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Exploring photogrammetric methods to extend Anthophilia research (Big-Bee) interim report

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Abstract

1. The decline of bee populations has become a growing concern due to the importance of bees' roles in pollination and maintaining ecosystems (Klein et al., 2007). Several factors that have contributed to the decline in bee populations include habitat loss, pesticide use, climate change, and the spread of diseases (Potts et al., 2010).
2. Approximately 2,171,588 bee specimens have digitized label data in the US collections; however, only a fraction of species can be assessed due to a lack of data on key species-level traits. Thus, data collection must be extended past labeled data.
3. Photogrammetry – a 3D image reconstruction method – proves to be a viable option for creating accurate models of bees; however, there are computational and data limitations that can affect model generation runtime and accuracy. Thus, additional data – such as volume – can be measured which is unobtainable from images.
4. Macro-photography poses issues when used as input for photogrammetry methods due to the limited depth of field. Focus-stacking methods can create in full focus images that are appropriate inputs for photogrammetry.

1 | INTRODUCTION

Bees are the world's largest pollinators playing a key role in maintaining the health of ecosystems and global food production. Out of the 35% of global food production that animal pollination accounts for, bees contribute to a total of 5% to 8% of the world crop (Klein et al. 2007). However, bee populations around the world are decreasing in numbers and diversity. As it stands, only small amounts of reliable data are available as to which behavioral and anatomical traits might make bees more vulnerable to their changing environment. The majority of existing records document only the taxon names, dates, and locations which are not enough to fully determine the reasoning behind specific declining populations. Our project goal is to create 3D bee models, and subsequently an anatomical and volumetric dataset, that can then be used to study bee traits. The project will link ecological and anatomical data to expand the research value of changing bee populations and help researchers respond to the crisis of global pollinator declines. We will start by discussing our problems of interest as well as our materials and data, followed by our preliminary findings, discussion, and our future work.

2 | PROBLEMS OF INTEREST

The first and foremost goal of this project is to create accurate high-resolution 3D models of bees from Cheadle Center's bee specimens. Our current method involves using photogrammetry software, namely Agisoft Metashape, to extract image data from many close-up high-quality photos of these specimens and then render them as digital models **(Fig. 1)**. By the end of this capstone project, we hope to identify the ideal parameters in Agisoft Metashape that will generate the "best" models according to our criteria, which include both quantitative and qualitative metrics. On the qualitative side, we try to optimize models based on subjective appearances, such as the clarity of the wings or eyes, and quantitatively, we are attempting to perform pixel comparisons between the original images and our model.

Fig. 1: *Macro photograph of Agapostemon texanus*

After we have identified our ideal parameters for model generation and start batch rendering through all of our bee image data, our other primary goal is to create a database of anatomical traits with measurements taken from our models. These anatomical traits will encompass information on bee volume, eye width, antenna length, etc. This database will help to supplement our current data on bee anatomy and hopefully can be used to understand what traits can make a bee either more vulnerable or resilient to environmental change, whether it be natural or human-induced. The mass amount of models that will be rendered at this stage of the project will also be helpful for teaching bee anatomy to students without having to view or handle actual specimens.

The tertiary goal for this project – and one that may not be realistic to achieve during the length of this capstone – is to train an image recognition model using our bee models. Our aim here is to create images with our bee models rendered in backgrounds that you would naturally find those bees in. We can use those images in conjunction with similar images of actual bees to train a machine-learning model that would be able to identify photos containing bees. This model would then be used to photograph and identify bees in controlled studies to pinpoint geographic distributions of species and even their evolution over time.

3 | MATERIALS AND METHODS

3.1 | MACROPHOTOGRAPHY AND FOCUS STACKING

Macro Photography of bees poses the challenge of a shallow depth of field due to increased magnification. Through focus-stacking, we are able to achieve a greater depth of field in an image than what would be possible using a single image. Focus-stacking is performed by capturing a series of photos of the subject with varying focus points which is then stitched together to create a single composited image that is in full focus from front to back **(Fig. 2)**. This is crucial as the entire object of interest must be in complete focus for accurate alignment during the photogrammetry process.

Fig. 2: *Using focus-stacking to create a full-focus image*

The image-capturing process has been automated by mounting the camera on a tripod and placing the subject on a remotely controlled rotating and sliding stage **(Fig. 3)**. This ensures consistency and reduced variance that may be caused by human error. Our subject is rotated along the vertical *y*-axis; thus, the images will follow an arc path. In addition, the subject slides horizontally along the *x*-axis towards and from the camera which adjusts the camera's focus point.

