small number of individuals over time, however, invariably requires photographs, a searchable archive for the photographs and an expeditious means of comparing the photographs to find matching patterns (Bolger et al. 2012). Larger numbers of individuals that have been photographed multiple times present a prohibitive difficulty for manual searching as it becomes exponentially more time-consuming and errorprone as the number of surveyed individuals increases. The method therefore requires digital photographs stored in a digital archive, searched by image-recognition software (Arzoumanian et al. 2005; Kelly 2001; Speed et al. 2007; Van Tienhoven et al. 2007; Martin-Smith 2011).

Though the value of software-based photo-recognition of animals is clear, and many attempts have been made to employ it (Speed et al. 2007; Van Tienhoven et al. 2007; Gamble et al. 2008; Auger-Méthé et al. 2011; Lahiri et al. 2011; Bolger et al. 2012; Petrovska-Delacrétaz et al. 2014), the challenge of building such software is not trivial. In order for software to be able to compare each new picture with every other picture stored in a database and so find every matching color pattern for every animal, it has to discern and store information about the animal's markings in the pictures, and it has to compensate for variation in the size, quality, pixel density and orientation of the picture while it does so (Kelly 2001; Bolger et al. 2012). It also has to be reasonably easy to use and provide the user with the means to validate both input and output. A secondary requirement for the use of photo-recognition is that the animals' markings remain stable over time. Although this is usually the case, there are exceptions (Gowans and Whitehead 2001; Yoshizaki et al. 2009; Jonas et al. 2011; Waye 2013) and so mark stability should be examined case-by-case. Mindful of previous efforts to program and implement image-based visual recognition systems, we have designed a semi-automated software system, which we have named "Foto-Spottr", which has innovative attributes enabling efficient searching through a database of digital images to find likely matches to a given individual animal.

We used Fowler's Toads (*Anaxyrus fowleri*) as our focal species for the design our system. These toads have unique patterns of irregular dark dorsal spots which identify can them like a fingerprint (Fig. 1). A trained researcher can readily recognize an individual toad from photographs, even when the images are taken years apart. A long-term mark-recapture study of this species at Long Point, Ontario, Canada (Smith and Green 2006; Greenberg and Green 2013; Green and Middleton 2013) had used toe-clipping to identify individuals but, in recent years, also took digital photographs in order to confirm individual identities in cases where the toe-clips were hard to read. Thus a large bank of digital photographs was readily available for our use in designing and testing our software system and for examining the stability of individual markings over time.

To be comparable, photographic images of the animals need to be standardized. That is, they need to show the same part of the animal at the same orientation to the camera and be of the same pixel density, brightness and contrast. Some of this may be achieved as the photo is taken by holding the animal in a particular way against a particular background and maintaining the camera's settings, orientation and distance from the subject for all pictures (Doody, 1995). Though it is clearly advantageous to have as much consistency as possible among the pictures, maintaining an exact and fully repeatable picture-taking protocol in the field, especially using hand-held cameras, can be difficult and time-consuming. Computational post-processing to align the animals' identifying features among various photographs is anyway unavoidable and we chose to emphasize this aspect of the process in order to simplify picture-taking in the field as much as possible.

Foto-spottr is able to use pictures that were not necessarily taken for use in animal identification or were taken under difficult and variable field conditions. We use digital photographs taken in the field, at night, using a small, handheld waterproof camera (e.g. Pentax Optio or equivalent). The image density is set to 2 to 4 megapixels/image. Larger images than that are neither necessary nor desirable as they slow down processing and occupy greater archive space. Each photograph shows the dorsal surface of a single toad against a plain background

(Fig. 1A). A lab timer included in each picture serves both as a size standard and a device to record an image identifying number.

The animals in the images vary in size in three ways: the animal's actual body size, the pixel density of the image and the amount of the frame filled by the animal. The animal, also, is not necessary aligned consistently with respect to the frame. To compensate, we the user of the software can call up the image into a processing environment and place a generalized animal shape on the image of the animal to roughly specify the region of interest. For toads, the animal's outline could be approximated with a triangle on the head and a pentagon on body, anchoring the vertices at the posterior corners of the eyes (Fig. 1A). This process takes only a second and compensates for variations in image size and orientation. In the present version of Foto-Spottr, only the rectangular region of the animal's back is used for image matching.

Once the region of interest is specified, an automatic color segmentation routine (Cheng et al., 2001) finds most or all of the spots and highlights them in color (Fig 1B). The user then has the option to review the result and makes corrections as necessary. Using the mouse, the user can outline additional spots for the computer, refine the shapes of spots or remove erroneously highlighted areas, generally due to sand or debris adhering to the animal's back or shadows resulting from the uneven surface of the animal. This step may not be necessary for high-quality photographs of animals with well-defined spots, or may take up to a minute or two to compensate for low-contrast photographs of animals with ill-defined spots. The computer then stores a two-color image of the highlighted spots within the specified region of interest, linked to the original image.

