PREDICTIVE CLASSIFICATION OF INSECTS

BACKGROUND

[0001] As part of a Sterile Insect Technique (SIT) program, insects be may be classified as male or female and selectively sterilized before being released into the wild. Such programs may be implemented to minimize or eliminate insect-borne diseases and/or to manage insect populations in certain areas. Depending on the program, classification and sterilization may be performed at one or more stages of insect development.

[0002] Existing approaches for classification are various. For example, some approaches have attempted to classify males and females using non-visual attributes, such as wing beat frequency. Other approaches have relied on visual attributes such as abdomen size and antennae. Visual approaches have typically relied on humans visually inspecting each insect (or a batch of insects) and determining whether the particular insect is male or female (or whether the batch includes females that could contaminate a batch of males).

BRIEF SUMMARY

[0003] Various examples are described including systems, methods, and devices relating to classifying insects using predictive models.

[0004] A system of one or more computers can be configured to perform particular operations or actions by virtue of having software, firmware, hardware, or a combination of them installed on the system that in operation causes or cause the system to perform the actions. One or more computer programs can be configured to perform particular operations or actions by virtue of including instructions that, when executed by data processing apparatus, cause the apparatus to perform the actions. One general aspect includes a system, including: an imaging device configured to capture images of insects and a computing device in communication with the imaging device, and configured to at least: instruct the imaging device to capture an image that depicts at least a portion of an insect of a plurality of insects at a first location. The computing device is also configured to receive, from the imaging device, the image. The computing device is also configured to determine, using an industrial vision classifier: (i) a first classification of the image into at least one category based at least in part on features extracted from the image, and (ii) a first confidence measure corresponding to the first classification. The computing device is also configured to execute an instruction to cause movement of the insect to a second location based at least in part on the first classification and the first confidence measure. The computing device is also configured to determine, using a machine learning classifier comprising a core deep neural network model and a recurrent neural network model: (i) a second classification of the image into the

at least one category based at least in part on the image, and (ii) a second confidence measure corresponding to the second classification. The computing device is also configured to determine a third classification of the image based at least in part on the first confidence measure and the second confidence measure. Other embodiments of this aspect include corresponding computer systems, apparatus, and computer programs recorded on one or more computer storage devices, each configured to perform the actions of the methods.

[0005] One general aspect includes a computer-implemented method, including: receiving a sequence of images that each depict at least a portion of an insect of a plurality of insects at a first location. The computer-implemented method also includes determining, using an industrial vision classifier, a first classification of the sequence of images into at least one category. The computer-implemented method also includes determining a first confidence measure corresponding to the first classification. The computer-implemented method also includes causing movement of the insect to a second location based at least in part on the first classification and the first confidence measure. The computer-implemented method also includes, in the event the first confidence measure falls below a threshold, determining, using a machine learning classifier comprising a core deep neural network model and a recurrent neural network model, a second classification of the sequence of images into the at least one category. The computer-implemented method also includes determining a second confidence measure corresponding to the second classification. The computer-implemented method also includes generating classification information relating to the insect based on the second confidence measure. Other embodiments of this aspect include corresponding computer systems, apparatus, and computer programs recorded on one or more computer storage devices, each configured to perform the actions of the methods.

[0006] One general aspect includes a system, including: an imaging device configured to capture images of insects, and a computing device in communication with the imaging device, and configured to at least instruct the imaging device to capture a sequence of images depicting at least a portion of an insect of a plurality of insects at a first location; use an industrial vision classifier to determine a first output corresponding to a first classification of a first image of the sequence of images. The computing device is also configured to use a first predictive model to determine a second output corresponding to a second classification of the first image of the sequence of images, the second output including a confidence measure of the first classification, the first predictive model comprising a core deep neural network model; execute an instruction to cause movement of the insect to a second location based at least in part on at least one of (i) the first classification or the second classification, and (ii) the confidence measure; use a second predictive model to determine a third output corresponding to a third classification of the sequence of images based at least in part on the second output from the first predictive model, the second predictive model

comprising a recurrent neural network model. The computing device is also configured to generate classification information based at least in part on the first output, the second output, and the third output. Other embodiments of this aspect include corresponding computer systems, apparatus, and computer programs recorded on one or more computer storage devices, each configured to perform the actions of the methods.

