Applied Computing and Intelligence

http://www.aimsciences.org/journal/aimsaci

Applied Intelligence and Computing
1(1): 1–30
DOI: to appear
Received: June 2022
Accepted: July 2022
Published: October 2022

Research Article

An Ant Cuticle Texture Classification Algorithm for Ecological Anaylsis

Noah Gardner[1], **John Paul Hellenbrand**[2], **and Chih-Cheng Hung**[1*]

[1] College of Computing and Software Engineering, Kennesaw State University, 1000 Chastain Road, Kennesaw, GA 30144, USA; email

[2] College of Science and Mathematics, Kennesaw State University, 1000 Chastain Road, Kennesaw, GA 30144, USA; email

* **Correspondence:** chung1@kennesaw.edu

Academic Editor: First-name Last-name

Abstract: There is a large variety of ant species, and most species are diverse in terms of size, shape, behaviors, and especially skin (cuticle) textures. However, the significance of ant cuticle texture is not widely researched. This research employs modern machine learning methods such as texture analysis and classification with CNN and clustering to automatically group similar ant species to allow for the study of influences cuticle texture on ant ecology.

Keywords: Texture Analysis, Image Processing, Clustering, Machine Learning, Myrmecology, Ecology

1. Introduction

Insects compose half of biodiversity and rank among the most dominant organisms in terrestrial ecosystems [1]. A key factor for the ecological success of insects is their exoskeleton, also known as cuticle. The cuticle protects insects from predation, provides structural support, prevents desiccation, and serves as a canvas for advertising visual and chemical signals [2]. Research has heavily focused on the macrostructures and internal chemical components that make the exoskeleton functional and more recent work is being done to understand the functional aspects of external cuticle micro sculpturing [3–5].

Texture is an important feature in many applications, such as image processing, pattern recognition, and computer vision. Analysis of textures can be broken into three main categories: texture classification, texture segmentation, and texture synthesis [6]. The process of classifying a texture into a set of categories and relies on three different approaches. In this paper, we focus on a *model-based approach* which attempts to extract parameters to reveal common patterns and use those parameters to automatically distinguish between different textures [7].

Although there is some work regarding grouping ants into categories of similar cuticle, automated classification has yet to become an active area of research. Due to the large number of different ant species, the classification of ants into categories of similar texture is difficult to accomplish manually. Texture analysis has shown promising results in related fields, such as plant identification [8]. With modern texture analysis methods, the classifications of ants can be automated and the results can be used to study the influence of cuticle texture on ant ecology.

We examine ants (*Formicidae*) as they display an extreme diversity of cuticle micro sculpturing across all subfamilies. Sculpturing ranges from parallel longitudinal ridges to deep oval impressions to erratic protuberances. The sculpturing has arisen convergently and independently throughout ant's evolutionary history, which suggests some inherent function. Cuticle sculpturing on ants may help increase strength and rigidness, resist abrasion, increase internal and external surface area, resist microbial growth, and rear beneficial anti-biotic producing bacteria [9–11]. These specific functions may be associated with certain sculpturing types and the purpose of classification is to group similar textures based on proposed function.

2. Related Work

Taxonomists have developed extensive terminology describing ant cuticle sculpturing as it is often a useful diagnostic trait to distinguish between closely related ant species [12, 13]. The definitive text on ant cuticle terminology — *The Glossary of Surface Sculpturing* — contains over 100 terms to describe the cuticle sculpturing patterns of ants [14]. There is often substantial overlap among terms, and closely related cuticle patterns are likely to be functionally similar. For example, the definition for "imbricate" is, "partly overlapping and appearing like shingles on a roof or scales on a fish," which is difficult to distinguish from the definition of tesselate, "made up of squares like a chess board, either in sculpturing or in color."