At this point, Foto-Spottr automatically searches for matching images by comparing the two-color spot pattern of the target image to that of every other image in a database. The match-quality between two images is based on the number of overlapping pixels in the two-color patterns, but the images need to be well aligned before this is meaningful. The step of cutting out a rectangle from the back is sufficient to get the patterns into rough alignment but a more precise alignment is computed in software. Foto-Spottr uses Lucas-Kanade affine template tracking (Baker and Matthews 2004; Schreiber 2007) to compute an affine transform that maximizes the similarity between the two images. This algorithm is designed to track moving objects through subsequent frames of a video, but we found that it is also ideal for correcting the differences between still images taken at different times. The affine transform overcomes many routine misalignment problems between pairs of photos and allows the system to make direct comparisons of images, rather than of data derived from images as is done in various other systems (Auger-Methe and Whitehead 2006; Speed et al. 2007; Lahiri et al. 2011; Petrovska-Delacrétaz et al. 2014). We used the public domain MATLAB function shared by Dirk-Jan Kroon (MATLAB Central <http://www.mathworks.com/matlabcentral/fileexchange/24677-lucas-kanade-affine-templatetracking>) to implement the robust Lucas–Kanade template tracking algorithm into our system. The final match-quality score is based on the number of overlapping pixels after the final alignment.

Once Foto-Spottr has completed its database search, it displays the ten best matches, based on % pixel overlap, alongside the target image so that the user can visually verify the match (Fig. 2). In the great majority of instances, the best match should be another image of the same individual taken at an earlier time. If not, and the animal has been caught before, then one of the next two to five best matching images will almost invariably be that individual. If there is no good match among the 10 closest matching images, it can be assumed that the animal is new and Foto-spottr will indicate its failure to find a match.

Applied to a test set of 560 pictures of Fowler's Toads that had been taken in previous population surveys of toads (Smith and Green 2006), Foto-spottr required about a minute of manipulation time per image but greatly decreased the number of comparisons that needed to be verified by eye. Applied to pictures of animals that had been identified with toe-clipping, our system placed the correct match among the top five possible matches 91% of the time. This was comparable to the accuracy of the best physical tagging techniques (Bolger et al. 2012). Even so, the pictures we used were not staged for software recognition; they were taken as a routine part of the field protocol of the time. We have since refined our field procedure to get better, more consistent pictures, and our success rate has increased. Foto-Spottr also found matches that were previously missed based on toe-clip identifications and was able to identify animals as they grew (Fig. 2), confirming the temporal and ontogenetic stability of the markings on these animals.

One new property of the process of identifying animals using an image-based system, compared to physically marking them, is that an animal's identity usually cannot be established at the time of capture. Images are therefore tagged with field-given "encounter" numbers and recorded as such in the field note-books. These later have to be amended with the animal's actual identification number. Thus each encounter with any particular animal had to be recorded and numbered along with the animal's specific ID, and field notes have to be corrected after the fact. Foto-Spottr is designed to streamline this process of logging ancilliary data associated with each image, such as existing toe-clip, PIT, VIE or VI Alpha Tag IDs, biometric information, and the date and location of capture..

There are numerous differences between Foto-Spottr and other available computer-assisted photo-ID systems.. Our system is currently implemented in MATLAB 8.0 (The MathWorks, Inc., Natick, MA, USA) to take advantage of shared functions such as Kroon's Lucas–Kanade algorithm. It is also pixel-based, with automatic recognition of shapes no matter how irregular in outline they may be, and uses position, size and shape information in searching for matches. These aspects distinguish Foto-Spottr from I^3S software (Van Tienhoven et al. 2007) which matches the position of user-selected points on the animal or, in its latest versions, user-drawn ellipses around spots and from WILD ID software (Bolger et al. 2012) which first uses a Scale Invariant Feature Transform (SIFT) operator to extract point information from images and then takes a “brute-force” approach to compare of all such features between pairs of images using a geometric algorithm. Both Stripespotter (Lahiri et al. 2011), which uses a dynamic programming algorithm adapted from signal-processing methods, and Identifrog (Petrovska-Delacrétaz et al. 2014), which employs principal components analysis adapted from machine-learning methods, are also more computationally intensive than Foto-spottr, and have stricter requirements for the images they can use. All these various systems approach much the same problems with success but we contend that our approach makes input easier and yields results more rapidly.

Our initial results indicate that Foto-Spottr is already as effective as any system currently available (Speed et al. 2007; Bolger et al. 2012). With optimization, its performance could be even further improved. The prototype of the software was initially installed on a Macbook Air (Apple Inc., Cupertino, CA, USA) laptop computer but we have now made a freely available version than can be readily installed in Windows™ systems. We expect to develop it as a stand-alone, open-source software system and user interface which will allow it to be used in the field.