[0007] One general aspect includes one or more non-transitory computer-readable media including computer-executable instructions that, when executed by one or more computing systems, cause the one or more computing systems to receive a set of images depicting at least a portion of an insect of a plurality of insects at a first location; determine, using an industrial vision classifier, a first set of classifications corresponding to the set of images; cause movement of the insect to a second location based at least in part on the first set of classifications. The instructions further cause the one or more computer systems to determine a second set of classifications for the set of images by at least inputting the set of images into a first predictive model including a core deep neural network model. The instructions further cause the one or more computer systems to determine a second set of confidence measures for the second set of classifications. The instructions further cause the one or more computer systems to determine a third set of classifications for the set of images by at least inputting the second set of confidence measures into a second predictive model including a recurrent neural network model. The instructions further cause the one or more computer systems to determine a third set of confidence measures for the third set of classifications. The instructions further cause the one or more computer systems to generate classification information based at least in part on the third set of confidence measures. Other embodiments of this aspect include corresponding computer systems, apparatus, and computer programs recorded on one or more computer storage devices, each configured to perform the actions of the methods.

[0008] One general aspect includes a computer-implemented method, including receiving a set of images depicting at least a portion of an insect of a plurality of insects at a first location and classifying using an industrial vision classifier, the set of images. The computer-implemented method also includes after classifying the set of images, determining a first classification for the set of images by least inputting the set of images into a first predictive model including a core deep neural network model. The computer-implemented method also includes causing movement of the insect to a second location based at least in part on the first set of classifications. The computer-implemented method also includes determining a set of features corresponding to the first classification. The computer-implemented method also includes determining a second classification for the set of images by at least inputting the set of features into a second predictive model including a recurrent neural network model. The computer-implemented method also includes determining a second confidence measure for the second classification. The computer-implemented method also includes generating classification information based at least in part on the second confidence measure. Other embodiments of this aspect include corresponding computer systems, apparatus, and computer programs recorded on one or more computer storage devices, each configured to perform the actions of the methods.

CLAIMS

1. A system, comprising:

an imaging device configured to capture images of insects; and

a computing device in communication with the imaging device, and configured to at least:

instruct the imaging device to capture an image that depicts at least a portion of an insect of a plurality of insects at a first location;

receive, from the imaging device, the image;

determine, using an industrial vision classifier:

(i) a first classification of the image into at least one category based at least in part on features extracted from the image; and

(ii) a first confidence measure corresponding to the first classification;

execute an instruction to cause movement of the insect to a second location based at least in part on the first classification and the first confidence measure;

determine, using a machine learning classifier comprising a core deep neural network model and a recurrent neural network model:

(i) a second classification of the image into the at least one category based at least in part on the image; and

(ii) a second confidence measure corresponding to the second classification; and

determine a third classification of the image based at least in part on the first confidence measure and the second confidence measure.

2. The system of claim 1, wherein the first classification, the second classification, and the third classification are the same.

3. The system of claim 1, wherein the computing device is further configured to at least instruct movement of the insect from the second location to a third location based at least in part on the third classification.

4. The system of claim 3, wherein the first location is an insect sortation device, the second location is an insect transportation device, and the third location is outside of the insect transportation device.

5. The system of any of claims 1-4, wherein:

the insect is located at the second location while the third classification of the image is determined; and

the computing device is further configured to at least instruct movement of the insect to third location based at least in part on the third classification.

6. The system of claim 5, wherein the second location is an insect sortation device and the third location is an insect transportation device.

7. The system of any of claims 1-6, wherein:

the image comprises a sequence of images and the first confidence measure comprises a plurality of first confidence measures corresponding to individual images of the sequence of images; and

the second confidence measure comprises a plurality of second confidence measures corresponding to the individual images of the sequence of images.

8. The system of any of claims 1-7, wherein the third classification of the image corresponds to one category of a plurality of categories comprising male, female, intersex, species, species, or gynandromorph.

9. The system of any of claims 1-8, wherein the insect comprises an adult mosquito.

10. A computer-implemented method, comprising:

receiving a sequence of images that each depict at least a portion of an insect of a plurality of insects at a first location;

determining, using an industrial vision classifier, a first classification of the sequence of images into at least one category;

determining a first confidence measure corresponding to the first classification;

causing movement of the insect to a second location based at least in part on the first classification and the first confidence measure;

in the event the first confidence measure falls below a threshold, determining, using a machine learning classifier comprising a core deep neural network model and a recurrent neural network model, a second classification of the sequence of images into the at least one category;

determining a second confidence measure corresponding to the second classification; and

generating classification information relating to the insect based on the second confidence measure.

11. The computer-implemented method of claim 10, wherein:

the core deep neural network model outputs a first output that comprises at least one of a first set of confidence measures corresponding to the sequence of images or a first set of features corresponding to the sequence of images; and

the recurrent neural network model takes as input at least one of the first set of confidence measures or the first set of features, and outputs a second set of confidence measures corresponding to the sequence of images.

12. The computer-implemented method of claim 11, wherein determining the second confidence measure comprises determining the second confidence measure based at least in part on the second set of confidence measures.

13. The computer-implemented method of any of claims 10-12, further comprising providing the sequence of images to a plurality of user devices for classification of the sequence of images by a plurality of non-expert users associated with the plurality of user devices.

