Innovative Digital Twin and Machine Vision Approaches for Molluscan Phenotyping

Kai Shen[1, 2], Huiping Yang[3], Xu Wang[1, 2]

[1] Gulf Coast Research and Education Center, University of Florida, Wimauma, FL, USA.

[2] Department of Agricultural and Biological Engineering, University of Florida, Gainesville, FL, USA.

[3] School of Forest, Fisheries, and Geomatics Sciences, University of Florida, Gainesville, FL, USA.

INTRODUCTION

- Accurately quantifying the shell dimensions is perhaps the most crucial process for breeding northern quahogs, *Mercenaria mercenaria* (also known as hard clams).
- Manual measurements of shell length, height, and width using a caliper (Fig. 1) are time-consuming and prone to human errors.
- To advance the northern quahogs breeding process, an approach to improving the efficiency and accuracy of shell dimension measurement is necessary.

(a) (b) (c)

Figure 1. Manually measuring shell length (a), height (b), and width (c) using a caliper

OBJECTIVES

- Accurately quantifying the dimensions of length, height, and width of hard clams in a timely manner.
- Replacing manually measuring dimensions with extracting trait values from digital twins of hard clams.
- Implementing phenotyping in high throughput.

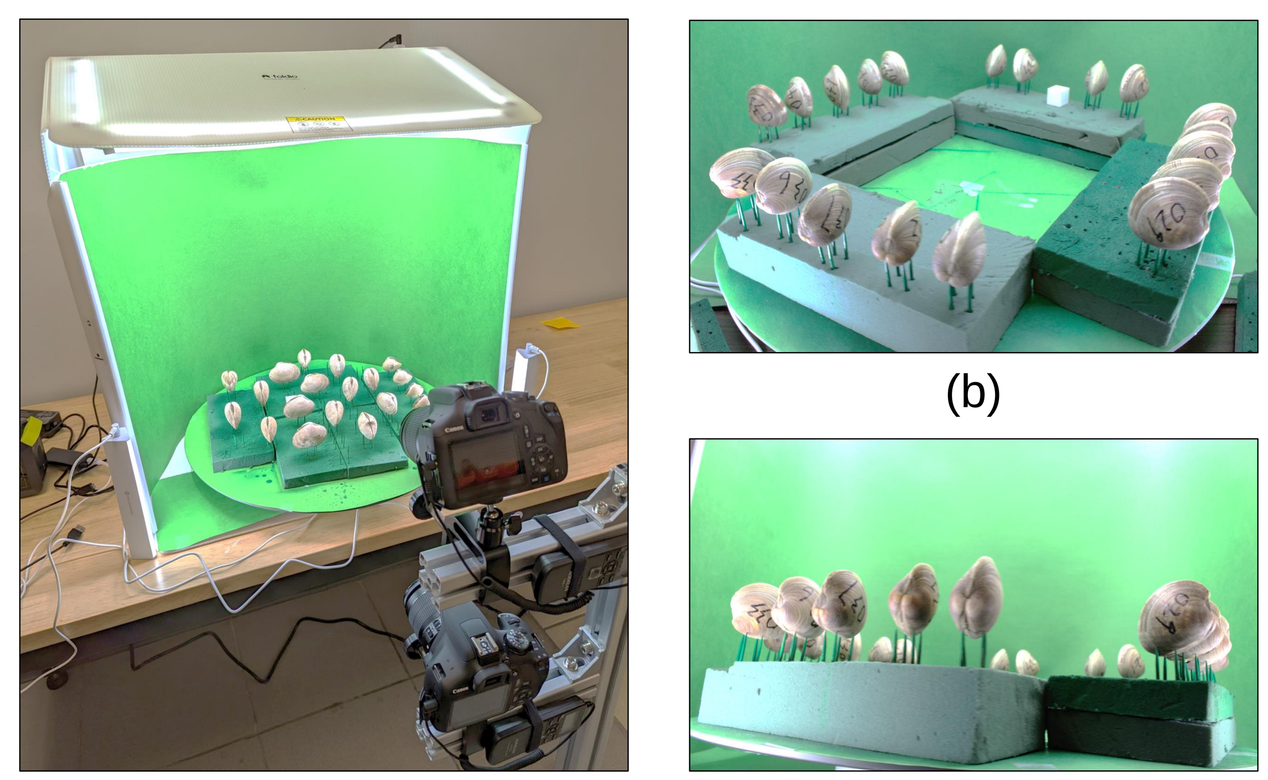
MATERIAL

- Market-sized northern quahogs (n = 95) were randomly selected as measuring samples from the shellfish farm located at the Fisheries and Aquatic Sciences Lab at the University of Florida.
- All quahogs were labeled with unique numbers (Fig. 2).
- In order to quantify the digital twin model's accuracy, dimensions of length, height, and width of all 95 quahogs samples were measured manually using an electronic caliper (Fig. 1).