Software-based visual recognition that enables individuals to be identified without harming them makes the extensive use of toe-clipping and other invasive marking methods increasingly difficult to justify. Identifying individual wild animals has standardly involved physically marking or tagging them and an assortment of methods has been applied to amphibians and reptiles (Donnelly et al. 1994; Ferner 2007). Such methods include tattooing (Perret and Joly 2002), freeze-branding (Lewke and Stroud 1974), toe-clipping (Waichman 1992; Phillott et al. 2007; Lemckert 1996, Reaser 1995) and injecting either passive integrated transponders (PIT) tags (Ott and Scott 1999; Blomquist et al. 2008; Hamed et al. 2008; Luhring 2009), visual implant elastomer (VIE) marks (Bailey 2004; Moosman and Moosman 2006; Grant 2008) or fluorescent Visible Implant Alphanumeric (VIA) tags (Buchan et al. 2005; Gower et al. 2006; Heard et al 2009) under the skin. Aside from ethical concerns related to these practices (Funk et al. 2005), there is potential for such invasive procedures to alter an animal's behavior, compromise its physical well-being and threaten its survival (McCarthy and Parris 2004, Bloch and Irschick 2005; Liner et al. 2007). This is a particular concern for work with protected species. Not surprisingly, therefore, visual identification of individual animals based on their natural markings is an attractive alternative (Kurashina et al. 2003; Bradfield 2004; Del Lama et al. 2011; Sharifi et al. 2013), provided those marking are sufficiently discernable and distinctive (Kenyon et al. 2009). Increasingly improved software and hardware for photo-ID systems will represent significant advances in field methods that will be of direct benefit to ecological knowledge and the recovery of threatened species.

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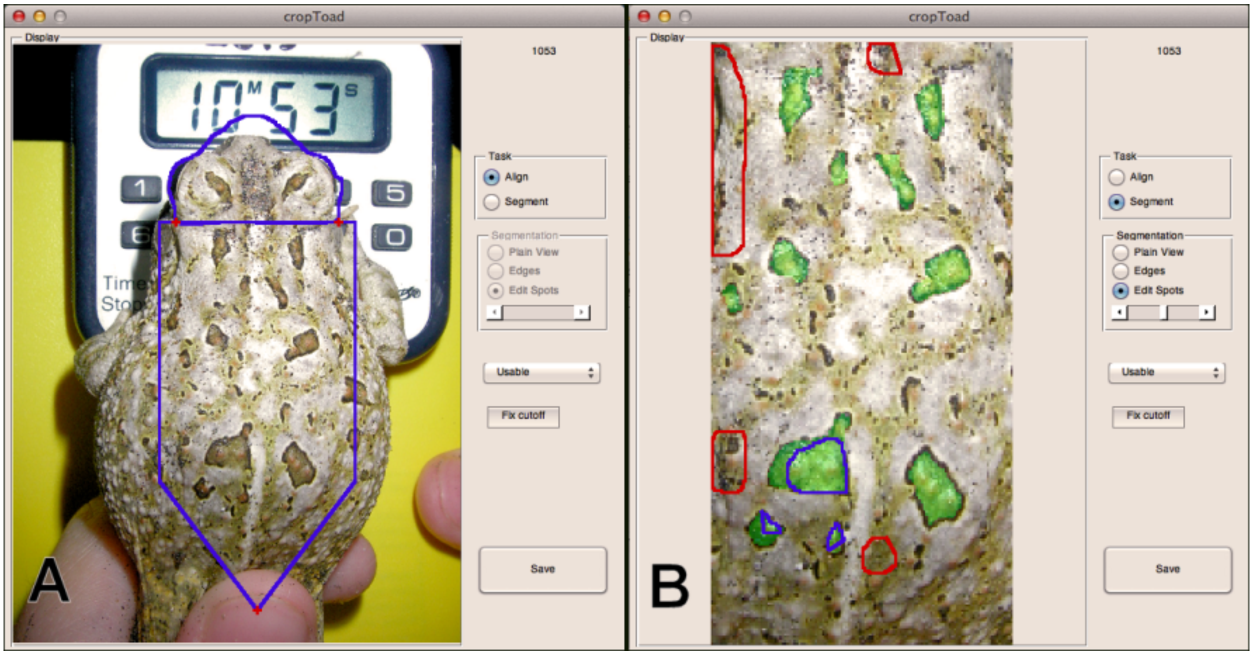
Figure legends

Fig. 1. Input window. A) Standard digital photo of the animal in question, in this case an adult female caught in 2013 and recorded as encounter No. 1053 for that year. The image has superimposed upon it the outline frame (blue) that specifies the region to be analyzed. The frame is placed by clicking on the image behind each eye and on the animal's posterior (red crosses). B) Editing window. Segmentation highlights all probable spots in green. This can be edited manually by outlining undetected spots (blue) or deleting incorrectly highlighted areas (red).