Cuticle sculpturing in ants has been explored thoroughly from a taxonomic perspective; however, the function of nano and microstructures on insect exoskeletons is a developing topic in entomology. Watson et al. reviews the literature of cuticle nano and microstructure function and proposes 21 possible functions associated with these structures [5]. Many of these functions are related to structures not found in ants such as scales and nanostructures. The review does include functions that may relate to ants such as friction control, enhanced surface area, and increased hardness. Watson et al. also describe seven types of cuticle structures ranging from hairs and scales to nano and micro structures [5]. The cuticle sculpturing of ants seems to fall within one type – complex microstructures.

The five broad functional groupings developed that describes the complex microstructures found on ants were derived from reviewing the variation of cuticle sculpturing across ants. These functional groupings were also reflected in Harris as many terms could be grouped together based on similar definitions and comparing the SEM photographs provided in the publication [14].

3. Proposed Approach

4. Methods

4.1. Sculpture Identification Protocol

A team of three assistants were in charge of the manual identification process. The team was trained to identify cuticle sculpturing through a process which consisted of one 45-minute introductory lesson explaining the project and texture categories and then given a training set of photos to identify from the genus *Polyrhachis*, whose members display among the highest diversity of cuticle patterns all categories. The training set identifications were reviewed together as a group. Once training was complete, assistants were assigned the same genera of ants to identify independently each week. A weekly meeting was held to discuss identifications and assign new ones. These identifications were collected in a spreadsheet and the identifications were assigned to individual ant species on a majority basis.

4.2. Dataset

In order to classify the cuticle, we used ant head images sourced from AntWeb [15]. In general, the ant head images are centered in the image, facing the front, and share a similar posture. However, some images may not be centered, show the ant head in a different orientation, or may have a drastically different resolution from the average image. Fortunately, each can have several scales available such that the images' scales can be roughly similar.

Table 1. Dataset Subclass Distribution

Label	Samples (n)	Samples (%)
Rough Dimpled	173	0.07
Rough Netted	503	0.21
Rough Ridged	317	0.13
Rough Tuberous	41	0.02
Smooth Gritty	16	0.01
Smooth	1393	0.57
Total	2443	1.0

Table 2. Dataset Class Distribution

Label	Samples (n)	Samples (%)
Rough	1034	0.42
Smooth	1409	0.58
Total	2443	1.0

Images were collected and classified by according to the sculpturing identification protocol. Overall, there are a total of 2443 images in the dataset. The class distribution with all considered subclasses is shown in Table 1, and the class distribution with overall distribution is shown in Table 2. The relatively small number of images in the dataset paired with the uneven class distribution makes it difficult to perform a meaningful classification. However, the goal of this project is to develop a classification algorithm that can be used to help classify over 200,000 ant images. Therefore, it is desirable to use a few representative images from each class to train the algorithm. Additionally, data augmentation and other methods are performed to increase the number of training images to create a more robust classification algorithm.