Figure 2. Labeled northern quahog samples.

DIGITAL TWIN GENERATION

- 3D point cloud models, representing digital twins of quahogs, were created by the Structure-from-Motion photogrammetry.
- To capture multi-view images of each clam, a round turntable (Fig. 3a), spinning at ~6º/sec counterclockwise, was adopted as the hard clam carrier.
- Two DSLR cameras, with one positioned to face slightly downward (Fig. 3b) and the other to face upward (Fig. 3c), simultaneously captured images at a rate of 1 image/sec, while the turntable spun.
- To capture as many details as possible, clams were placed on sticks to avoid contact between the clam and the surface of the turntable.
- All objects within the camera's field of view, except for the clams, were painted green to facilitate their removal as noise during subsequent processing.



(a) (b) (c)

Figure 3. Image acquisition for digital twin generation (a), capturing images in two view angles (b and c)

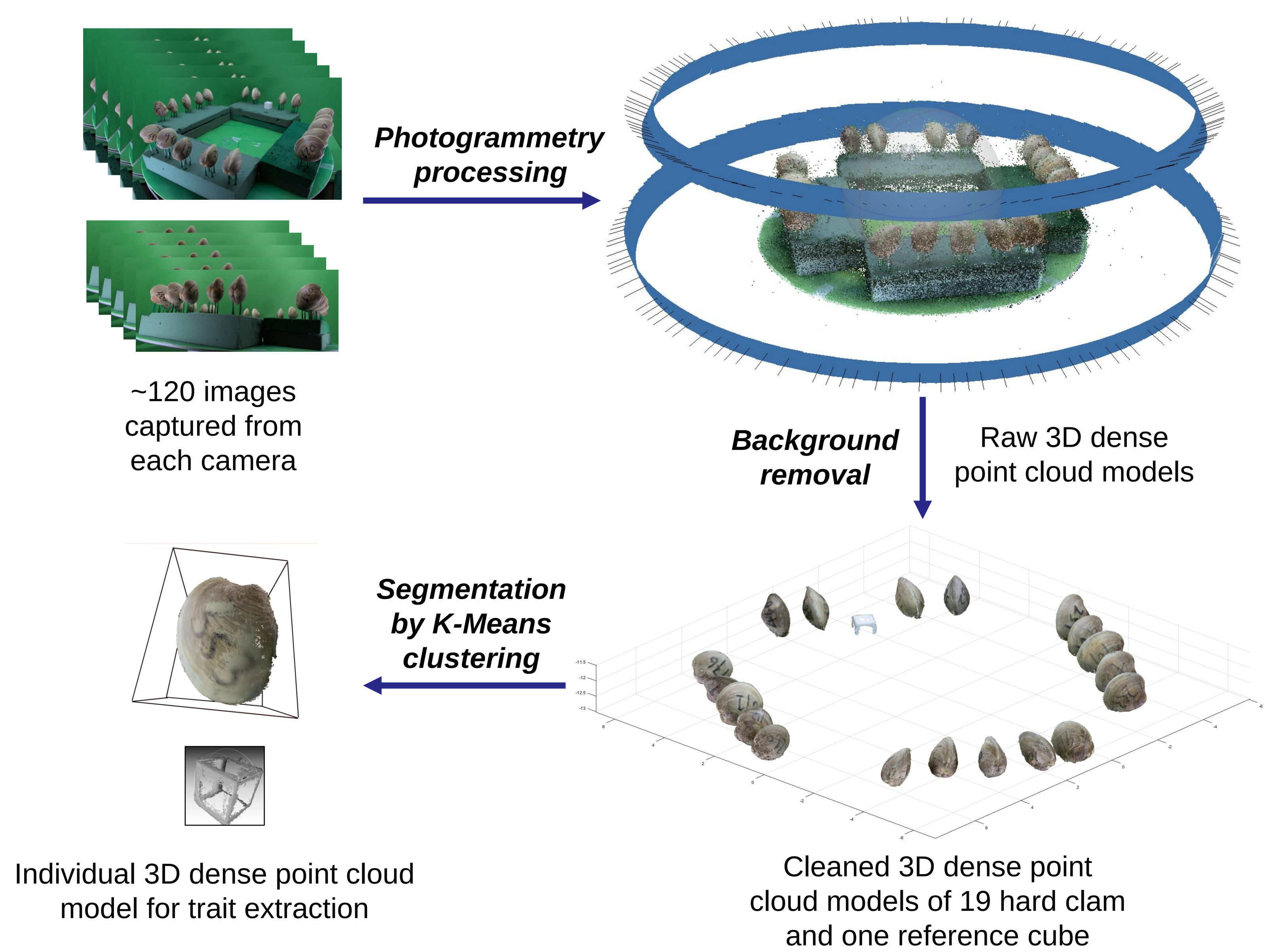


Figure 4. Generation of quahog digital twins from raw images

MODEL ACCURACY VALIDATION

- Approximately 240 images (~120 from each camera) taken from various perspectives over the hard clams (19 per plate) were imported into photogrammetry software for the 3D dense point cloud model generation (Fig. 4).