Fig. 2. Output window showing results of computer imaging searching for matches to the target (left image) image. The best match (right image) is clearly of the same toad caught when it was a juvenile three years previously in 2010 and assigned No. 1220. Despite differences in size, alignment and aspect in the two photos, the program found 72% alignment of the animal's spots in each image, as shown in the output window (lower left). To help confirm the match by eye, the aligned two-color spot patterns obtained from each image are displayed (far right).

Fig. 1


cropToad
Display
1053
Task
Align
Segment
Segmentation
Plain View
Edges
Edit Spots
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A
cropToad
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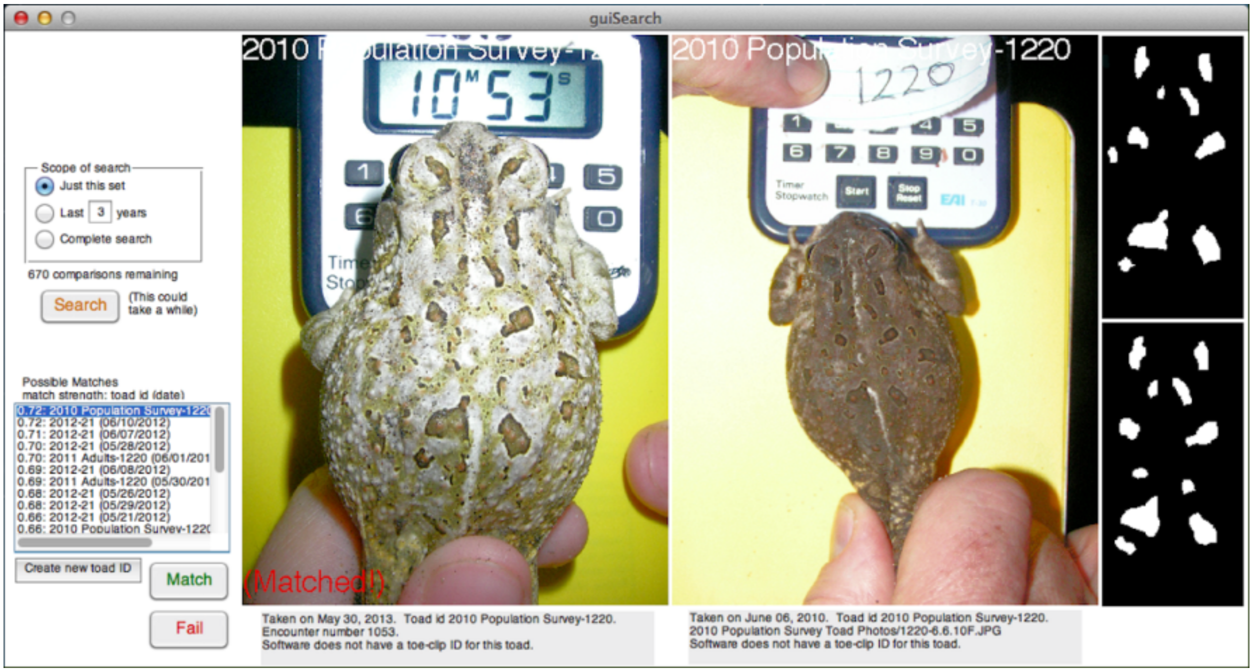
Fig. 2.


guiSearch
Scope of search
Just this set
Last 3 years
Complete search
670 comparisons remaining
Search
(This could take a while)
Possible Matches
match strength: toad id (date)
0.72: 2010 Population Survey-1220
0.72: 2012-21 (06/10/2012)
0.71: 2012-21 (06/07/2012)
0.70: 2012-21 (05/28/2012)
0.70: 2011 Adults-1220 (06/01/201
0.69: 2012-21 (06/08/2012)
0.69: 2011 Adults-1220 (05/30/201
0.68: 2012-21 (05/26/2012)
0.68: 2012-21 (05/29/2012)
0.66: 2012-21 (05/21/2012)
0.66: 2010 Population Survey-1220
Create new toad ID
Match
Fail
2010 Population Survey-1220
(Matched!)
Taken on May 30, 2013. Toad id 2010 Population Survey-1220.
Encounter number 1053.
Software does not have a toe-clip ID for this toad.
2010 Population Survey-1220
1220
Taken on June 06, 2010. Toad id 2010 Population Survey-1220.
2010 Population Survey Toad Photos/1220-6.6.10F.JPG
Software does not have a toe-clip ID for this toad.