4.3. Subimage Dataset

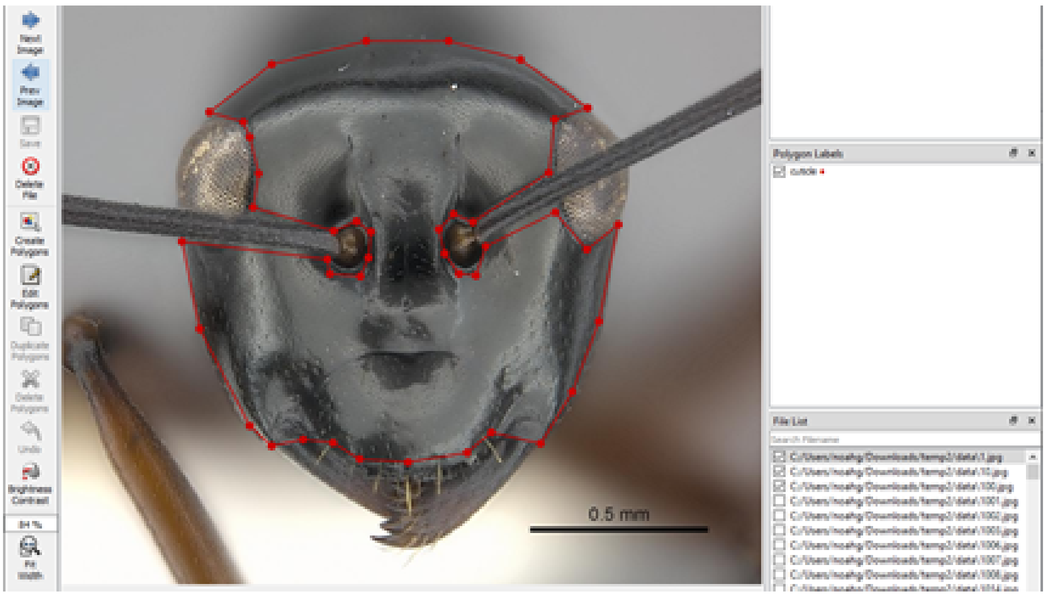

Figure 1. Hand segmented ant head image to separate head cuticle from other sections of the image. CASENT0217419 by Estella Ortega, from AntWeb, is licensed under CC BY 4.0

When using the Sculpture Identification Protocol, the class of the overall image is based only on the texture of the head, not the eyes, antenna, or any other exposed cuticle. We use image segmentation to analyze the texture by splitting the ant head image into a set of regions: *cuticle* and *background*. A benefit of this approach allows us to pull patches or subimages of various sizes from the region to increase the number of samples available for training and at the same time, reduce the number of features to simplify the classification algorithm. With a given subimage size to extract from the segmented image, we label each subimage extracted based on the class of the input image. Overall, there are 73 images that were hand segmented in this manner and the class distribution for various sizes of subimages are shown in Table 3.

Table 3. Subimage Dataset Class Distribution

Label	(8, 8)	(16, 16)	(24, 24)	(32, 32)
Rough	101584	23655	9790	5108
Smooth	104981	24356	10022	5177
Total	206565	48011	19812	10285

5. Experimental Results

5.1. Sculpturing Identification

In our initial trial, we examined the entire *Polyrhachis* genus, which was 581 eligible specimens out of the 775 species. 71% of the classifications were unanimous. We then expanded our categorizations to 2846 images of individual species from 13 genera. These genera were from the four major ant subfamilies Ponerinae, Myrmicinae, Formicinae, and Dolichoderinae along with Dorylinus and Ectatomminae. 87% (2486) of classifications were unanimous. This percentage represents the accuracy for the entirety of identifications starting November 2020 and ending in March 2021. Assistants were also asked to complete an ant cuticle assessment near the end of the identification process. The assessment consisted of images from forty species of ants that spanned all categories. The purpose of the assessment was to measure the consistency of identifications while removing any biases from weekly meeting discussions and cross referencing of other identifications. Unanimous classification was reached 90% of the time during the individual assessment.

Classifications became more consistent overtime. One likely reason for this increase was that students gained additional experience in cuticle classification over the course of these trials. However, definitions of cuticle texture categories were refined overtime. At the inception of the project, assistants based classifications off of reference photos and tentative definitions that were sometimes unclear. For example, striate was initially defined as "long linear ridges, corresponding in-between ridges vary in length." Also, some tentative categories had low agreement amongst the team. For example, striate initially was a broad category containing two subclasses (Severe and Mild) and encompassed longitudinal and latitudinal ridges. Based on several rounds of feedback from students and identification of these problem categories where there was low agreement, the definitions developed into the current classification system.

5.2. Binary Classification

In the first experiment, we investigate the ability of a basic CNN to classify cuticle texture into the two main categories: *rough* and *smooth*. The goal of this experiment is to determine if more intricate data preprocessing or a more powerful model is necessary to classify the texture of the ant. Images were resized to different sizes for CNN input and different samples per class were also tested. The dataset used is shown in Table 2, and the results are shown in Table 4.