- A reference cube with a side length of 2cm was used to determine point size, converting dimensions extracted from the 3D model to physical measurements.
- Points from the green background were removed automatically through an RGB-LAB filter.
- Individual quahog 3D models and the reference cube were segmented from the entire 3D dense point cloud using K-Means clustering.
- To verify the accuracy of the digital twin model, length, width, and height values were manually measured from 20 randomly selected quahog 3D point cloud models and compared to the ground truth values obtained using a caliper (Fig. 5). The root mean square error for all three measurements was within 0.5 mm.

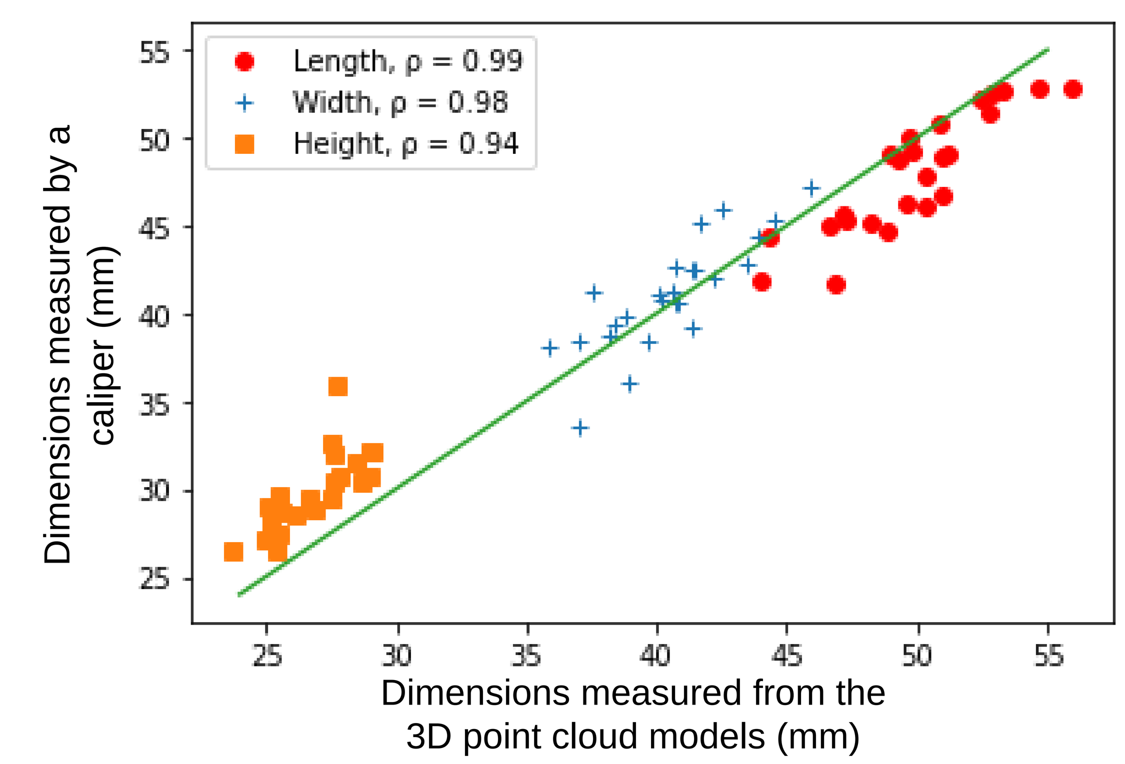


Figure 5. Comparison between the measurements from digital twin models and manual measurements.

CONCLUSIONS

- The proposed method successfully generated digital twin models of quahogs, demonstrating significant potential to improve the efficiency of quantifying hard clams' dimensions.
- The dimensional values extracted from these digital twin models corresponded closely with ground truth values, confirming the model's accuracy.
- Future work will focus on increasing the automation of dimension extraction from the 3D point cloud models.

ACKNOWLEDGEMENT

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