14. The computer-implemented method of any of claims 10-13, further comprising providing the sequence of images to at least one user device for classification of the sequence of images by at least one expert user associated with the at least one user device.

15. A system, comprising:

an imaging device configured to capture images of insects; and

a computing device in communication with the imaging device, and configured to at least:

instruct the imaging device to capture a sequence of images depicting at least a portion of an insect of a plurality of insects at a first location;

use an industrial vision classifier to determine a first output corresponding to a first classification of a first image of the sequence of images;

use a first predictive model to determine a second output corresponding to a second classification of the first image of the sequence of images, the second output comprising a confidence measure of the first classification, the first predictive model comprising a core deep neural network model;

execute an instruction to cause movement of the insect to a second location based at least in part on at least one of (i) the first classification or the second classification, and (ii) the confidence measure;

use a second predictive model to determine a third output corresponding to a third classification of the sequence of images based at least in part on the second output from the first predictive model, the second predictive model comprising a recurrent neural network model; and

generate classification information based at least in part on the first output, the second output, and the third output.

16. The system of claim 15, wherein the second predictive model is trained using multiple subsets of multiple sequences of labeled images, each sequence of the multiple sequences depicting a different insect.

17. The system of any of claims 15 and 16, wherein the sequence of images comprises a set of chronological images of the insect.

18. The system of any of claims 15-17, wherein the computing device is further configured to use the first predictive model to determine a fourth output corresponding to a fourth classification of a second image of the sequence of images, the fourth output comprising a fourth confidence measure of the fourth classification.

19. The system of claim 18, wherein the computing device is further configured to use the second predictive model to determine a fourth output corresponding to a fourth classification of the sequence of images based at least in part on the second output from the first predictive model and the third output from the second predictive model; and

generating the classification information is further based at least in part on the fourth output.

20. The system of claim 15, wherein:

the classification information identifies a category to which the first classification corresponds; and

the computing device is further configured to:

instruct the imaging device to capture an additional set of images when the confidence measure fails to meet a confidence threshold for the category; and

use the first predictive model to determine a fourth output corresponding to a fourth classification of one or more images of the additional set of images, the fourth output comprising an additional confidence measure of the fourth classification; and

generate updated classification information based at least in part on the fourth output.

21. One or more non-transitory computer-readable media comprising computer-executable instructions that, when executed by one or more computing systems, cause the one or more computing systems to:

receive a set of images depicting at least a portion of an insect of a plurality of insects at a first location;

determine, using an industrial vision classifier, a first set of classifications corresponding to the set of images;

cause movement of the insect to a second location based at least in part on the first set of classifications;

determine a second set of classifications for the set of images by at least inputting the set of images into a first predictive model comprising a core deep neural network model;

determine a second set of confidence measures for the second set of classifications;

determine a third set of classifications for the set of images by at least inputting the second set of confidence measures into a second predictive model comprising a recurrent neural network model;

determine a third set of confidence measures for the third set of classifications; and

generate classification information based at least in part on the third set of confidence measures.

22. The one or more non-transitory computer-readable media of claim 21, wherein the classification information comprises a prediction that the insect depicting in the set of images is at least one of a male insect, a female insect, an intersex insect, or a gynandromorph insect.

23. The one or more non-transitory computer-readable media of any of claims 21 or 22, wherein each confidence measure of the second set of confidence measures is input into a different layer of the recurrent neural network model.

24. The one or more non-transitory computer-readable media of any of claims 21-23, wherein at least one of the first predictive model or the second predictive model is trained by at least:

(i) identifying a subset of labeled training images;

(ii) using the subset of the labeled training images to train a version of the first predictive model;

(iii) classifying remaining labeled training images into at least one category;

(iv) identifying which labeled training images were misclassified;

(v) updating labeling of the misclassified labeled training images;

iteratively repeating (i) through (v) for different subsets of labeled training images and different remaining labeled training images.

25. A computer-implemented method, comprising:

receiving a set of images depicting at least a portion of an insect of a plurality of insects at a first location;

classifying, using an industrial vision classifier, the set of images;

after classifying the set of images, determining a first classification for the set of images by least inputting the set of images into a first predictive model comprising a core deep neural network model;

causing movement of the insect to a second location based at least in part on the first set of classifications;

determining a set of features corresponding to the first classification;

determining a second classification for the set of images by at least inputting the set of features into a second predictive model comprising a recurrent neural network model;

determining a second confidence measure for the second classification; and

generating classification information based at least in part on the second confidence measure.

26. The computer-implemented method of claim 25, wherein the insect is in an adult stage mosquito.

27. The computer-implemented method of any of claims 25-26, wherein the classification information comprises a prediction that the insect depicting in the set of images is at least one of a male insect, a female insect, an intersex insect, or a gynandromorph insect.