Table 4. Binary Classification of Full Size Images

Size	Samples (per class)	Accuracy (avg)	Loss (avg)
(64, 64)	250	70.83%	0.705
(64, 64)	500	74.9%	0.763
(64, 64)	750	76.72%	0.712
(128, 128)	250	71.93%	0.977
(128, 128)	500	74.39%	1.133
(128, 128)	750	75.7%	1.137
(256, 256)	250	71.0%	1.353
(256, 256)	500	73.31%	1.532
(256, 256)	750	74.96%	1.504
(512, 512)	250	68.16%	1.790
(512, 512)	500	71.25%	1.625
(512, 512)	750	71.74%	1.852

Acknowledgments

We would like to thank the constructive feedback provided by the reviewers.

References

1. A. Sheikh, Nz Rehman, and Ritesh Kumar. Diverse adaptations in insects: A review. *Journal of entomology and zoology studies*, 5:343–350, 2017.
2. P. J Gullan and P. S Cranston. *Insects: an Outline of Entomology.* Wiley, Hoboken, 2009. OCLC: 1048427241.
3. Subbaratnam Muthukrishnan, Seulgi Mun, Mi Y. Noh, Erika R. Geisbrecht, and Yasuyuki Arakane. Insect Cuticular Chitin Contributes to Form and Function. *Current Pharmaceutical Design*, 26(29):3530–3545, September 2020.
4. Steve Gunderson and Rebecca Schiavone. The insect exoskeleton: A natural structural composite. *JOM*, 41(11):60–63, November 1989.
5. Gregory S. Watson, Jolanta A. Watson, and Bronwen W. Cribb. Diversity of Cuticular Micro- and Nanostructures on Insects: Properties, Functions, and Potential Applications. *Annual Review of Entomology*, 62(1):185–205, January 2017.
6. T.R. Reed and J.M.H. Dubuf. A Review of Recent Texture Segmentation and Feature Extraction Techniques. *CVGIP: Image Understanding*, 57(3):359–372, May 1993.
7. P. Maillard. Comparing texture analysis methods through classification. *Photogrammetric Engineering and Remote Sensing*, 69:357–367, 2003.
8. Safia Boudra, Itheri Yahiaoui, and Ali Behloul. Plant identification from bark: A texture description based on Statistical Macro Binary Pattern. In *2018 24th International Conference on Pattern Recognition (ICPR)*, pages 1530–1535, August 2018. ISSN: 1051-4651.

9. Robert A. Johnson, Alexander Kaiser, Michael Quinlan, and William Sharp. Effect of cuticular abrasion and recovery on water loss rates in queens of the desert harvester ant *Messor pergandei*. *Journal of Experimental Biology*, 214(20):3495–3506, October 2011.
10. Adrian Brückner, Michael Heethoff, and Nico Blüthgen. The relationship between epicuticular long-chained hydrocarbons and surface area - volume ratios in insects (Diptera, Hymenoptera, Lepidoptera). *PLOS ONE*, 12(4):e0175001, April 2017.
11. C. R. Currie. Coevolved Crypts and Exocrine Glands Support Mutualistic Bacteria in Fungus-Growing Ants. *Science*, 311(5757):81–83, January 2006.
12. Bonnie B. Blaimer. Taxonomy and Natural History of the Crematogaster (Decacrema)-group (Hymenoptera: Formicidae) in Madagascar. *Zootaxa*, 2714(1):1, January 2019.
13. Brian L. Fisher and Stefan P. Cover. *Ants of North America: a guide to the genera*. University of California Press, Berkeley, 2007. OCLC: ocm80180487.
14. R. A. Harris. A Glossary Of Surface Sculpturing. *Occasional Papers in Entomology*, December 1979.
15. Vincent Perrichot and Brian Fisher. AntWeb: digitizing Recent and fossil insects for an online database of the ants of the world. In *Digital Fossil International Conference*, September 2012.