Fig. 3: *Camera and stage setup for focus-stacking*

The stage controller's rotational *y* start and end position is set as well as the horizontal *x* start and end position. Then the number of rotational steps *n* and horizontal steps *m* is set. Note that it is important to have significant overlap between images. At each step n_i in the rotation arc, *m* images will be captured with varying areas in the camera's depth of focus. This results in *nm* images being captured and n stitched images after focus stacking.

3.1 | PHOTOGRAMMETRY

Photogrammetry is a technique for measuring and mapping an object or scene using photographs of an object or scene. It provides a contactless method for extracting accurate measurements and creating a 3D representation of the object.

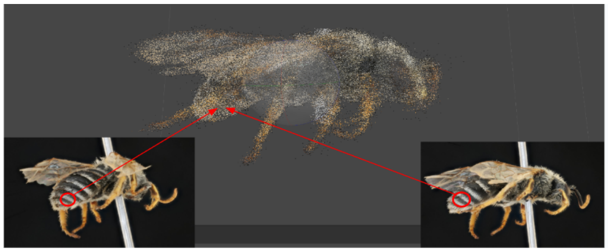

Fig. 4: *Feature matching between two images that contain overlap*

Metashape provides a photogrammetry pipeline that can generate 3D models from photographs. It is important to note that the photographs must have significant overlap in order to accurately represent the subject. This is crucial for the first step of photogrammetry – feature matching. Through feature matching, Metashape identifies overlapping features between photos and creates a point that corresponds to the matched features of two or more images **(Fig. 4)**. Each point has a set of Cartesian coordinates (X, Y, Z) . In addition, this step also calculates the positions of the cameras **(Fig. 5)**. As a result, a 3D point cloud, composed of these points, is created. The upper limit of points to be generated can be specified. Increasing this number has trade-offs such as higher detail or increased runtime. These trade-offs are further examined in Sections 4 & 5. After a 3D point cloud is generated through feature matching, the user can manually or formulaically remove unwanted points such as noise, outliers or extraneous objects in the scene.

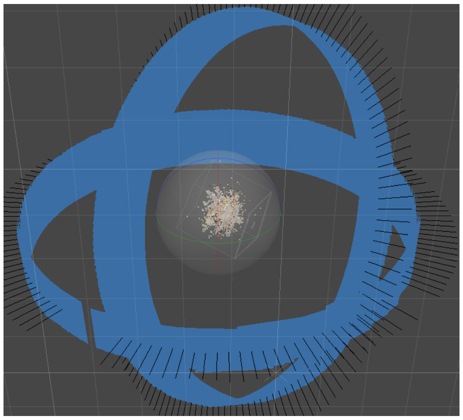

Fig. 5: *Calculated camera positions based generated through feature matching*

Once the 3D point cloud has been sufficiently filtered, a mesh can be created from the 3D point cloud data through which points are connected to create faces. The number of faces can be specified among other parameters which have a large effect on the outcome of the mesh. Insufficient faces can lead to holes or fragmentation which is undesirable. Once the 3D mesh has been generated, the model is then textured using the original photos to create a photo realistic reconstruction of the subject.

4 | PRELIMINARY FINDINGS

4.1 | BENCHMARKING

In our benchmarking tests, we found that the number of photos taken for the bee model significantly impacted the run time for rendering the model. Specifically, the more photos we took, the longer the run time. Additionally, we discovered that the type of computer used also affected the run time, with computers equipped with more powerful GPUs producing faster results. For example, the computers in the DREAM Lab, which have AMD Radeon Pro W6600 GPUs, produced results for the same models almost twice as fast as those in the VR Room with NVIDIA Qaudro P4000 GPUs.

4.2 | QUALITY OF BEE MODEL

Our findings revealed that creating high-quality 3D models of bees posed several challenges, particularly in rendering the hairs and wings of the bee. Due to the thin and numerous nature of the hairs, and the translucent nature of the wings, rendering them accurately proved difficult. However, taking photos of the bee from multiple angles, instead of just one arc of photos, resulted in higher quality models and helped to prevent holes from forming in the model. By capturing the bee from different perspectives, we were able to ensure that all areas of the bee were captured in sufficient detail.

4.3 | BACKGROUND MASKING

To reduce errors in the model caused by the background, we found that masking the background was necessary **(Fig. 6)**. Without this step, the background would often blend with certain parts of the bee, negatively impacting the accuracy of the model. By masking the bee, we were able to isolate it from the background, and as a result, the model was more precise.

Fig. 6: *.png image of Apoidea where background has been masked out*

4.4 | CROPPING DURING ALIGNMENT

During the alignment process, we found that cropping the images of the bee was critical to ensuring accurate modeling. Cropping out obstructions, such as the stand that the bee was placed on, helped to eliminate disruptions in the model **(Fig. 7)**. To stay consistent, we cropped each image to the same dimensions ensuring consistent quality as well as the use of the masking feature in Metashape that is unavailable otherwise. Though we reduce the dimension of the image itself, we still retain the same image quality used in our texture. This is because the areas that were cropped out were utilized in point cloud generating; therefore, important data was not lost. Without cropping these objects, the program was unable to find tie points between photos which resulted in incorrect alignment. The reduced dimension also significantly decreased the runtime of the alignment step as there are less pixels for Metashape to compare.

