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Automated face recognition of rhesus macaques

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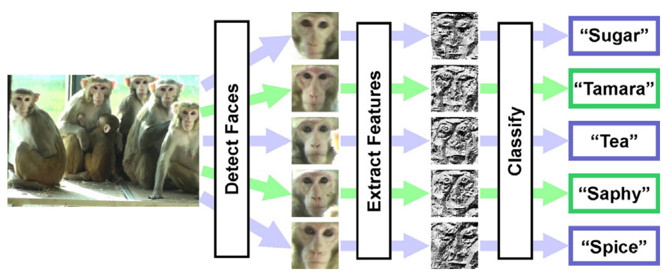
HIGHLIGHTS

- First study showing automated face recognition of rhesus macaques.
- High levels of classification accuracy.
- Methods can be implanted in real time using standard hardware.
- Potential application to social analysis demonstrated.

GRAPHICAL ABSTRACT



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ABSTRACT

Background: Rhesus macaques are widely used in biomedical research. Automated behavior monitoring can be useful in various fields (including neuroscience), as well as having applications to animal welfare but current technology lags behind that developed for other species. One difficulty facing developers is the reliable identification of individual macaques within a group especially as pair- and group-housing of macaques becomes standard. Current published methods require either implantation or wearing of a tracking device.

New method: I present face recognition, in combination with face detection, as a method to non-invasively identify individual rhesus macaques in videos. The face recognition method utilizes local-binary patterns in combination with a local discriminant classification algorithm.

Results: A classification accuracy of between 90 and 96% was achieved for four different groups. Group size, number of training images and challenging image conditions such as high contrast all had an impact on classification accuracy. I demonstrate that these methods can be applied in real time using standard affordable hardware and a potential application to studies of social structure.

Comparison with existing method(s): Face recognition methods have been reported for humans and other primate species such as chimpanzees but not rhesus macaques. The classification accuracy with this method is comparable to that for chimpanzees. Face recognition has the advantage over other methods for identifying rhesus macaques such as tags and collars of being non-invasive.

Conclusions: This is the first reported method for face recognition of rhesus macaques, has high classification accuracy and can be implemented in real time.

1. Introduction

Automated methods for monitoring behavior of laboratory animals such as rodents and zebrafish are becoming widespread (Bains et al., 2016; Nema et al., 2016; Steele et al., 2007). They allow the monitoring of behavior effects in response to experi-

Abbreviations: LBP, local binary patterns; NN, nearest neighbor; LDA, local discriminant analysis; SVM, support vector machine.

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mental manipulations such as drugs, lesions, genetic modifications and disease. Concurrently similar automated behavior systems are being developed for monitoring health and welfare in a range of species including farm and laboratory animals (Roughan et al., 2009; Rushen et al., 2012). Rhesus macaques are one of the most common non-human primate species used in biomedical research including neuroscience research but to date the use of automated systems with non-human primates has been limited.

A major challenge in measuring the behavior of any group-housed animal is to reliably identify an individual animal. With macaques this is not an issue if the animals are singly-housed but welfare concerns are driving a move towards pair- and group-housing of non-human primates in many countries. One solution is to add a tracking device to each animal; for example these could be colored jackets (Rose et al., 2012) or collars (Ballesta et al., 2014) in combination with video monitoring or electronic devices such as RFID tags (Maddali et al., 2013). These require regular handling of the animals and it is not currently known how the use of jackets and collars affects the behavior of the animals (personal observations with rhesus macaques suggest that the use of jackets can drastically reduce social behaviors such as grooming).

Another solution is to use biometric identification based on the distinguishing visual characteristics of that species (e.g. coat pattern; Kühl and Burghardt, 2016). This has the advantage of being non-invasive. Rhesus macaques, in common with many primate species, do not have obvious individually identifiable features but the macaques themselves are capable of recognizing conspecifics by their faces (Parr et al., 2000). Face recognition technology has already been used in several non-human primate species including guenons (Allen and Higham, 2015), chimpanzees (Freytag et al., 2016) and gorillas (Loos, 2012) but not rhesus macaques. Freytag et al. (2016) achieved success rates of over 90% with images of captive chimpanzees.