6240 x 4160

3700 x 1966

***Fig. 7**: Image cropping with dimensions*

5 | DISCUSSION

In this project, our main goal is to create an accurate 3D model of bees using photos taken from multiple angles and to measure volumetric quantities of these bees for research on the declining bee population. Our preliminary findings have provided us with valuable insights into the 3D modeling process, which can help us achieve our goals more efficiently and accurately.

We found that the number of photos used affects run time, but not necessarily the quality of the model **(Fig. 6 and 7)**. This information allows us to optimize our modeling process by reducing the number of photos used without sacrificing accuracy. We also discovered that taking photos from multiple arcs reduces the risk of holes in the model, but takes longer as we use more photos. This trade-off is important to consider when balancing accuracy and efficiency.

***Fig. 8**: Model using 180 photos*

***Fig. 9**: Model using 90 photos*

Additionally, we learned that the choice of the computer affects run time significantly, with the DREAM Lab computers being about 30% faster than the VR Room computers. This is important to keep in mind when planning our modeling sessions to ensure we use the most efficient resources available.

We also discovered that the quality of the photos used affects the texture rendered in the model. As such, it is crucial to take high-quality photos of the bees to ensure the accuracy of the texture in the final model.

Lastly, we found that masking the background and aligning the photos correctly are crucial steps in reducing errors and warping in the model. By cropping the images to focus solely on the bee and removing any obstructions in the background, we were able to achieve a more accurate model as there were less unnecessary matched features in the point cloud.

In conclusion, our preliminary findings have provided us with insights that can help us create a more efficient and accurate 3D model of bees for research purposes. By optimizing our modeling process through the use of high-quality photos, reducing the number of photos used while balancing accuracy, and ensuring correct alignment and background masking, we can obtain more accurate volumetric quantities of bees to further our understanding of their populations.

6 | FUTURE WORK

To deal with the issue of longer runtimes, we will be working with the DREAM Lab to take advantage of Microsoft Azure. Azure is a cloud computing platform that uses high-end hardware to manage the configuration and operation of virtual hardware and software on their servers. Since each model takes around an hour to produce, batch processing UCSB's bee models will likely take days to complete. By using Azure's more sophisticated hardware, we will be able to significantly decrease the run time for our models especially when we reach the point of creating batches.

By the end of the year, we hope to come up with a set combination of model parameters that produce the most accurate and detailed models. This process entails exploring the functions of the point density cloud and the mesh as well as the optimal amount of photos needed to create a model. We will determine the best model through a quantitative process using pixel comparisons of the original photos to the model. Finally, after establishing the best parameters, we will batch process as many bee models as possible to create a library of models.

Our end goal is to then use these bee models to create a dataset of anatomical and volumetric measurements. Using volumetric functions in Metashape and documented measurements in our photos, we will be able to measure each part of the bee and document it. Our reach goal would then be to use this large dataset to train a model that recognizes bees and even specific species. By the end of our time on this project, we hope to have progressed the anatomical study of bees with our models to determine potential features that affect their survival.

7 | REFERENCES

Klein AM, Vaissière BE, Cane JH, Steffan-Dewenter I, Cunningham SA, Kremen C, Tscharntke T. Importance of pollinators in changing landscapes for world crops. Proc Biol Sci. 2007 Feb 7;274(1608):303-13. doi: 10.1098/rspb.2006.3721. PMID: 17164193; PMCID: PMC1702377. https://doi.org/10.1098/rspb.2006.3721

Potts SG, Biesmeijer JC, Kremen C, Neumann P, Schweiger O, Kunin WE. Global pollinator declines: trends, impacts and drivers. Trends Ecol Evol. 2010 Jun;25(6):345-53. doi: 10.1016/j.tree.2010.01.007. Epub 2010 Feb 24. PMID: 20188434. https://doi.org/10.1016/j.tree.2010.01.007

Seltmann KC, Allen J, Brown BV, Carper A, Engel MS, Franz N, Gilbert E, Grinter C, Gonzalez VH, Horsley P, Lee S, Maier C, Miko I, Morris P, Oboyski P, Pierce NE, Poelen J, Scott VL, Smith M, Talamas EJ, Tsutsui ND, Tucker E (2021) Announcing Big-Bee: An initiative to promote understanding of bees through image and trait digitization. Biodiversity Information Science and Standards 5: e74037. https://doi.org/10.3897/biss.5.74037

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