Face recognition technology was originally developed for use with humans and is becoming commonplace in daily life. Uses include automatic passport gates at airports, tagging of faces in photos on Facebook and use of facial image to unlock smart phones. Many of the early techniques focused on either reducing the dimensionality of the facial image or on extracting a particular feature from the image and then on classifying this output. Some of these methods for face recognition include EigenFaces (based on principal component analysis) and FisherFaces (based on linear discriminant analysis; Belhumeur et al., 1997). Some of the main challenges facing any face recognition system are coping with changes in light intensity and pose. A method based on local binary patterns (Ahonen et al., 2006) has been shown to be relatively robust to changes in light intensity. Most recently deep learning techniques have been applied to face recognition with a high level of success (Freytag et al., 2016 for chimpanzees; Parkhi et al., 2015 for humans).

Here I describe methods for performing face detection and recognition on images and videos of rhesus macaques. The methods were developed under the constraints that training and processing should be possible on a standard PC and that there should be the possibility of using the methods for online (real-time) analysis. To make it easier to integrate into existing setups I have focused on the more established face recognition methods rather than the latest methods. These methods are validated on a model image set of 34 adult macaques and are tested under a range of challenging conditions. I demonstrate an application of these methods to monitoring social relationships in group-housed macaques. Finally I show that these methods can be applied in real time at frame rates of up to 15 frames per second using a standard laptop and an USB camera.

2. Materials and methods

2.1. Animals

All methods presented were developed using group-housed rhesus macaques (*Macaca mulatta*) at a breeding facility. The monkeys were housed in groups of 6–25 (ages in the range 0–20 years) in large indoor enclosures (enclosures consist of two separate areas; the first has dimensions 8.04 m length × 3.35 m width × 2.8 m height and the second has dimensions 6.12 m length × 1.5 m width × 2.8 m height). The enclosures have high levels of enrichment and access to natural light The housing exceed the national guidelines (UK Home Office Code of Practice) and all necessary approvals for this study (including ethical through the local Animal Welfare and Ethics Review Board) were given. As part of routine husbandry at the colony the monkeys are tattooed with an abbreviation of their ID on their chests. This is done under ketamine sedation at the approximate age of 12 months and allows care staff to identify individuals.

2.2. Video

High definition video footage was collected using a camcorder (Sony HDR-SR12E). For each group the camera was set up on an internal window overlooking the main enclosure and aimed at the rear of the enclosure (this area included a large bay window where the monkeys liked to sit and socialize with each other). The videos were converted from AVCHD format to the more common MPEG-4 format (settings: 1920 × 1080 size, 20 frames per second frame rate and 4000 kbps bit rate) using Aiseesoft HD Video Converter (www.aiseesoft.com). Each video was annotated with the date and group information.

2.3. Facial image sets

Three main image sets were used in this study. The first image set (detection training image set) consisted of images of macaque faces (1189 images), eyes (385 images) and noses (451 images) manually cropped from videos stills featuring many different monkeys (cropping was performed using Adobe Lightroom; www.adobe.com). This image set included images of both sexes and a wide range of ages from new born to fully adult. The set was used to train the cascade classifiers used for face and feature detection (Section 2.4). Examples of the images used in the set are shown in Fig. 1A. The second image set (detection testing image set) consisted of a range of 428 images containing between 0 and 4 faces and representing multiple different views. This image set included frames from the videos recorded with the camcorder, frames taken from Point Grey USB cameras (see Section 2.7) and photos taken with a Canon camera (Canon 7D); the idea being to test the performance across a range of different setups. The number of faces and the location of each face within the frame was identified by a human observer to produce a ground-truth dataset for testing face detection performance.

The third image set (recognition image set) is based on images extracted from four different breeding groups using the face detection techniques discussed in Section 2.4. This produced over 100,000 facial images of macaques (each video was processed at a rate of 2 frames per second), collected from videos taken on multiple days over a one year period. These images were manually sorted according to the identity of the monkey and a subset of images per monkeys were further sorted by the quality of the facial image. From this a smaller image set for testing face recognition was constructed that contained 50 well-aligned images and 100 random images from each of 34 adult monkeys (30 female and 4 male; age range 3–20 years). Only adults were included as the facial features of infants changed substantially over the one year